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SEASONAL ABUNDANCE AND DIVERSITY OF INSECTS ON *Sclerocarya birrea* AND *Berchemia discolor* IN TSHIKUNDAMALEMA, LIMPOPO PROVINCE, SOUTH AFRICA

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Declaration

I Phindulo Rollet Ramavhale hereby declare that this dissertation for Master of Science in Agriculture in the School of Agriculture at the University of Venda, submitted by me, has not been submitted to any other university before. All reference materials contained therein have been acknowledged.

Student's signature ________________________________ Date ____________________

Supervisor's signature________________________________ Date ____________________

Co-supervisor's signature ______________________________Date ____________________

Dedication

I dedicate this research dissertation to Cheryl Ramavhale, Pearl Ramavhale, Caroline Labani, Josephine Ramavhale and Aaron Masipa.

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Abstract

Indigenous trees play important roles in livelihoods for rural communities. *Sclerocarya birrea* and *Berchemia discolor* are indigenous in Africa and are used in rural communities for food and livestock feed, as well as for medicinal and construction purposes. These trees are subject to attack by insects, which can result in lower tree productivity. However, there is no documented information about insects found on both tree species in South Africa. This study investigated the seasonal abundance and diversity of insects on *S. birrea* and *B. discolor* in Tshikundamalema Area, Limpopo Province, South Africa. Five trees were selected for each of the two tree species at two sampling sites with different vegetation cover, one site mainly the woodland bushveld while the other site was savannah grasslands. Canopy fogging was used to sample insects. Insect samples were collected at one time point for each of the seasons: summer (February), autumn (May), winter (July) and spring (November). Insects were identified to morphospecies and Simpson's diversity index was used to compare insect diversity on both trees. Analysis of variance was used to compare the abundance of insects across seasons. The most abundant insects were collected from Coleoptera, followed by Hemiptera, Hymenoptera, Diptera, Lepidoptera and Orthoptera. A total of 3259 insects belonging to the six Orders were collected. All specimens belonging to Coleoptera, Hemiptera and Hymenoptera (3216 in total) were identified to Family level, with a total of 97 morphospecies, belonging to 19 Families. Insects from Diptera, Lepidoptera and Orthoptera were not identified further due to their low numbers. The abundance and diversity of insects were affected by seasons, sites and tree species. The number of insects was high during the spring season with 1782 insects, and summer coming second with 1104 individuals, followed by autumn (238 insects), then winter (92). *B. discolor* sampled for a great number of insects (1741) as compared to *S. birrea* (1475). The woodland bushveld (1924 insects) surpassed the savannah grassland (1292 insects) site in terms of the insect numbers sampled.

Key words**:** *Berchemia discolor,* canopy fogging, diversity index, insect diversity, *Sclerocarya birrea,* seasonal abundance

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LIST OF ABBREVIATIONS

Cocci - Coccinelidae

Curcu - Curculionidae

Bupr - Buprestidae

Chry - Chrysomelidae

Psyl - Psyllidae

Pent - Pentatomidae

Rhyp - Rhyprochromidae

Memb - Membracidae

Lyg - Lygaeidae

Core - Coreidae

Rhop - Rhopalidae

Alyd - Alydidae

Arad - Arадidae

Cerc - Cercopidae

Miri - Miridae

Nabin - Nabidae

Form - Formicidae

Brac - Braconidae

Vesp - Vespidae

CHAPTER 1: INTRODUCTION

1.1. Background

Most of the Eastern and Southern parts of Africa are faced with food insecurity (Tiisekwa *et al.,* 2004, cited in Kalaba *et al.,* 2009), hence the dependence on natural resources for livelihood improvement is common in most rural areas (Kalaba *et al.,* 2009). The importance of indigenous trees is the provision of immediate basic needs, such as food, medicine, beverages and building materials for most people living in the rural areas (Mojeremane & Tshwenyane, 2004; Anim, 2012). Besides the beneficial aspects of these indigenous tree plants for the human population, livestock also depend on them for food, especially *Acacia* species which are very nutritious and serve as supplements for low quality roughage for goats (Ncube & Mpofu, 1994).

Insects are known to inhabit various parts of trees, with many known to affect tree health in various ways, including defoliation and wood boring (Fumiss & Caroline 1977 cited in Piirto, 1994). Bark beetles (Curculionidae: Scolytinae) lay their eggs under the bark in the phloem of woody plants where their larvae feed and develop (Six & Wingfield, 2011), and they are known to be associated with pathogenic fungi (Beaver 1989, cited in Six & Wingfield, 2011). Some bark beetles may be damaging or lethal to trees at high beetle population density (Raffa *et al.,* 2008 cited in Anderegg *et al.,* 2015).

Marula tree, *Sclerocarya birrea,* is a tree belonging to the Family Anacardiaceae and is native to Africa, but also found in Australia as an exotic tree species (Orwa *et al.,* 2009). The tree is medium sized with height ranging between 7 m to17 m, and has a crown which stands leafless for several months in a year (Akinnifesi *et al.,* 2008). *Sclerocarya birrea* is an important tree in most rural communities with very significant socio-economic value, such as generating income during the fruiting season (Palmer & Pitman, 1974; Adel, 2002). It is a multipurpose tree species. It produces edible fruits, which are eaten fresh or fermented to make beer, the kernels are eaten as snacks and oil extracted from it, bark is used for medicinal purposes and leaves are browsed by livestock (Ngorima, 2006). The wood is used for carvings such as wooden spoons, decorative figures and plates (Shackleton & Shackleton, 2002).

Several studies have been conducted on *S. birrea,* which include fruit yield and quality (Petje, 2003), and use of marula products for domestic and commercial purposes (Shackleton *et al.,* 2002). Of all studies done to date, none have been done on insect population dynamics on *S. birrea.* It is important to understand the interaction of insects with *S. birrea* and *B. discolor*. Some insects are disease vectors while some are herbivorous; both have impacts on the productivity of trees (Lowman, 2006).

Berchemia discolor (Family: Rhamnaceae) is a tree with height varying from 3 m to 20 m and has a straight stem with rough, dark grey bark that flakes longitudinally (Orwa *et al.,* 2009). The tree has a dense rounded crown. It is native to Africa and found only within the African continent. Few studies, among them one on the value addition and processed products of indigenous products in Namibia (Bille *et al.*, 2013) made mention of *B. discolor,* but there are hardly studies about tree-insect interactions carried out on *B. discolor.*

Seasonal variation in the abundance of insect species is an adaptive phenomenon evolved to take advantage of the good weather conditions (Arun & Vijayan, 2004). Insect seasonal abundance reflects periodic food supply and seasonal changes (Mani, 1968, cited in Lowman, 1982). In tropical savannas, the difficult period for most herbivorous insects is usually the dry season, when leaves are less nutritious (Braby, 1995). Most phytophagous insects rely on the vegetation for feeding and reproduction; hence it is thought that the availability of food influences insect populations (Lowman, 2006).

1.2. Problem statement

Sclerocarya birrea and *Berchemia discolor* are important and the most widely used tree species in Tshikundamalema area, a rural area in Limpopo Province, South Africa. They are mainly used for food, medicine, feed for livestock and wood carvings. Insects are known to affect the productivity of trees through feeding (Lowman, 2006). However, there is no information about diversity and abundance of insects on both *S. birrea* and *B. discolor.*

1.3. Justification of the study

Various studies have been carried out on most indigenous trees, including the study on marula fruit yield and quality (Petje, 2003), but none of them focused on insect-tree interactions and insect seasonality on *B. discolor* and *S. birrea*. There is no information on insect seasonal abundance and diversity on *S. birrea* and *B. discolor* in Tshikundamalema. Knowledge about insect seasonal abundance and diversity on *S. birrea* and *B. discolor* is important in order to understand potential pests that can impact the productivity of both tree species.

1.4. Research questions

I. Are there differences in the seasonal abundance and diversity of insects between *Sclerocarya birrea* and *Berchemia discolor*?

II. Are there differences in the abundance and diversity of insects between any two sites with different vegetation cover?

1.5. Study objectives

The overall objective of this study was to determine the comparative diversity and abundance of insect communities on *S. birrea* and *B. discolor* canopies across seasons at two sites in Tshikundamalema.

The specific objectives of the study were:

I. To assess seasonal abundance and diversity of insects on *S. birrea* and *B. discolor.*
II. To determine if the diversity and abundance of insects differs between sites.

1.6. Hypotheses

I. There are no differences in insect seasonal abundance and diversity on both *S. birrea* and *B. discolor*.
II. There are no differences in abundance and diversity of insects between sites.

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CHAPTER 2: LITERATURE REVIEW

2.1. The importance of indigenous trees

Indigenous trees are an important part of the landscape, and influence human health and the environment in a vital way (Lebel 2003, cited in Powell *et al.,* 2013). The role of many indigenous trees and their fruit goes beyond nutrition and health; it extends to income generation and social values such as: presenting of drinks and fruits to guests on special occasions such as at weddings and traditional ceremonies (Bille, Shikongo-Nambabi & Cheickyoussef, 2013). In their study, Bille *et al.* (2013) showed that in Namibia, distilled liquor made from *Berchemia discolor* fruits and another made from palm fruits are sold for income generation, with palm liquor commonly used in the Oshikoto region. Some locals in Botswana are known to use marula jelly and marula oil from *Sclerocarya birrea* for cosmetics and Ximenia oil from *Ximenia caffra* for cooking.

Many people from around the world rely on indigenous trees to get a major portion of their food (Turner *et al.,* 2011 cited in Feyssa *et al.,* 2012). The reliance of many groups of people on indigenous trees for food has continued for hundreds of years (Feyssa *et al.,* 2012). Wild fruits are an important source of food in most rural communities especially during the periods of food shortage (Bille *et al.,* 2013), and their consumption has always been associated with potential health benefits (Isabelle *et al.,* 2010). Ailments such as tonsillitis, burns, stomach aches, cough, toothaches, skin allergies, heartburn and constipation are often treated using the decoction from *S. birrea*, *B. discolor* and *Ximenia caffra* (Bille *et al.,* 2013).

Anim (2012) reported that in Nigeria trees are used in indigenous farming systems (agroforestry systems) with the aim of restoring degraded areas, increasing people's access to valued forest products, thus conserving existing forest ecosystems. Numerous studies have acknowledged the use of trees in generally increasing farm productivity (Raintree, 1998); not only do they act as wind breaks, but they provide fuelwood and construction material (Brills *et al.*, 1996), control soil erosion (Igbuanugo, 1993) and bring socioeconomic improvement to rural communities (Ajake, 2008). However, plant productivity is affected by biotic and abiotic factors, including insects and diseases.

2.2. Effects of insects on trees

Herbivory is a common event which, when severe, can result in the reduction of plant productivity due to nutrient loss (Whitfeld *et al.,* 2012). Many plants have evolved to withstand insect damage in various ways, including; rapid leaf expansion (Coley and Aide 1991, cited in Whitfeld *et al.,* 2012) and delayed leaf sprouting. Nonetheless, there are plants which invest more resources in defense than in rapid growth and are known to harbour less herbivorous insects than plants which have fair distribution of resources to various physiological processes (Herms & Mattson, 1992).

Many insects are found high in the canopy (Sutton & Hudson, 1980, cited in Lowman 1982). Insect feeding activities on trees result in defoliation, and if feeding continues, the alterations of carbon, nitrogen and water flux is inevitable and subsequently affecting nitrogen cycling (Schowalter *et al.,* 1986). Insect herbivory causes trees to lose their photosynthetic capacity and resources due to leaf area reduction (Kosola *et al.,* 2001). In some part, insects have a beneficial impact in recycling senescent plant materials, hastening the return of the organic matter to the soil (Hoy, 1962). Insects have various modes of lifestyles and ecological requirements during different life stages, and therefore have better resource utilization potential (Arun & Vijayan, 2004). Much remains unknown about the tree canopy as an insect habitat (FAO, 1999).

2.3. Effects of seasonal changes on insect abundance and diversity

The variation in the abundance and diversity of insects across seasons is a common incident which occurs over time for various reasons, including macroclimatic and microclimatic changes, as well as variation in the availability of food (Wolda & Wong 1988). There is evidence that rainfall can directly influence arthropod abundance through physiological effects on reproduction, development or activity; for example, rainfall is necessary for the initiation of breeding for Dipterans such as shadflies (Chaniotis *et al.,* 1971). The emergence of the beetle *Heliocoris dilloni* from the soil in Kenya is also initiated by rainfall (Kingstone & Coe, 1977). Rainfall may also indirectly affect insect populations by its effect on food availability as suggested by (Janzen 1973 cited in Pinheiro *et al.,* 2002).

The abundance of insects, especially the phytophagous types is influenced by the availability of palatable leaves (Lowman 1982). Trees species such as *S. birrea* stand leafless in winter (Akinnifesi *et al.,* 2008), which may result in less numbers of herbivorous insects occurring on this tree species during the winter season. According to Braby (1995), dry seasons are the most difficult and pose significant suppression on insect numbers due to reduced food availability. However, there is a notion that the severe reduction in the abundance of insects during the winter season is restricted to tropical habitats (Janzen, 1973, cited in Pinheiro *et al.,* 2002), although the findings by Pinheiro *et al.* (2002) showed no connection between insect abundance and the winter seasons. There are other important factors such as rainfall, patterns of leaf production and the abundance of natural enemies which may cause significant changes in the number of insects (Wolda, 1978; 1989; Denlinger, 1980 cited in Basset, 1999).

