University of Venda
Creating Future Leaders
University of Venda

Activity patterns, species composition and dietary analysis of bats on two macadamia farms in Levubu, South Africa.

VUSANI MPHETHE

11582175

A Thesis submitted to the School of Environmental Sciences, University of Venda, in fulfilment for the degree of Masters of Environmental Sciences.

Supervisor: Prof P J Taylor

Co-supervisor: Mr J N Steyn

Co-supervisor: Prof M C Schoeman

January 2017

LIBRARY

© University of Venda

University of Venda
Creating Future Leaders

LIBRARY
CALL No.
ACC No.

Declaration

I, **Vusani Mphethe**, hereby declare that this dissertation is my own unaided work. It is being submitted for the degree of Masters of Environmental Sciences to the University of Venda. The material herein has not been submitted for a degree or other degree to this or any other university.

Signed (Student): ..... Date: 17/08/2017

Signed (Supervisor): ..... Date: 17/8/2017

© University of Venda

University of Venda
Creating Future Leaders

Abstract

Bat predation of pest insects has been documented to have a significant economic benefit in agro-ecosystems worldwide. The Soutpansberg range is situated in the savanna biome of northern South Africa and is a hotspot for plant endemism and animal diversity. Previous studies have documented that 66% of local bat species forage over macadamia farms. A study was carried out to provide data on the activity patterns and species composition of all insectivorous bats as well as the diet of two species of bats (*Mops midas* and *Nycteris thebaica*) roosting on two macadamia farms in the Levubu region, Limpopo, South Africa. Using SM2 detectors acoustic surveys were conducted on 128 detector