2.4. Effects of abiotic factors on insect diversity and abundance

Climatic changes and extreme weather events affect plants and animals. Due to the relationship that insect herbivores have with their host plants, insects are expected to suffer directly or indirectly the effects of climate change through the changes experienced by their host plants (Cornelissen, 2011). Climatic and weather changes affect the status, population dynamics, intensity and feeding behaviour of insects (Khaliq *et al.,* 2014). Climatic changes are known to have altered the rate of development, fecundity and various physiological functions of many insects (Yamamura, 1998). Temperature is known to affect insects' life cycles either by reducing or extending it. High temperature is known to reduce the number of days it takes an insect to fully develop (Regniere *et al.,* 2012).

According to Wolda (1978; 1989; Denlinger, 1980 cited in Basset 1999) rainfall is one of the important factors which affects the abundance of insects in dry habitats. A study by Arun & Vijayan (2004) indicated that the abundance of insects was at the peak during the southwest monsoon (the period which receives the highest annual rainfall). Arun & Vijayan (2004) determined that the highest number of insects caught during the high rainfall period (southwest monsoon), were commonly from the Orders Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera. Furthermore, the highest diversity of insects occurred during the high rainfall seasons; the northeast and southwest monsoon (Arun & Vijayan, 2004). Pinheiro *et al.* (2002) determined in a study carried out in Brazil, that the abundance of Diptera, Homoptera, Lepidoptera and Orthoptera was randomly distributed over seasons, although Isoptera, Coleoptera, Heteroptera and Hymenoptera peaked during the wet season. However, it would be incorrect to generally conclude that rainfall alone coincides with high numbers of insects, considering that there are several factors including disease, predators (Mooney *et al.,* 2010, cited Whitfeld *et al.,* 2012), parasitoids and abiotic environment (seasonality) involved in determining the abundance of insects (Whitfeld *et al.,* 2012).

2.5. The important indigenous trees in Limpopo Province

In many developing countries around the world, people use indigenous trees for various purposes, varying from consumption, income generation, crafts, firewood and shade (Shackleton *et al.,* 2000; Leakey & Simons, 1998; Chivaura-Mususa *et al.,* 2000 cited in Shackleton *et al.,* 2002). Fruits of tree species such as *Adansonia digitata, Ximenia caffra, Sclerocarya birrea, Berchemia discolor* and *Ziziphus mucronata* are commonly and frequently used for fruits in many parts of the Limpopo Province (FAO, 2011), although *Adansonia digitata, Sclerocarya birrea* and *Berchemia discolor* have other uses than just edible fruits. According to Tshikundamalema villagers, *Adansonia digitata* bark threads can be used for making ropes and the leaves can be eaten cooked as vegetable on the other hand, *Berchemia discolor* barks can be used to dye reed-made baskets (pers. comm).

In Tshikundamalema, the most commonly used indigenous trees are *Sclerocarya birrea* and *Berchemia discolor*, although there are several other trees which are used for various purposes. The fruits of *Berchemia discolor* are used for brewing a wine-like alcoholic beverage and can also be eaten or dried for later consumption. *Berchemia discolor* provides many households in Tshikundamalema with shade. *Sclerocarya birrea* fruits on the other hand are mainly used for brewing a famous local beer known as “mukumbi” which is usually sold for cash and also used for traditional ceremonies.

2.6. *Sclerocarya birrea*

2.6.1. The importance of *S. birrea*

Sclerocarya birrea plays an important role in the diet and culture of people in many African countries, especially in Southern Africa, where the tree species play an essential role in the livelihood of the rural populations in many areas, including Limpopo Province, South Africa (Hall *et al.,* 2002). It was found that over 90% of residents of Allandale, Edinburgh, Hokwe and Rolle-A in Bushbuckridge collected marula fruit to make beer, to consume and to extract the kernels from the shell and process into jam (Shackleton *et al.,* 2002). The marula tree is also one of four most important plants used for food in Swaziland (Anon, 2002 cited in Hall *et al.,* 2002). The leaves and bark are used for treating stomach ailments and other kinds of human illnesses including malaria, fevers, constipation, sores, epilepsy, arthritis, toothaches and other bacterial infections (Maroid & Abdelwahab, 2012).

In many other places within South Africa and Zimbabwe, kernel extraction for consumptive purposes, fuel wood, crafting utensils and fruit consumption constituted some of the major uses of *S. birrea* (Hall *et al.,* 2002). A study by Adel (2002), revealed that about 30% of the Kwanyama, Kwambi, Ndonga, and Mbalantu ethnic groups in Namibia eat marula caterpillars for food. Furthermore, 37% of the households interviewed by Adel (2002) listed that they used burnt marula bark to relax their hair.

2.6.2. Morphology and distribution

Sclerocarya birrea is a medium sized tree, 7-17 m in height with a rounded spreading crown which stands leafless for several months in a year (Akinnifesi *et al.,* 2008). Its twigs are thick with spirally arranged composite leaves at their ends and its lateral roots branch at the upper 60 cm of soil (Orwa *et al.,* 2009). Marula trees have long taproots which enable them to survive in semi-arid environments (Mark *et al.,* 2009).

Sclerocarya birrea produces many fruits during the fruiting season (Quin, 1959). The fruit is an egg-shaped or plum-like fleshy drupe 3 to 5 cm in diameter with a relatively tough skin. Marula fruits drop and ripen on the ground. Ripe fruit can be eaten fresh, generally by biting or cutting through the thick skin and sucking the juice out or chewing the flesh after the skin is removed (Hall *et al.,* 2002). The fruits have a hard shell which encases the nut and a small piece of bone tool, shaped to a special pattern, is sometimes used for removing the kernel from the opened shell (Shone, 1979). Two or three kernels 1 to 1.5 cm in length are enclosed in each hard, light brown, oval-shaped stone. These kernels can be eaten raw or roasted, and they have a delicious taste. They are generally used to complement the diet during winter or drought periods, being pounded and mixed with vegetables (Shone, 1979).

Sclerocarya birrea is a widespread species throughout the semi-arid deciduous savannahs of much of sub-Saharan Africa. It occurs in Botswana, Democratic Republic of Congo, Eritrea, Ethiopia, Gambia, Kenya, Malawi, Mozambique, Namibia, Niger, Senegal, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe (Maroyi, 2013). The tree is exotic to Australia and Israel (Orwa *et al.,* 2009). Figure 2.1 shows both the native and exotic distribution range of *S. birrea.* The optimal growth conditions of the species are frost free areas with deep soils which have good drainage and the tree would generally not be found in areas with water logging and south-facing slopes are also undesirable (Hall *et al.,* 2002). *S. birrea* leaves are browsed by animals and the animals browse to the maximum height which they can reach, and they are browsed especially by giraffe and antelopes (Shone, 1979).

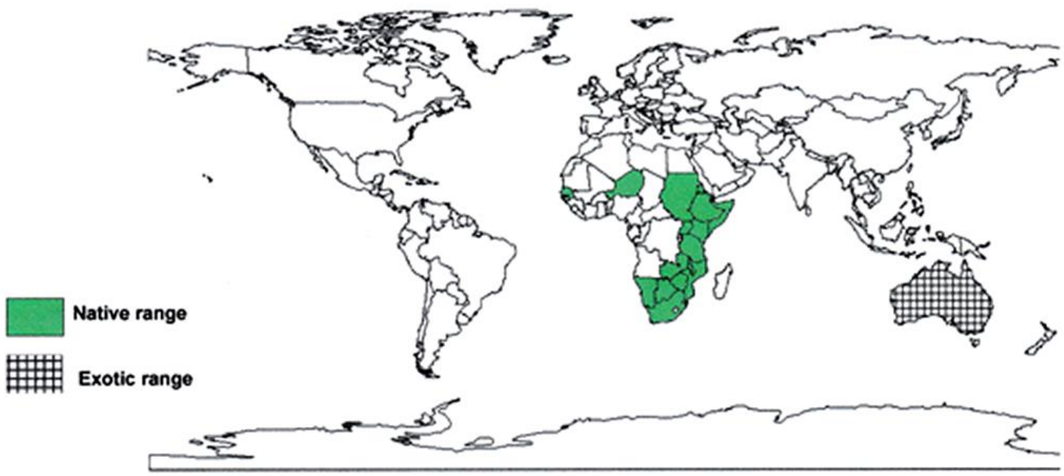

Figure 2.1 *Sclerocarya birrea* distribution range (Orwa *et al.,* 2009)

2.6.3. Biology of *Sclerocarya birrea*

Sclerocarya birrea is considered primarily dioecious species (single tree with either male or female flowers only), but occasionally monoecious individual plants (bearing both male and female flowers) may occur (Orwa *et al.,* 2009). The fruit is abscised when ripening commences so that final ripening takes place on the ground (Orwa *et al.,* 2009). In South Africa, flowering occurs from September to November, and fruiting from January to March.

2.6.4. Insects found on the trees of Anacardiaceae Family

There is lack of information on insects associated with *Sclerocarya birrea* subspecies *caffra*, although coleopterous wood borers and lepidopterous leaf feeders including mopane worms (*Gonimbrasia belina*) are known to be associated with this tree species (Hall *et al.,* 2002). However, according to a Department of Agriculture, Forestry and Fisheries marula guideline (2010), the most important pest affecting marula are the marula fruit flies and the marula beetles.

Marula flowers are scentless to humans, although they are visually attractive to bees and other insects, including flies, hoverflies and, less commonly, wasps (Muok *et al.,* 2011). A study by Kumar *et al.* (2012) showed that environmental factors including temperature, and time of the day, have an effect on pollination activity of insects. An observation on one of the Anacardiaceae trees, mango (*Mangifera indica*) showed that most of the insects sampled were 'visitors' to the trees as opposed to herbivores with 39 different insect families recorded. The common insect pests on Anacardiaceae Family were found to be fruit fly (*Bactrocera (Dacus) correctus*), leaf caterpillar (*Carea angulate*), purple winged moth (*Bombytelia delatrix*), psyllids (*Trioza jambolanae*), thrips (*Leeuswenia ramakrishnae*) and white fly (*Dialeurodes eugeniae*) (Kumar *et al.,* 2012). However, the findings by Kumar *et al,* (2012) were specific to *Mangifera indica* and may not fully explain the abundance and diversity of insects on *Sclerocarya birrea* because *S. birrea* stands leafless during the winter season while *M. indica* does not.

2.7. *Berchemia discolor*

2.7.1. The importance of *B. discolor*

Berchemia discolor fruits are used to make white wine and dried fruits are also sold in markets in areas where *B. discolor* is found in abundance (Barrion *et al.,* 2001). The fibres from the roots and the bark of *B. discolor* are used in making baskets, and they also produce a reddish dye used to paint the baskets to decorate them (Coates-Palgrave, 1988). A strong alcoholic drink is brewed from the fruits. The roots have medicinal uses such as treating stomach aches and toothaches (Orwa *et al.,* 2009).

2.7.2. Morphology and distribution

Berchemia discolor is a tree with height ranging from 3 m to 20 m. The tree has a rough stem with dark grey bark that flakes longitudinally; it also has a dense, rounded crown (Orwa *et al.,* 2009). The leaves alternate and have shiny upper surface and are broadly elliptic (Palmer & Pitman, 1972). *Berchemia discolor* is named after M. Berchem, a French botanist. *'Discolor'* means 'with two colours', referring to the fact that the upper and the lower leaf surfaces have different colours (Orwa *et al.,* 2009).

Berchemia discolor is native to Africa and is found in Angola, Botswana, Eritrea, Ethiopia, Kenya, Malawi, Zimbabwe, Mozambique, Namibia, Somalia, South Africa, Swaziland, Tanzania, Uganda, Republic of, Zambia and Madagascar (Orwa *et al.,* 2009). It is mainly found in areas where the mean temperatures are generally 14 to 30 °C with the mean annual rainfall of 760 mm to 1200 mm. It grows well in soils of various origins, but survives well in well drained soils in woodlands (Venter F & Venter J, 1996). Figure 2.2 shows the native distribution ranges of B. discolor.

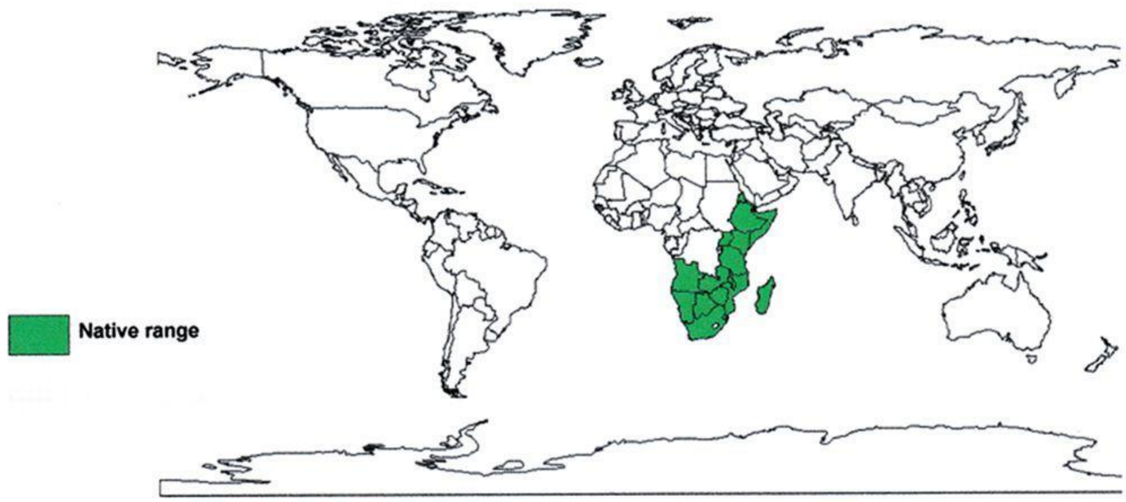

Figure 2.2. *Berchemia discolor* distribution range (Orwa *et al.,* 2009)

2.7.3. Biology of *Berchemia discolor*

The time from flower fertilization to fruit ripening is 4-5 months (Barrion *et al.*, 2001). Flowering starts at the onset of rains, while fruit ripening occurs towards the end of the long rains. In South Africa, for example, flowering occurs from October to January and fruiting from January to July (Orwa *et al.,* 2009). The fruits of *B. discolor* are ellipsoid and 4-5 mm in diameter. They are green when young, turning yellowish brown after ripening (Orwa *et al.,* 2009).

2.7.4 Insects found on the trees of Rhamnaceae Family

In a study about intensity and diversity of flower-visiting insects in relation to *Ziziphus mauritiana* Lamk in India, a total of 86 insect species were recorded and it was found that the diversity of pollinators on *Z. mauritiana* was affected by the phenology of flowers, and the number of pollinators increased with the increase of plant density (Mishra *et al.*, 2004). According to Mishra *et al.* (2004), the diversity of insects was high on dense plant populations as opposed to isolated plant populations, although it was determined that overall 32 species of wasps, 30 flies, 18 butterflies and 6 bees were found.

In Europe, a survey conducted on five tree species of the Rhamnaceae Family (*Rhamnus cathartica*, *R. alpine, R. saxatlis, R. orbiculata* and *R. alaternus*) and insect associations showed that insect fauna of the Rhamnaceae Family accommodated a large number of polyphagous

Lepidoptera, Coleoptera and Hemiptera (Malicky *et al.,* 1970). On the other hand, a study by Orwa *et al.,* (2009) on *Z. mauritiana* showed that the damage incurred on the tree species was commonly by fruit-borers, leaf eating caterpillars, weevils, leafhoppers and mealy bugs. *Berchemia discolor* has a dense, rounded crown as described in Orwa *et al.,* (2009), consequently it is expected to harbour more insects, particularly leaf herbivores (Marques *et al.,* 2000 cited in Whitfeld *et al.,* 2012).

2.8. Sampling in the canopy

Approximately 50 000 of the 800 000 to 1 000 000 insect species currently described occur in South Africa, belonging to 28 of 30 insect Orders (Auerswald & Lopata, 2005). Didham & Fagan (2003) reported that during September and October 2003, a team of scientists sampled for insects using various methods such as pitfall trapping, Winkler and Berlese extraction of soil and litter, canopy fogging, flight interception trapping, foliage beating, light trapping, sticky trapping, chemical and colour attractants, and hand collecting. Didham & Fagan 2003 reported that 10 000 individual samples were collected belonging to Coleoptera, Diptera, Hemiptera, Lepidoptera, Hymenoptera and Thysanoptera, with Coleoptera, Diptera and Hymenoptera being the most abundant.

Tropical forests are predicted to harbour most of the insect diversity on earth, but few studies have been conducted to characterize insect communities in tropical forests (Acton, 2013). In 1982, the tropical biologist Terry Erwin assumed that beetles represent 40% of all arthropods (Didham & Fagan, 2003), which later was supported by Odegaard (2000) cited in Didham & Fagan (2003) to be only 23%. Moreover, Hammond (1992) and Stork (1993) cited in Stork *et al,* (1997) determined Coleoptera as the largest group, followed by Lepidoptera, Hymenoptera and Diptera, while the rest of the other orders combined constituted a number which was almost equal to the Lepidoptera order alone.

The canopy fauna contains the largest portion of all arthropods across different habitats (Stork 1993). However, there are no studies to verify that the canopy fauna represents 66% of all forest insects (Didham & Fagan, 2003), although (Hammond *et al.,* 1997) suggested that the greatest abundance of insects occurs in the soil and as many as 70-80% of the species are restricted to ground habitats. A major limitation is the lack of agreement on methods used for insect collection (Lamarre *et al.,* 2012). Deciding which insect sampling technique to use is an important consideration for ecologists and entomologists, yet to date few studies have presented a quantitative comparison of the results generated by standardized methods in tropical insect communities (Lamarre *et al.,* 2012).

Canopy communities may be composed of organisms drawn from a wide range of taxa, and the insect assemblages may be particularly species-rich (Basset *et al.*, 1997). The highly diverse insect samples collected from tropical canopies have been used as a basis for estimates of global species richness made by Stork (1988). There are a few sampling methods which are suitable for arboreal insects with canopy fogging and collapsible bag/branch clipping sampling method and sweep netting being the most productive (Blanton, 1989). For both sampling methods (canopy fogging, collapsible bag/branch clipping, sweep netting), there are various complementary techniques which help with better canopy access if the tree species being sampled are too tall. Such techniques vary from technical climbing (where the person sampling has to climb the tree with ropes while operating the sampling apparatus), canopy walkways, canopy toboggans (Figure 2.3), canopy rafts and construction cranes may well be employed during sampling to enhance the sampling efficiency due to improved canopy access (Lowman, Moffett & Rinker, 1993).

Knockdown of arthropods from vegetation using fogging is used mainly in samples of arboreal arthropods (Basset *et al.*, 1997). Canopy fogging is a commonly used sampling method for collecting arboreal insects. When using canopy fogging, a non-persistent insecticide (pyrethrum) is sprayed onto the target tree canopy from an apparatus (fogger) which may be handheld or hoisted on tree branches using ropes (Erwin 1983; Stork 1991; Kitching *et al.,* 1993). The pyrethrum insecticide has a knockdown effect and the insects which are knocked down fall onto the collecting sheets laid under the canopy (Lowman, Moffett & Rinker, 1993). Canopy fogging method was first used around 1966 and came to be recognized as a good sampling method because it revealed large numbers of insect species, many of which were new to science during the time (Erwin, 1982 cited in Erwin, 1990). Before the use of canopy fogging for sampling insects from trees, the information on insect abundance and diversity was erratic because it was derived from sampling methods which measured insect activity more than they did abundance (Stork, 1988). In his study, Stork (1988) used canopy fogging sampling method and revealed that the major groups of insects were Hymenoptera, Coleoptera, Diptera, and Hemiptera, although orders such as Thysanoptera, Orthoptera, and Collembola occurred in low numbers. A collapsible bag on the one hand is a nylon bag which closes with a drawstring. It is attached to a support hoop with Velcro tabs poked through removable plastic liner. The bag gets slipped quickly over the branch, and the drawstring is pulled to capture the resident insects and the branch is cut with a pole pruner. Chloroform-soaked cotton ball is dropped into the bag to kill the insects (Blanton, 1989).

A study by Blanton (1989) which compared canopy fogging method and collapsible bag showed canopy fogging as a more efficient sampling method over the collapsible bag method. Blanton (1989) found that the proportions of herbivore and carnivore biomass in collapsible bag samples (63% and 35%, respectively) closely resembled those in fogging samples (67% and 26%) and recommended the use of both methods for best results. Each of these two methods has its own positive and negative sides: the disadvantages of canopy fogging include the limitation to sampling at dawn due to daily air exchange (Berry, 1964 cited in Blanton, 1989) and sometimes the difficulty to access canopies if sampling is being carried out on very tall trees (Blanton, 1989). The challenge with using the collapsible bag sampling method is that only the branches which can fit into the bag may be sampled. The branches which are being sampled have to be cut and enclosed in the collapsible bag with chloroform-soaked cotton balls for insects to be killed (Blanton, 1989). This is severe destructive sampling and may not be desirable. With canopy fogging, it is possible to determine whether to sample from the whole tree or do partial plant sampling (where only a small collecting sheet would be used or large collecting sheets which covers the whole area under the canopy cover), while this is not practical with collapsible bag sampling; since the branches which samples are to be collected form have to be cut.

Sweep netting is another sampling method which can be employed both on shrubs and very high canopies (with the use of a sled as depicted in Figure 2.3). The nets come in various shapes and sizes, each designed for particular insect groups (Stubbs & Chandler, 1978); for example, Grootaert *et al.* (2008), stated that sweep nets are preferable to suction traps when collecting fragile insects like many flies species. While employing a sweep net, the collector does not target specific specimen, but carries out a random sampling of the fauna present in the vegetation. The diameter of the metal frame may be determined according to individual needs, but a 38 cm diameter opening is ideal for tree sampling (Lowman *et al.,* 1993). The nets are usually sprayed with non-persistent knockdown insecticide (Prentex, active ingredient 3% Resmethrin) to allow for easy transfer of insect samples from the net to vials (Lowman *et al.,* 1993). The limitation of sweep net sampling method may come when the canopy is too dense, or too high to require the use of the sleds; and not low enough to access with the sweep net. According to Orwa *et al.,* (2009), *Berchemia discolor* and *Sclerocarya birrea* grow to the heights of 3 m to 20 m and 7 m to 17 m respectively, making it ideal for the use of canopy fogging sampling method instead. Canopy fogging is a time-effective method which can collect comprehensive insect samples of taxa living in tree canopies (Basset *et al.,* 1997). Using pyrethrum knockdown sampling method, Basset *et al.,* (1997) arranged leaf-feeding beetles in groups; specialists (177), generalists (272), uncertains (13), incidentals (693), additionals (263) and proven feeders (462).

Figure 2.3. A portrayal of the uppermost canopy access with a sled (Lowman *et al.,* 1993)

Canopy fogging is a comprehensive and time effective canopy sampling method, although it might pose a few challenges; for example, hand-held/backpack foggers may not effectively deliver the insecticide to the upper crowns of trees with heights exceeding 25 m (Blanton, 1989). However, the trees sampled in this study only grow to the heights of 20 m (*B. discolor*) and 17 m (*Sclerocarya birrea*) Orwa *et al.,* (2009), which can be easily reached by the insecticide delivered by hand-held/backpack foggers.

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CHAPTER 3: MATERIALS AND METHODS

3.1. Study sites

Sampling was carried out at two sites in the Tshikundamalema area in Limpopo Province within Mutale Municipality. The area is about 90 km north of Thohoyandou town. The average elevation of the area is 600 m above sea level. Daily temperatures vary between 25 °C to 40 °C in summer whilst they vary between 20 °C and 25 °C in winter (Mhlongo & Amponsah-Dacosta, 2014). The average annual rainfall is about 500 mm (Soil Classification Working Group, 1991 cited in Mzezewa & Gwata, 2012).

Selection of the two sites for this study was based on differences in vegetation types. The sites are about 50 km apart. Both areas have many *Sclerocarya birrea* and *Berchemia discolor* trees. The land is used for cultivation and livestock farming at both sites.

The first site was located near Tshikundamalema Traditional Authority offices with GPS coordinates S 22°55ˈ44.7ˮ, E 30°38ˈ21.6ˮ. The site has woodland bushveld vegetation with sandy soils (Figure 3.1). The site is situated less than 200 m from Mutale River. Figure 3.2 shows an aerial view of site 1, with an inset for a close-up view.

Figure 3.1. Woodland bushveld vegetation type near Tshikundamalema Tribal Authority

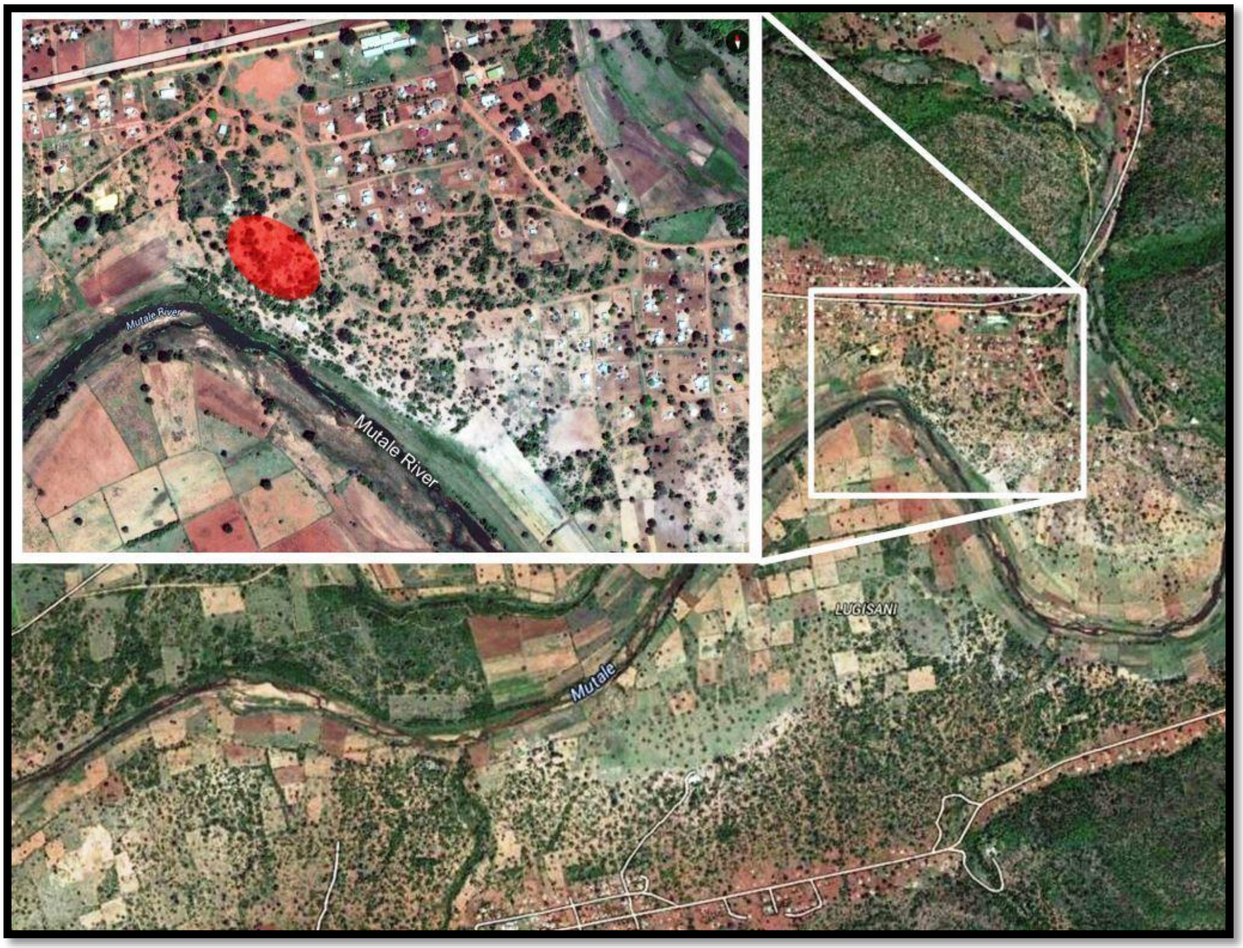

Figure 3.2. An Aerial view of Tshikundamalema (woodland bushveld) study site: Inset showing enlarged area

The second site was located at Zwigodini area and has sandy loam soils with a savannah grassland biome. Figure 3.3 shows the savannah vegetation type at Zwigodini. The GPS coordinates are S 22°29ˈ48.3ˮ, E 30°37ˈ99.5ˮ. The area is next to The Big Tree landmark, which is a tourist attraction site. Figure 3.4 shows an aerial photograph of Zwigodini.

Figure 3.3. Savannah grassland vegetation type at Zwigodini study site.

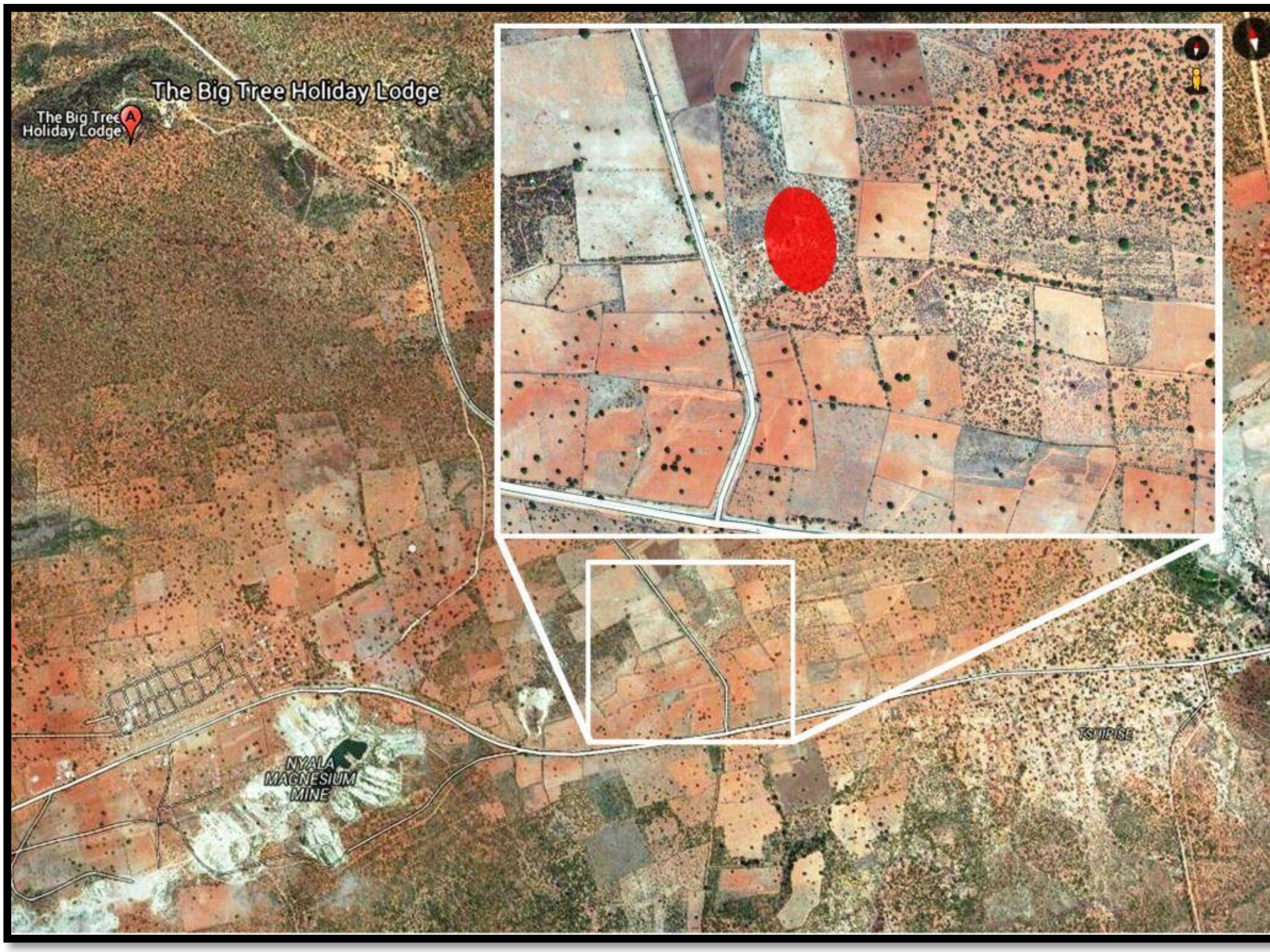

Figure 3.4. An Aerial view of Zwigodini (savannah grassland) study site: Inset showing enlarged area

3.2 Sampling procedure

A Falcon Model 4000 series, hand-held thermal fog applicator was used to partially fog the tree canopies using pyrethrin insecticide (Figure 3.5), which has a knockdown effect on insects. Insect samples were collected at one time point for each season of the year; summer (February), autumn (May), winter (July) and spring (November). Sampling was carried out early in the morning before sunrise to avoid windy conditions under which the contact of the chemical with the insects would be minimized (Erwin 1989). Five *Berchemia discolor* and five *Sclerocarya birrea* trees from each of the two sampling sites were fogged, making a total of twenty trees sampled during each sampling visit. When sampling from the trees, collecting sheets measuring 1.5 m x 3 m were carefully laid under each canopy to be fogged, so that sampling the canopy was only partial. After fogging, 10 to 15 minutes were allowed for the insects to fall onto the collecting sheets before the insects were collected into vials with 70 % ethanol for preservation until identification.

Figure 3.5. Pyrethrin insecticide cloud approaching a *Berchemia discolor* canopy with a collecting sheet spread under the canopy.

3.3. Insect identification

The insect samples were then taken to the laboratory and grouped to Orders using morphological characteristics, according to Scholtz and Holm (1996). The insects were further identified to families and grouped to morphospecies with the use of a binocular microscope to observe the morphological structures. Insects from different Orders and families were grouped to morphospecies based on their morphological characteristics.

3.4. Data Analysis

Insect diversity data was analysed using the Simpson diversity index.

Simpson's index (D) = $\frac{\sum n(n-1)}{N(N-1)}$

Where N= the total number of insects of all species; and

n = the total number of organisms of a particular species

D is the Simpson's Index (Hill, 1973).

The analysis determined the diversity of insects within trees of the same species (e.g. within *S. birrea*), across sites as well as seasons (summer, autumn, winter and spring). ANOVA was used to test for significant difference on insect numbers across the woodland bushveld and savannah grassland sites, *S. birrea* and *B. discolor* trees and the seasons.

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CHAPTER 4: IDENTIFICATION OF INSECTS TO MORPHOSPECIES

Abstract

The identification of insects to morphospecies was carried out on insects collected from the canopies of two tree species (*Sclerocarya birrea and Berchemia discolor*) at two sites (woodland bushveld and savannah grassland). Twenty trees were sampled: five *B. discolor* and five *S. birrea* from each of the two sites using canopy fogging sampling procedure. All the insect specimens were identified to orders, but only insects from Coleoptera, Hemiptera and Hymenoptera orders were identified further to family, then to morphospecies based on their external morphological characteristics; because they were the most abundant insects in the whole sample. The total number of individuals from the three orders was 3216. Order Coleoptera had the largest number of morphospecies (46), followed by Hymenoptera (27), then Hemiptera (20).

Key words: *Berchemia discolor,* canopy fogging, morphospecies, savannah grassland, *Sclerocarya birrea,* woodland bushveld.

4.1. Introduction

In order to understand insects for whatever reason, be it for pest management or ecological functions among other things, it is important to identify the insects first. However, not too many insects have been identified to species level because of limited human resources, as well as the time required to identify insects to species level. Systematic entomologists have come up with the use of morphospecies to differentiate insects based on their externally visible morphological characteristics (Derraik *et al*., 2010) for speedy identification of insects, especially for diversity and ecological studies. The use of morphospecies when identifying insects does not require insects to be identified to species level, but rather insects are identified to Order and Family, then to morphospecies (Barratt *et al*., 2003). The morphology of genitalia is one of the most useful characteristics used in the classification of insects to morphospecies (Novotny & Basset, 2000). Using morphospecies may be useful for non-specialists who may find themselves identifying insects for various reasons without compromising scientific accuracy (Oliver & Beattie 1993 cited in Derraik *et al*., 2010). Furthermore, morphospecies may be used only to a certain point; normally the initial sorting stage, before the specimens are passed to qualified entomologists who would then identify them further to species level (Beattie & Oliver 1995 cited in Derraik *et al*., 2010).

In many studies, insects are identified to obtain data for determining the species abundance and composition, although they may sometimes be identified simply to categorise them as pests and beneficial insects (Stork 1988; Blanton 1989; Lamarre *et al.,* 2012). In some ecological studies, for example, Lowman (1982) and Blanton (1989), identified insects to the Order level and grouped them according to their feeding behaviour; whether they were chewers, suckers, floral feeders or predators. Pinheiro *et al*. (2002) determined (at the Order taxonomic level) that the abundance of coleopteran insects correlated with climatic variables, although it was admitted in the study that it is difficult to predict abundance because it can be affected by other factors such as food availability and predation.

Several methods can be employed when sampling for insects, depending on the type of insects being sampled and the nature of place where the insects are being sampled. The methods may vary from hand picking, sweep netting, branch clipping, canopy fogging and various flight interception methods such as: window pane trap and malaise traps amongst many other sampling methods (Blanton, 1989; Lowman *et al.,* 1993).

4.2. Research questions

The study aimed to answer the following questions:

- What insects are prevalent on *Berchemia discolor* and *Sclerocarya birrea* in Tshikundamalema?
- What characteristics can be used to separate morphospecies of the most diverse insect Orders in this area?

4.3. Materials and methods

Insect sampling was carried out in two sites located in Tshikundamalema area, the woodland bushveld and the savannah grassland, as stated in Section 3.1.

The insect samples were collected from five *Sclerocarya birrea* and five *Berchemia discolor* trees from each of the two sites using canopy fogging; making a total of ten trees sampled from each site. The samples were identified to Family, then to morphospecies level using the insect identification keys according to Scholtz and Holm (1996). The samples were collected at one-point time during each sampling season; summer, autumn, winter and spring as outlined in Chapter 3.

The insect samples were taken to the laboratory and grouped to Orders using morphological characteristics, according to Scholtz and Holm (1996). In total, six insect Orders were collected (Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera and Diptera), and only three Orders (Coleoptera, Hemiptera and Hymenoptera) were identified further to Family and grouped to morphospecies, with the use of a binocular microscope to observe the morphological characteristics. The number of insects from the three Orders; Coleoptera, Hemiptera and Hymenoptera totalled 3216.

In the Order Coleoptera, Family Coccinellidae, colour, shape and size of the insect specimens were used in determining the morphospecies. Some members from Chrysomelidae and Curculionidae have their hind femur appearing to be swollen, and some of their groups were grouped based on those characteristics. Figure 4.1 shows one the Curculionidae with a swollen femur characteristic. Individuals from Order Hemiptera, Family Psyllidae, were grouped to morphospecies based on the colour patterns on their wings and their general colour and sizes. Many families within the Order Hemiptera had very apparent similarities (colour, shapes, sizes, ocelli, and eyes) which were used to group them. From Order Hymenoptera, the individuals were grouped to families, then to morphospecies following their wing venation and shapes, their general shapes (especially the shape of the abdomen) and colours.

Figure 4.1. Curculionidae with a swollen characteristic femur used to group insects to morphospecies.

After the preliminary identification, the samples were taken to the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya (Figure 4.2) for confirmation by Dr. Robert Copeland; at Taxonomist based in ICIPE, Nairobi.

Figure 4.2. Identification of insects using a binocular microscope at ICIPE

From each insect family, individuals with similar morphological characteristics were grouped together as morphospecies. Figures 4.3 and 4.4 show the examples of different morphospecies from order Coleoptera: Curculionidae Family. The insects were separated to morphospecies because of their different appearances; one morphospecies was hairy, while the other was not, and their general shape on the dorsal part of the abdomen differed. Individuals similar to each of these insects were grouped in the same morphospecies.

Figure 4.3. Morphospecies from Order Coleoptera and Family Curculionidae

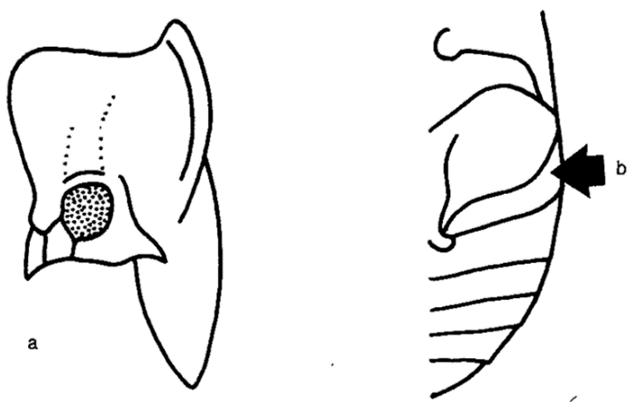
Figure 4.4. Morphospecies from Order Coleoptera and Family Curculionidae

4.4.1. Coleoptera

Most of the individuals belonging to this Order (Coleoptera) have strongly sclerotized bodies and are characterised by the fore (mesothoracic) wings which are hardened to form rigid elytra which meet along the middle line (Scholtz & Holm, 1996). The elytra cover the hind wings which are membranous. Order Coleoptera has four sub-Orders; Archostemata, Myxophaga, Adephaga and Polyphaga. Adephaga and Polyphaga are the most common sub-Orders within the coleopteran Order.

When identifying insects from Order Coleoptera to Family, the first step to take is identify the sub-Order to which the specimens belong. In order to associate the insect specimens to a particular sub-Order, insect identification keys from Scholtz and Holm (1996) were used. Figure 4.5 shows the features which were used when determining the sub-Orders from the coleopteran Order.

KEY TO THE SUBORDERS OF COLEOPTERA



1 Prothorax without notopleural suture; hind coxae movable and first visible sternite complete transversely... Polyphaga
Prothorax with notopleural suture (fig. a); hind coxae usually divide first visible sternite into two lateral pieces (fig. b) (all Adephaga).. 2
2 First abdominal sternite divided by coxae; wings in resting position not rolled.................................... Adephaga
First abdominal sternite complete; apical portion of wings rolled in resting position; mostly small and very rare insects.. 3
3 Antennae filiform or serrate; larvae wood-boring... Archostemata
Antennae clubbed; 2 mm or smaller; larvae and sometimes adults aquatic.. Myxophaga

Figure 4.5. Features and keys used for identifying the sub-Orders of Coleoptera (Scholtz & Holm 1996).

After the sub-orders were determined, the specimens were identified to Family using insect identification keys from Scholtz & Holm (1996). All of the specimens identified form the coleopteran order belonged to the Polyphaga sub-order. The identification keys such as the type of the antennae were the first keys for the Polyphaga sub-Order; the most common antennae type being the filiform, serrate, moniliform, geniculate, lamellate and capitate. The geniculate antennae type was most common in the Curculionidae family. The size of the elytra (whether it was shorter than the abdomen or it covered the abdomen completely), the alignment of the hind wings (whether they were in resting position or not), the number of tarsal segments and whether the tarsal claws were toothed/bristled or appendiculate at base were used for identifying the Families of Coleoptera. From Order Coleoptera, 46 morphospecies, belonging to four Families; Coccinellidae, Curculionidae, Buprestidae and Chrysomelidae were identified.

4.4.1.1. Coccinellidae

From Family Coccinellidae, nine morphospecies were identified. The insects were grouped according to the similarities of their morphological characteristics, i.e. their sizes, colour (spots and lines) and shapes. The summary of the characteristics which were used to separate the morphospecies is given in Table 4.1 below. Figure 4.6 a & b depicts two specimens which were of the same sizes and shapes, but different spots, pronotum, and antennae.

Table 4.1. The characteristics used to separate the morphospecies of Family Coccinellidae

Morphospecies	Characteristics
Cocci_1	Cream white colour with nine black spots on each elytron, less than 2mm in size (Figure 4.6b)
Cocci_2	Black with cream white spots with cream white bands; from front and back, at the lateral part of the elytra, almost meeting at the middle (Figure 4.6a)
Cocci_3	Shiny black, less than 2mm in size
Cocci_4	Orange with six black spots on each elytron
Cocci_5	Hairy, light brown with black bands on the elytra starting from the end of the pronotum and joining up further towards the middle of the of the elytra to form light brown spots on each elytron. Two black spots present towards the back of the elytra. (see Figure 4.7)
Cocci_6	Shiny black, about 4mm in size
Cocci_7	Shiny, light brown with two longitudinal bands on each elytron
Cocci_8	Black with one red spot on each elytron
Cocci_9	Black with light brown colour on the ventrad part of each elytron

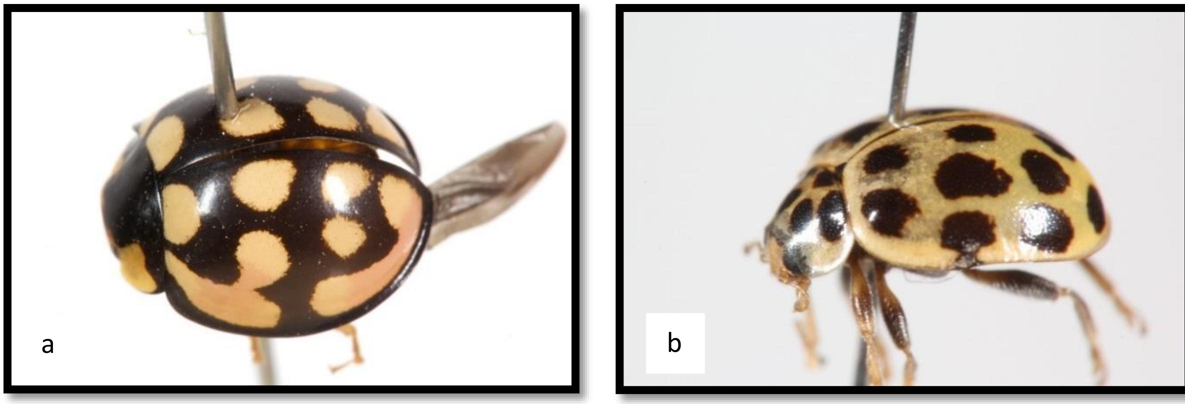


Figure 4.6. a & b. A depiction of two relatively similar specimens which were grouped under different morphospecies

Figure 4.7. One of the insects grouped under cocci_5 morphospecies

4.4.1.2. Curculionidae

The Family Curculionidae was separated into seven morphospecies. The common characteristic of individuals from this Family was the geniculate antennae and the elongated snout. The morphospecies were separated based on differences in sizes; some individuals were just slightly more than a millimetre in size, i.e. the two specimens depicted in Figures 4.8a and 4.8b. The colour of the legs, shape of the snout and the size and colour of the eyes of the specimen in Figure 4.8a distinguished it from the individuals in Figures 4.8b and 4.9. The other morphological characteristics which were used to group insects from the Family Curculionidae were their distinctly different colours, body sizes and shapes. The characteristics used to separate the morphospecies of the Curculionidae family are summarised in Table 4.6.

Figure 4.8a & b. Curculionidae insects which were separated to different morphospecies based on the snout shapes and leg colour differences.

Figure 4.9. A Curculionidae insect which is about a millimetre in size with a more enlarged back from a side view

Table 4.2. The characteristics used to separate the morphospecies of Family Curculionidae

Morphospecies	Characteristics
Curcu_1	Strongly bended snout, light brown legs, hairy, less than 2mm and grey eyes
Curcu _2	Slightly shorter snout, hairy, less than 2mm and eyes with orange spots
Curcu _3	Black, shiny light brown eyes, about a 1mm and a raised dorsad
Curcu _4	Swollen femur and opisthognathous head position
Curcu _5	Short snout, hairy, grey with uneven black patches which combine to form an elliptic shape from a top view
Curcu_6	Slightly bended snout and the pronotum is elongated
Curcu _7	Black and embossed with at least seven lines which runs laterally on each elytron

4.4.1.3. Buprestidae

Buprestidae insects are commonly called jewel beetles, a name which they are given due to their beautiful greenish and black shiny colours. Buprestids are also known as needle beetles because of their characteristic long body shapes. There were no morphospecies in the Family Buprestidae because all 14 insect samples collected were similar throughout the whole sampling period of this study. One of the members of the Buprestidae Family is shown in Figure 4.10 below; with the elongated body and shiny green and black colour.

Figure 4.10. A Buprestid insect with its characteristic shiny colours and needle-like body shape

4.4.1.4. Chrysomelidae

The Family Chrysomelidae had the largest number of groupings among all the other Families within the Order Coleoptera. Twenty-nine morphospecies were identified from the Family Chrysomelidae. Many of the specimens varied in a distinctive way in terms of their body sizes shapes, colour and the lengths and number of antennal segments. Some insects from the Family Chrysomelidae were grouped to morphospecies according to the following characteristics: the number of tarsal segments and the shapes and formation of their tarsal claws. One of the tarsal claws characteristic used to group certain insects which already had markedly similar body shape, size and colour is represented in Figure 4.11 below with the tarsal segments of some specimens bilobed, while some had noticeable bisetose empodium between their tarsal claws and some had noticeable bristles on their tarsal claws.

There were two particular groups of Chrysomelidae insects that looked like Coccinellidae, except that their elytra were transparent and showing the insect shape clearly enough to identify them as Chrysomelidae (Figure 4.12a & b). Many other Chrysomelidae specimens where noticeably different, such as the ones shown in Figure 4.13 a & b. The characteristics used to distinguish different Chrysomelidae morphospecies are summarised in Table 4.3.

Figure 4.11. A depiction of the bristled tarsal claw of a Chrysomelidae insect

Figure 4.12a & b. A depiction of two same-shaped Chrysomelidae specimens which were grouped under different morphospecies

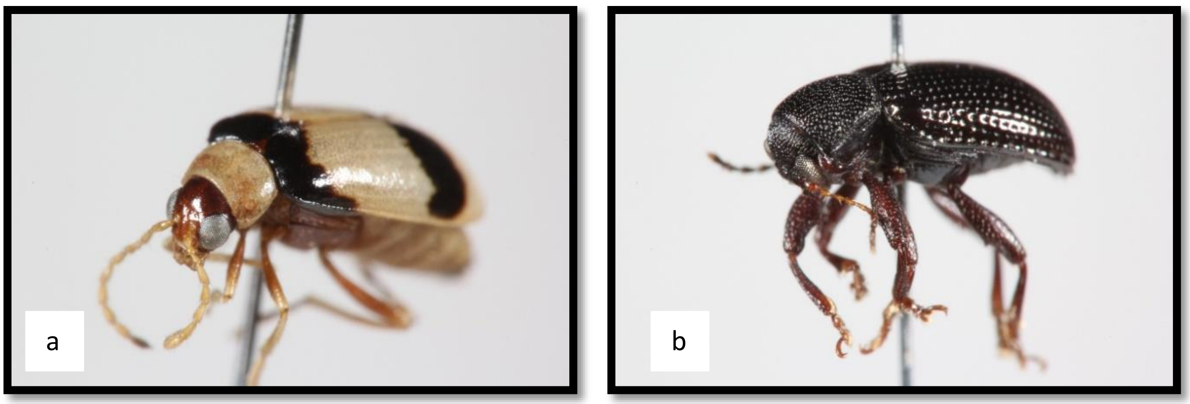


Figure 4.13a & b. Two Chrysomelidae insects which shows how different some specimens were

Table 4.3. The characteristics used to separate the morphospecies of Family Chrysomelidae

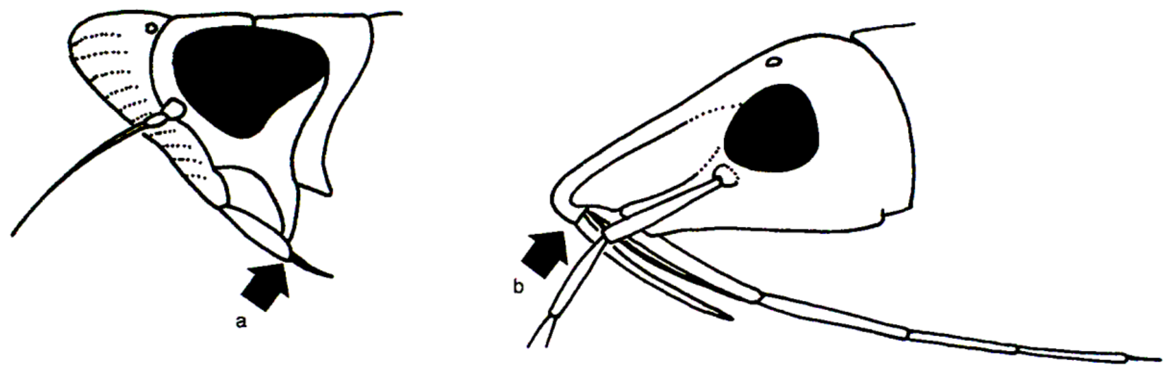
Morphospecies	**Characteristics**
Chrys_1	Brown, hairy and about 5 mm in size
Chrys _2	Brown, hairy and about 5 mm in size, with noticeable bristles on tarsal claws
Chrys _3	Dome shaped with slightly transparent elytra and pronotum, and black spot present on the elytra and pronotum (Figure 4.8a)
Chrys _4	Dome shaped with slightly transparent elytra and pronotum, four spots present on the pronotum, and black lines forming a sigma-shape on each elytron (Figure4.8b)

Chrys _5	Cream white with two black bands which moves from the ventrad to the dorsad part of each elytron (Figure4.9a)
Chrys _6	Brown, about 2 mm innsize
Chrys _7	Black, shiny with dark brown legs (Figure 4.9b)
Chrys _8	Reddish elytra, green pronotum and legs
Chrys _9	Black, with elongate and swollen hind femur
Chrys _10	Metallic red and green elytra and black shiny head
Chrys _11	Cream white with six black spots on each elytron
Chrys _12	Shiny black elytra and shiny light brown head
Chrys _13	Metallic green, about 5 mm in size
Chrys _14	Metallic brown, about 5 mm in size
Chrys _15	Black with spines all over the elytra and the pronotum
Chrys _16	Light brown with black spots and spines on the elytra and the pronotum
Chrys _17	Grey with two dark grey colour bands on each eltron
Chrys _18	Orange with two black spots on each elytron
Chrys _19	Light brown with two dark brown lines which runs parallel on each elytron
Chrys _20	Light brown with a black band which overlaps on the elytra at the posterior
Chrys _21	Orange elytra with a black head
Chrys _22	Metallic green and black with swollen an elongated hind femur
Chrys _23	Cream white with three black parallel colour band; one black band sits on both elytra
Chrys _24	Black with two cream white spots on each elytron
Chrys _25	Metallic green elytra with orange head and legs
Chrys _26	Cream white with ten small spots on each elytron
Chrys _27	Black head, yellow elytra, each with three spot on each elytron; two towards the end of each elytron and one nearer the pronotum
Chrys _28	Orange with two black band colours which starts from the ventrad part of one elytron to the other
Chrys _29	Brown with swollen an elongated hind femur

4.4.2. Hemiptera

Hemiptera is the largest Order of the Exopterygota insects with over 60 000 described species (Scholtz & Holm 1996). The characteristic piercing and sucking mouth part is what distinguishes this Order (Hemiptera) from the rest of other insects Orders, despite that Coccoidae and Aphidoidae families from the same Order (Hemiptera) do not have the piercing and sucking mouth parts. Hemiptera is divided into two Sub-orders:Homoptera and Heteroptera, with all members of the former Suborder (Homoptera) being phytophagous. The features and keys which are used to identify the Hemiptera suborders are shown in Figure 4.14 below.

KEY TO THE SUBORDERS OF HEMIPTERA



Fore wings, when present, of more or less uniform texture, without distinct differentiation into corium and membrane and usually held roofwise over abdomen at rest; insertion of labium close to prosternum, without an intervening sclerotized gula (fig. a); never truly aquatic .... Homoptera

Fore wings, when present, usually sclerotized basally, membranous apically and overlapping flat over abdomen at rest; insertion of labium usually remote from the prosternum (fig. b), with a sclerotized gular region intervening; includes several aquatic groups .... Heteroptera

Figure 4.14. Features and keys used for identifying the sub-Orders of Hemiptera (Scholtz & Holm 1996).

From Order Hemiptera, a total of 1975 specimens were identified, belonging to twenty morphospecies and twelve Families. Psyllidae had five morphospecies followed by Rhopalidae (with four morphospecies), then Alydidae, Aradidae, Cercopidae, Miridae, and Nabidae; which had two morphospecies each. Pentatomidae, Rhyprochromidae, Membracidae, Lygaeidae and Coreidae all had one morphospecies.

The grouping of various morphospecies from each Family was based on their distinct differences in colour, sizes and general shapes of the insects. For example, Figure 4.15 a & b shows some huge differences of colour and shapes of insects from the Family Cercopidae. Apart from the visible differences, two other similar groups of specimens from the Family Psyllidae were separated only due to their different cercus, though the assumption held that it could be gender differences. The morphospecies of Psyllidae, Rhopalidae, Alydidae, Aradidae, Cercopidae, Miridae, and Nabidae are shown in Table 4.4.

Figure 4.15a & b. A depiction of two different Cercopidae specimens which were grouped under different morphospecies

Table 4.4. The characteristics used to separate the morphospecies of order Hemiptera

Morphospecies	Characteristics
Psyl_1	Light brown head with green abdomen, the dorsal part of wings with black dots
Psyl_2	Light brown with many small black and dark brown spots on wings with cercus which suggest that it is female
Psyl_3	Light brown with many small black and dark brown spots on wings with cercus which suggest that it is male
Psyl_4	Light brown head with green abdomen and transparent wings which are twice as long as the abdomen
Psyl_5	Light brown head, cream white abdomen with clear wings and about 2mm in size
Rhop_1	Black with red pots, about 5 mm in size with cercus which suggest that it is male
Rhop_2	Black with red pots, about 5 mm in size with cercus which suggest that it is female
Rhop_3	Grey with four black dots on the edges of each hemi-elytron
Rhop_4	Orange with two black spots on each hemi-elytron and two on the head. The scutellum is bordered by a black colour also.

Alyd_1	Brown with dark brown colour which marks the posterior boarders of the hemi-elytra
Alyd_2	grey with black colour which marks the posterior boarders of the hemi-elytra
Arad_1	Dark brown pronotum and scutellum, dark brown bordered with light brown colour on the abdominal segments which protrude on the sides and posterior of the insect
Arad_2	Dark brown with two four antennal segments; the third one being cream white while the rest are dark brown
Cerc_1	Black with red spots on each side (Figure 4.15a)
Cerc_2	Cream white with orange spots on the head and pronotum, dark brown wings with light cream white patches (Figure 4.15b)
Miri_1	Light brown head and scutellum, black hemi-elytra, each with brown spots at the end
Miri_2	Light brown with black membranous wings and the abdomen
Nabi_1	Light brown antennae bended to point backwards
Nabi_2	Light brown with black membranous wings, antennae bended to face side ways

4.4.3. Hymenoptera

The Order Hymenoptera has two sub-Orders; Symphyta and Apocrita. Symphyta sub-Order consists of sawflies which are mainly phytophagous, while Apocrita is more diverse comprising of bees, wasps and ants. The Hymenoptera identified in this study were all from the Apocrita sub-Order. Apart from using antennal segments, tarsal segments and maxillary palpi as used in the Coleopteran and Hemipteran Orders, wing venation is important when identifying insects from the Order Hymenoptera. Individuals of Apocrita sub-Order have a distinct constriction between the propodeum and the remainder of the abdominal segments.

Three Families were identified from the Order Hymenoptera: Braconidae, Formicidae and Vespidae. Fourteen Formicidae morphospecies were identified, eleven Braconidae and two Vespidae. A total of 513 Hymenoptera specimens were collected. The variation of form, colour and sizes of the insect samples was very noticeable; which made the grouping to morphospecies simple. Most braconids were grouped and identified based on their wing venation differences. A depiction of noticeable differences in colour on some braconids is in Figure 4.16a & b below.

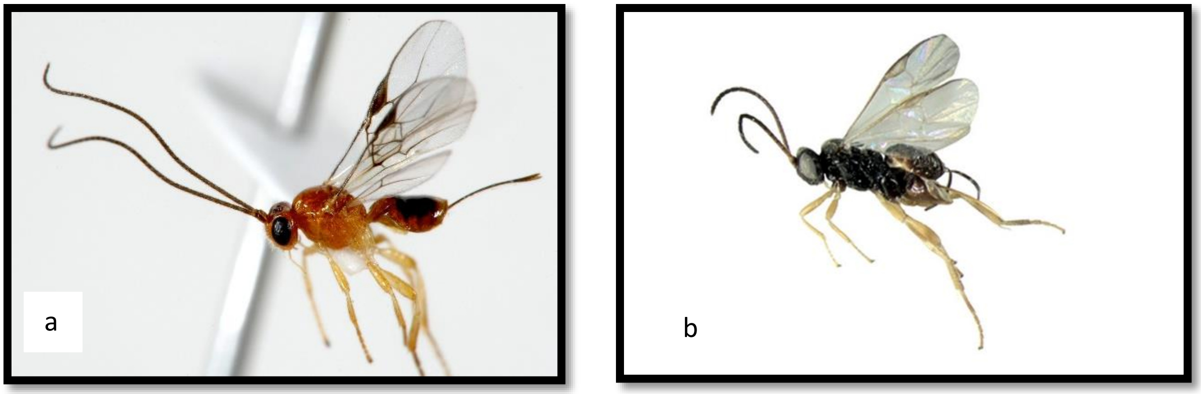


Figure 4.16a & b. A depiction of two different Braconidae specimens which were grouped under different morphospecies

Table 4.5. The characteristics used to separate the morphospecies of Order Hymenoptera

Morphospecies	Characteristics
Form_1	Brown, about 1mm in size, with flat truncus
Form_2	Light brown head and prothorax with a black abdomen
Form_3	Shiny black and winged
Form_4	Black head, reddish brown from the truncus all the way to the second node of the abdomen and reddish-brown legs
Form_5	Black head, reddish brown from the truncus all the way to the second node of the abdomen and reddish-brown legs, winged
Form_6	Brown from the head to the petiole (which is not clearly visible), black abdomen with light grey hairy band on the third abdominal tergite
Form_7	Grey with black antennae
Form_8	Light brown with black tergites and brown sternites the last two abdominal segment black
Form_9	Grey and winged, about 2mm in size
Form_10	Black from the head to the second abdominal segment, with orange abdomen which has two black bands on the third and fifth segment
Form_11	Black with a well-defined petiole

Form_12	Black, elongated body, the petiole similar to the second abdominal node
Form_13	Light brown head, abdomen almost a perfectly shaped round and black
Form_14	Light brown with a petiole which has two spines
Brac_1	Black from to the petiole, yellow abdomen, black transparent wings
Brac_2	Bright orange body with a black head
Brac_3	Black from head to abdomen, clear transparent wings with black veins
Brac_4	Black body, light brown legs and transparent wings
Brac_5	Black from head to the second abdominal node and black slightly transparent wings
Brac_6	Black head, truncus and abdominal tergites with yellow sternites
Brac_7	Light brown to orange body colour with first three sternites and tergites black
Brac_8	Black, tiny (about 1mm) with yellow sternites and black tergites
Brac_9	Orange, clear white trans parent wings and a black spot on the head which covers only the part where there are ocelli
Brac_10	Orange with black, hardly transparent wings
Brac_11	Orange with clear transparent wings and black legs
Vesp_1	Black with hairy truncus, light brown head and noticeably narrow on the first and second nodes
Vesp_2	Black with white bands at the end of the first and the second abdominal nodes, wings black and transparent

4.5. Discussion

The use of morphospecies when identifying insects helps, to minimise the time taken to identify the insect specimens (Derraik *et al*., 2010). The identification of morphospecies is not necessarily the species identification, but the grouping of insect specimens based on the similarities of their morphological characteristics and it is usually done by parataxonomists as the initial insect identification stage (Barratt *et al.,* 2010). There are great numbers of insects, yet limited knowledge necessary for their identification; hence the identification of insect to morphospecies helps enhance the practicability of conservation surveys thereby reducing the time required to identify the insect specimens (Derraik *et al.,* 2002).

The Coleoptera, Hemiptera and Hymenoptera insect samples collected during this study were identified to Family and then to morphospecies. The criteria used to identify and group morphospecies in this study is indicated in Tables 4.1 to 4.5. The coleopteran Order had forty-six morphospecies, which made it the most diverse order in this study; Chrysomelidae alone had twenty-nine morphospecies, Coccinellidae had nine morphospecies and Curculionidae had seven morphospecies. The Order Hymenoptera came second to Coleoptera, with twenty-seven morphospecies followed by Hemiptera with nineteen morphospecies. These findings agree with what Lowman (1982) found in a study of the seasonal variation in insect abundance, where it was shown that high portions of Coleoptera, Lepidoptera and Hemiptera were represented, although lepidopterans were too few in this study, to even consider for further identification. Lowman (1982) further indicated that the most represented family from Coleoptera was Chrysomelidae. This is despite the differences in sampling techniques; Lowman (1982) used sweep net and light traps while canopy fogging sampling technique was used for this study.

The order Hemiptera was the least diverse order of the three (Coleoptera, Hymenoptera and Hemiptera), with seven groups of morphospecies; the most diverse being Psyllidae with five morphospecies, followed by Rhopalidae with four morphospecies. A much similar study on biodiversity of arthropods from Australian rainforest canopies by Kitching *et al.,* (1993) showed that Coleoptera, Hymenoptera, Hemiptera and Collembola were the most abundant Orders sampled using canopy fogging in the tropical and subtropical forests.

From Order Hymenoptera, three Families were collected; Braconidae, Formicidae and Vespidae. The most diverse was Formicidae, with fourteen morphospecies, followed by Braconidae, with eleven morphospecies, then Vespidae with only two morphospecies. Table 4.5 shows the criteria used to identify the morphospecies of the Families; Brachonidae, Formicidae and Vespidae.

4.6. Conclusion

Berchemia discolor and *Sclerocarya birrea* trees in Tshikundamalema are mostly inhabited by insects from Coleoptera, Hymenoptera and Hemiptera orders; Coleoptera being the most diverse. Further studies are needed to identify the pests and beneficial insects from these Orders on *B. discolor* and *S. birrea.*

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CHAPTER 5: SEASONAL ABUNDANCE AND DIVERSITY OF INSECTS IN TSHIKUNDAMALEMA

Abstract

The identification of insects to morphospecies was carried out on insects collected from the canopies of two tree species (*Sclerocarya birrea and Berchemia discolor*) at two sites (woodland bushveld and savannah grassland). The Simpsons Diversity index showed that the diversity of insects was affected by tree species and seasons. The t-test statistics was used to determine the significant difference on insect abundance on the two-tree species *S. birrea* and *B. discolor*, the four seasons and two sites. *B. discolor* had a greater abundance (1741) as compared to *S. birrea* (1475). The spring season had the largest number of insects, followed by summer, autumn then winter. The diversity of insects was affected by tree species and seasons, but only slightly affected by sites. The diversity of insects was high on *S. birrea* over *B. discolor*, with the diversity index of 0.804 and 0.741 respectively, although the seasons did not extensively affect the diversity of insects except for the winter season which had the lowest diversity index of 0.434. The woodland bushveld and savannah grassland sites both had a large diversity of insects, although they did not differ significantly.

Key words: *Berchemia discolor*, insect abundance, *Sclerocarya birrea*, Simpsons Diversity Index

5.1. Introduction

The abundance of insects is affected by seasons. For example, in tropical savannahs, the difficult period for most plant feeding insects is usually during the dry season, when leaves are less nutritious (Braby, 1995); thus, their abundance is affected by food availability (Mani, 1968, cited in Lowman, 1982). Arboreal insects are among the most abundant (Sutton & Hudson, 1980 cited in Lowman, 1982), with large numbers accommodated generally by tree species with large canopy volumes (Kitching *et al.,* 1993). For insects to be sampled effectively from large volume canopies, suitable canopy sampling methods such as canopy fogging or branch clipping are known to yield better results (Blanton 1989). Nevertheless, Yanoviak *et al* (2001) argued that canopy fogging only sampled for 30 to 33% of insects from the tree canopy when comparing with post-fogging insect samples collected from the same canopies. The cause of such an effect may be due to the inaccessibility of the insects hiding under the barks and leaf-miners (Marques *et al.,* 2006). Pinheiro *et al.,* (2002) showed that the use of different sampling techniques may yield better results than just one sampling method would, considering that insect of different taxa may be more common in certain micro environments.

There is no information on insect abundance and diversity on *Sclerocarya birrea* and *Berchemia discolour* in Tshikundamalema. The results presented below include insect Orders, Families and morphospecies of arthropods collected from *S. birrea* and *B. discolor* canopies from the Savannah grassland and woodland bushveld sites. The total number of individuals sampled from six insect Orders (Coleoptera, Hemiptera, Hymenoptera, Diptera, Orthoptera and Lepidoptera) was 3259. Individuals from Coleoptera, Hemiptera and Hymenoptera Orders were further identified to family and morphospecies levels (which constituted 3216 individuals).

5.2. Research questions

The study aimed to answer the following question:

- Do tree species, site and seasons affect the diversity and abundance of insects?

5.3. Materials and Methods

Twenty trees; five *Berchemia discolour* and five *Sclerocarya birrea* trees were sampled from two sites (savannah grass land and woodland bushveld). The sampling method used was canopy fogging with the use of pyrethrum insecticide (as described in Chapter 3).

Insects were identified to Order, Family and morphospecies before the statistical analyses. The t-test statistics was used at 95% confidence interval to determine the significant difference on insect abundance on the two-tree species, *S. birrea* and *B. discolor*, the four seasons and two sites. The Simpson's diversity index was used to calculate the diversity of insects across sites, seasons and tree species.

Simpson's index (D) = $\frac{\sum n(n-1)}{N(N-1)}$

Where N= the total number of insects of all species; and

n = the total number of organisms of a particular species (Hill, 1973)

5.4. The abundance of insects across sites, tree species and seasons

The results presented in Table 5.1 show all the 19 insect Families with 97 morphospecies sampled from the woodland bushveld and savannah grassland sites, 20 trees belonging to *Berchemia discolor* and *Sclerocarya birrea* species and all four seasons. The "Total" column represents the total number of insects for the tree species, sites and seasons. Table 5.2 summarises the total number of insects from Orders, Families and morphospecies.

Table 5.1. The summary of table 5.1 in the appendix, showing the number of insects sampled from *Sclerocarya birrea* and *Berchemia discolor* across the woodland bushveld and savannah grassland sites and seasons.

	Summer				Autumn				Winter				Spring			
	Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld	
	B. discolor	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*
Total	245	298	215	346	83	62	21	72	16	10	17	49	408	170	736	468

Table 5.2. Summary data of the three insect Orders contributing the most to insect abundance and diversity in Tshikundamalema.

ORDER	FAMILY	No. of morphospecies	Total no. of insects caught
Coleoptera	Coccinellidae	9	107
	Curculionidae	7	64
	Buprestidae	1	13
	Chrysomelidae	29	557
	TOTAL (Coleoptera)	46	741
Hemiptera	Psyllidae	5	921
	Pentatomidae	1	7
	Rhyprochromidae	1	10
	Membacidae	1	14
	Lygaeidae	1	23
	Coreidae	1	9
	Rhopalidae	4	946
	Alydidae	2	7
	Aradidae	2	4
	Cercopidae	2	11
	Miridae	2	17
	Nabidae	2	3
	TOTAL (Hemiptera)	24	1972
Hymenoptera	Formicidae	14	356
	Braconidae	11	142
	Vespidae	2	5
	TOTAL (Hymenoptera)	27	503
TOTAL		**97**	**3216**
DIPTERA			26
ORTHOPTERA			6
LEPIDOPTERA			11

5.5. Seasonal abundance of insects in woodland bushveld and savannah grassland

The differences in the number of insects between *Sclerocarya birrea* and *Berchemia discolor,* the two sampling sites and season is shown in Table 5.1 above. The largest number of insects was collected in spring than all the other seasons, followed by the summer season. *B. discolor* represented the largest number of insects during the spring season, despite *S. birrea* having more insects than *B. discolour* during summer, autumn and winter. The number of insect sampled during the spring season (1782 individuals) varied significantly with those collected during the summer season (1104 individuals). The winter season had significantly lower numbers than all the other seasons, with only 92 individuals, while autumn had 238 individuals.

5.6. Seasonal abundance of insects during the four seasons on two tree species and two sites

Figure 5.1 summarises the results presented in Table 5.1. *Sclerocarya birrea* had the largest number of insects during summer from both savannah grassland and woodland bushveld sites during the four seasons. The largest number of insects was collected during the spring season. There was a significant difference in the abundance of insects caught from *S. birrea* and *B. discolor* from the woodland bushveld and savannah grassland sites. *Berchemia discolor* had relatively large number of insects than *S. birre*a, though *B. discolor* from the woodland bushveld had a larger number of insect compared to the *B. discolor* trees from the savannah grassland site. In summer, there was no significant difference in the number of insects caught in each tree species in the woodland bushveld and savannah grassland, although *B. discolor* had relatively large number of insects as compared to *S. birrea*. The autumn season had lesser insects caught as compared to summer with *B. discolor* in the woodland bushveld having the lowest number of insects. *Berchemia discolor* and *Sclerocarya birrea* in the savannah grassland did not differ significantly in the number of insects caught. The lowest number of insects was sampled during the winter season. The abundance of insect on *Berchemia discolor* and *Sclerocarya birrea* from the savannah grassland did not differ significantly, although *S. birrea* from the woodland bush veld had a significantly high abundance of insects than *B. discolor*.

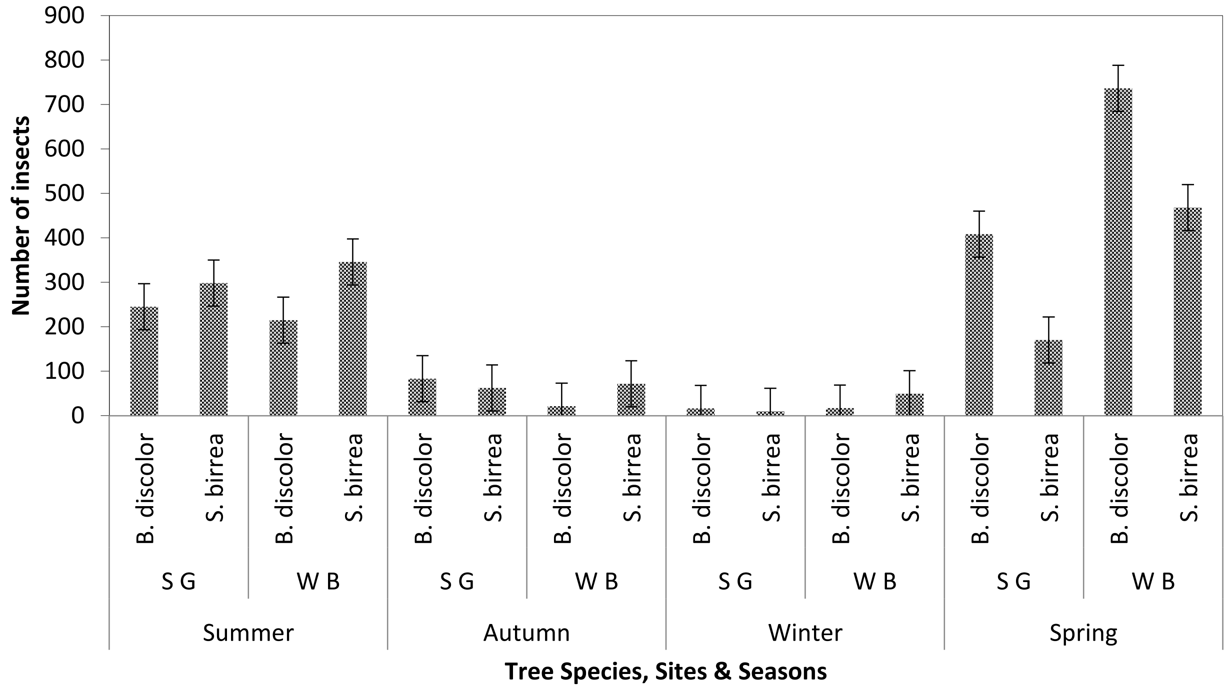

Figure 5.1. A summarised graphic representation of Table 5.1 (the number of insects sampled from different tree species, sites and seasons)

The comparison of insect abundance on *Sclerocarya birrea* and *Berchemia discolor* during all the sampling seasons is represented in Figure 5.2 below. The highest number of insects was recorded for *Berchemia discolor* during the spring season, followed by insects collected from *Sclerocarya birrea* during the spring and summer seasons. These numbers were significantly different from the numbers collected in spring from *B. discolor*. Collections from *B. discolor* in summer were significantly lower than the spring collections from the same tree species, but did not differ significantly from the summer and spring collections from *S. birrea*. The lowest numbers for both tree species were collected during winter, but these were not significantly different from the autumn collections for both tree species.

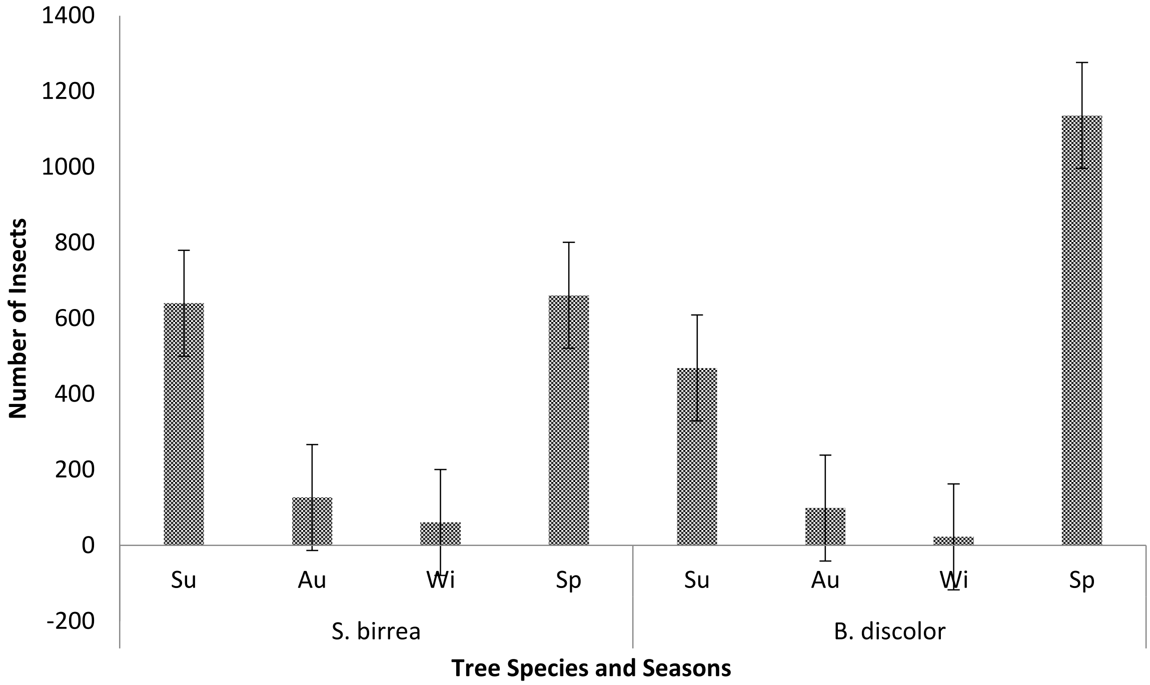

Figure 5.2. Seasonal abundance of insects between *Sclerocarya birrea* and *Berchemia discolour*

5.7. Insect Diversity

Simpson index of diversity was used to analyse the diversity of insect species between tree species, sites and seasons. Table 5.3 below shows a summary of insect species diversity across tree species, sites, and seasons. The diversity was either very high or high at sites, tree species and seasons, except for winter where diversity was low (with Simpson's Diversity index of 0.434).

Table 5.3. The analysis of Species diversity across the woodland bushveld and savannah grassland sites, *Sclerocarya birrea* and *Berchemia discolor* trees and seasons

		Simpson's Diversity Index
Tree Species	*S. birrea*	0.804
	B. discolor	0.741
Sites	Woodland bushveld	0.739
	Savannah grassland	0.786
Seasons	Summer	0.817
	Autumn	0.818
	Winter	0.434
	Spring	0.728

ANOVA at 95% confidence level, i.e. $p < 0.05$, was used to test for significant differences among the 19 insect morphospecies from the two-tree species, two sites and four seasons. The results are presented in the tables below.

Table 5.4. ANOVA Statistics on the significant difference on insect abundance sampled from *Berchemia discolor* and *Sclerocarya birrea* in woodland bushveld and savannah grassland sites during summer, autumn, winter and spring.

	df	Sum Sq	Mean Sq	F value	P value
TreeSpp	1	0.014	0.014	0.03	0.863994
Seasons	3	13.877	4.626	9.919	0.000376
TreeSpp:Seasons	3	1.480	0.493	1.07	0.389778
Residuals	16	7.380	0.461		

The results in Table 5.4 above table shows that the insect species abundance was affected significantly by seasons (F=9.919; df=3,16; P=0.0004). The tree species did not have a significant effect on insect abundance (F=0.03; df=1,16; P=0.86). There was no evidence for a Tree species by Season interaction (F=1.07; df=3,16; P=0.39).

Table 5.5 The pairwise comparison of the significant difference on insect abundance during summer, autumn, winter and spring.

	Difference	Lower	Upper	P adjusted
Spring-Autumn	2.1298343	0.9399316	3.3197370	0.0005367
Summer-Autumn	1.8231645	0.6332619	3.0130672	0.0023484
Winter-Autumn	1.0336479	-0.3403334	2.4076292	0.1790825
Summer-Spring	-0.3066697	-1.2782212	0.6648817	0.8034070
Winter-Spring	-1.0961864	-2.2860891	0.0937163	0.0764876
Winter-Summer	-0.7895167	-1.9794193	0.4003860	0.2675066

The pairwise comparison of seasons at 95% confidence level showed that there was significant difference between spring and autumn (p value 0.0005) and summer and autumn (p value 0.002). There was no interaction during the other seasons ($p>0.05$).

5.10. Discussion

The largest numbers of insects sampled during this study were from the Hemiptera Order, with most insects recorded from Rhopalidae and Psyllidae (946 and 921 individuals respectively). Overall, Hemiptera constituted 60.51% of the whole sample, Coleoptera (23.66%) and Hymenoptera (15.74%). Diptera, Orthoptera and Lepidoptera constituted the lowest percentages; 0.80%, 0.18% and 0.34% respectively. These results differ from what Pinheiro *et al.* (2002) found Coleoptera, Hymenoptera, Isoptera, and Diptera were the numerical dominant orders, constituting 26%, 23%, 20% and 20.5% respectively in a savannah vegetation during the dry season using malaise and window traps. Kitching *et al.,* (1993) determined that Hymenoptera, Coleoptera, Hemiptera Psocoptera and Collembola were the most dominant orders sampled during their study on rain forest canopies in Australia. The differences in results of various studies may be a consequence of differences in climatic zones, seasons, sampling methods and tree species from which the samples were collected.

The results in Table 5.4 show that the tree species did not have effect on the abundance of insects. However, seasons had a significant effect on insect abundance. There was however no interaction between tree species and seasons ($p>0.05$). Table 5.5 shows seasonal differences with p-values less than 0.05. From Table 5.5, the p-values which are less than 0.05 indicate that autumn differed from spring and from summer, with no other pairwise comparison showing interactions.

The differences which exists between spring and autumn may be because spring is a flowering season, (which normally occurs between September and November) for *Sclerocarya birrea* and October to January for *Berchemia discolor* (Orwa *et al.,* 2009) and may be inviting to pollinators (Mishra, Gupta & Yadav 2004), on the other hand, autumn is a relatively dry season in South Africa. Furthermore, the abundance of insects during the summer season may have been caused by the abundance of food resources (Mani 1968 cited in Lowman 1982). *Sclerocarya birrea* had particularly more insects than *Berchemia discolor* during the summer season, although this was different for the spring season (*B. discolor* had significantly large number of insects than *S. birrea*). The lowest number of insects was recorded during the winter season. There were more insects recorded in autumn compared to winter. In both seasons (autumn and winter), *S. birrea* trees from the woodland bushveld site had the most insects, although insects from *B. discolor* were slightly more than the insects collected from *S. birrea* at the savannah grassland in both seasons.

The diversity of insects was affected by tree species and seasons, while the tree species only affected the diversity of insects slightly; on *S. birrea,* the Simpson's Diversity index was 0.804 (which is very high), while the diversity of insects on *B. discolor* was high (0.741). The Simpson's Diversity Index did not significantly differ by sites; the woodland bushveld (0.739) varied very little from the savannah grassland (0.786). Therefore, the seasons affected the diversity of insects significantly. The diversity of insects was low during winter, high during spring and very high during summer and autumn. However, there was very little or no considerable difference between summer (0.817) and autumn (0.818).

5.11. Conclusion

The abundance and diversity of insects were significantly affected by seasons. The spring season recorded the highest number of insects; it is most likely that most of the insects sampled during spring were pollinators since it is a flowering season. The summer season had significantly higher numbers of insects; dropping just slightly below the spring season. The summer season is a rainy season (Arun & Vijayan, 2004) and a season in which many tree species would have sprung new leaves, and therefore availing unlimited food resource for most insect herbivores (Lowman, 1982). The tree species with the highest abundance of insects was *Berchemia discolor,* this could be due to its dense canopy (Orwa *et al.,* 2009), hence the inevitability of harbouring large number of insects. The winter season had the lowest insect abundance and the diversity was low also. There are few important factors such as lack of food resources Braby (1995) and loss of habitat due to tree leaflessness during the winter season (Akinnifesi *et al.,* 2008) which could have instigated the low numbers and less diversity of insects.

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CHAPETR 6: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1. Discussion

The aim of the study was to determine the seasonal abundance and diversity of insects in two tree species occurring in two different vegetation types. The diversity of insects was affected by tree species, seasons and vegetation type.

The top three insect Orders found were Hemiptera, Coleoptera and Hymenoptera. Order Hemiptera had the largest number of insect, contributing 60.51 % of the insects collected, while Coleoptera (23.66 %) was the most diverse Order of all the 97 morphospecies identified. Chrysomelidae family alone made up 63.04 % of morphospecies in the Order Coleoptera and 29.90 % of all morphospecies identified in the study. Despite Hemiptera having the most insect abundance, it had the least total number of morphospecies identified. Hymenoptera had the least insect abundance with 15.74 %, but had the second most diverse of all the Orders.

Some studies in Europe have shown that a great predictor of arthropod assemblage composition was local plant species composition (Proches & Cowling, 2007; Botha *et al.,* 2016). This must be the greatest reason why other insect orders, families and morphospecies were found to be more abundant in one tree species than another (*S. birrea* or *B. discolor*). In this case more insects were collected in *B. discolor*, although the statistic results in Table 5.4 shows that tree species did not significantly affect the abundance of insects. The results in Table 5.3 shows that insect diversity varied slightly in comparison with each site: where it was higher in savannah grassland (0.786) than woodland bushveld (0.739) but in terms of numbers, more insects were collected from the woodland bushveld site than from the savannah grassland.

Several studies have shown that certain factors like vegetation percentage cover, density, height and the associated microclimate have a significant effect on dung beetle and grasshopper species composition. A study on some of South Africa's biomes (Savannah, Grassland, Nama Karoo & Forest biome) found that the differences in insect assemblages in different plant assemblages were more convincing than those of different biomes (Schaffers *et al.,* 2008). Results in Table 5.3 have also shown that diversity of species was very high on *S. birrea* (0.804) tree species than on *B. discolor* (0.741-high) irrespective of vegetation type.

Botha *et al.* (2016) found that arthropods species assemblages were better described by their geographic positions rather than plant characteristics associated with biome (i.e. grass and tree cover). Certain insect species may only thrive under specific climate or temperature conditions;

this may explain the variation of insect orders and diversity in different seasons, since some species relocate to different sites with change in seasons in order to survive. Seasons come with change in temperatures, food supply, and level of rain fall. Some insects such as ants (Hymenoptera) are more abundant after rainfall, thus their abundance would be more favoured in rainy or wet seasons. The results in Table 5.3 show that diversity differed according to season: it was very high in autumn (0.818), followed by summer (0.817), then spring (0.728-high) and winter (0.434), where it was relatively low.

According to Moore (2013), the largest insect Order by number of species is Coleoptera, it is recorded that one in five living animal species is a beetle. This could be the reason why the results of this study showed that despite Hemiptera having the highest insect abundance, Order Coleoptera had the highest insect diversity (number of morphospecies). Coleoptera is said to make about one out of four of all known insects, with about 280 000 different insect species in the world.

Most morphospecies in this study were collected during spring which is pollination season; this may explain why Hymenoptera was among the three top orders, with higher diversity than Hemiptera, and came second in diversity to Coleoptera, although it had the lowest insect abundance of the three major Orders collected.

According to Ethridge and Shook (2017), most of insect diversity is found on the ground, thus the sampling method used in this study being canopy fogging might have missed a great abundance and diversity of certain species orders and thus being bias to species existing on top of trees. We can conclude that the species identified are not really a representative of the abundance and diversity of insects in the site but might be indicative of canopy insect diversity and abundance of the two tree species under study.

6.2. Conclusion

The study showed that vegetation type, tree species and season affect insect diversity and abundance. Tree species seems to have more effect on the abundance and diversity of insects than surrounding vegetation type. *Berchemia discolor* had a higher abundance of insects than *S. birrea*, while *S. birrea* had greater insect diversity than *B. discolor*. Diversity Index difference between tree species was 0.063. Vegetation type seems to have more effect on abundance than on diversity. Woodland bushveld had more insects than savannah grassland (Figure 5.1). However, savannah grassland had a relatively higher insect diversity compared to woodland bushveld. Seasons had more significant effect on both abundance and diversity as opposed to tree species and sites. Autumn was the season with the greatest diversity while the spring season had the greatest insect abundance. The winter season had less number of insects and low diversity.

6.3. Recommendations

This study could be furthered; investigating why vegetation type have more effect on the abundance of insects than it actually has on the diversity. A further study could be conducted to unravel why the savannah grassland (being drier than the woodland bushveld) would have a higher insect diversity when compared to the woodland bushveld.

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Appendix

Table 5.1. A detailed table 5.1 showing number of insects sampled from *Sclerocarya birrea* and *Berchemia discolor* across the woodland bushveld and savannah grassland sites and seasons.

	Summer				Autumn				Winter				Spring			
	Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld		Savannah Grassland		Woodland Bushveld	
	B. discolor	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*	*B. discolor*	*S. birrea*
Morphospecies																
Cocci_ 1	0	0	5	0	2	0	0	2	0	0	0	0	0	29	2	15
2	0	4	5	4	0	0	0	0	0	0	0	0	0	4	0	9
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
5	0	0	3	0	0	0	0	0	0	0	0	0	0	5	0	0
6	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	2	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0

9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curcu_ 1	0	6	0	1	1	0	1	2	0	0	2	1	0	1	0	11
2	0	1	6	20	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
7	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Bupr_ 1	1	2	2	2	0	4	0	0	0	0	0	0	0	1	1	0
Chry_ 1	11	3	0	4	0	0	0	0	0	0	0	0	7	7	4	4
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
3	10	3	13	10	0	0	0	0	0	0	0	0	0	0	1	18
4	3	0	2	6	0	0	0	0	0	0	0	0	0	0	7	0
5	2	3	0	0	0	0	0	0	0	0	0	0	1	4	0	0
6	0	68	1	16	0	0	0	0	0	0	0	0	2	1	0	0
7	4	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1
8	4	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0
9	1	11	3	17	0	0	6	0	0	1	0	0	0	0	18	1

10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
12	0	0	0	37	0	0	0	0	0	0	0	0	0	3	16	34
13	0	16	0	0	0	0	0	0	0	0	0	0	0	0	6	4
14	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	2
21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
24	0	1	0	0	0	0	0	0	0	0	0	0	1	1	31	3
25	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1	2	3	7	0	0	0	0	0	0	0	0	0	0	0	0
27	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

28	0	0	0	0	7	10	0	2	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Psyl_ 1	12	29	0	25	0	4	0	0	0	0	0	37	262	21	83	81
2	43	45	0	0	22	0	0	0	8	1	10	9	0	0	10	141
3	0	2	3	0	0	0	3	0	0	3	1	1	2	1	1	0
4	5	5	11	1	0	0	0	0	0	0	0	0	4	11	1	13
5	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
Pent_ 1	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	1
Rhyp_ 1	1	0	2	0	0	6	0	0	0	0	0	0	0	1	0	0
Memb_1	6	0	0	3	0	0	0	0	0	3	0	0	0	0	0	2
Lyg_ 1	2	0	0	6	0	0	0	0	0	0	0	0	15	0	0	0
Core_ 1	0	0	1	4	0	4	0	0	0	0	0	0	0	0	0	0
Rhop_ 1	26	34	9	130	6	0	0	2	0	0	0	0	0	1	282	4
2	21	0	33	0	0	0	0	0	0	0	0	0	1	0	33	5
3	23	0	0	0	0	0	0	50	0	0	0	0	63	0	41	0
4	0	0	0	0	3	4	0	0	0	0	0	0	0	0	160	0
Alyd_ 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6

Arad_ 1	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerc_ 1	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Miri_ 1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	12	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Nabi_ 1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Form_ 1	1	9	11	4	0	0	0	0	0	0	0	1	3	5	3	9
2	7	0	0	0	0	0	0	1	6	0	0	0	11	19	0	10
3	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	6
4	0	0	0	0	0	2	0	0	0	0	0	0	0	23	6	1
5	9	3	5	5	0	0	0	0	0	0	0	0	7	0	0	2
6	0	9	47	18	8	3	0	0	0	0	0	0	0	4	0	0
7	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	20	0	0	18	0	1	0	0	0	0	0	0	0	1	1
9	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
10	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0

11	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
13	0	0	0	0	0	9	0	0	0	0	0	0	15	0	1	0
14	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1
Brac_ 1	11	1	16	13	0	7	0	0	1	1	1	0	0	0	0	8
2	3	1	0	8	1	0	2	1	1	0	1	0	0	1	0	0
3	0	0	0	0	6	0	3	5	0	0	1	0	0	1	0	1
4	1	1	0	0	0	6	0	0	0	0	1	0	0	0	0	0
5	0	0	0	2	0	0	5	0	0	0	0	0	0	0	0	2
6	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1
7	0	0	1	0	0	3	0	1	0	0	0	0	1	0	3	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
10	2	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Vesp_ 1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	245	298	215	346	83	62	21	72	16	10	17	49	408	170	736	468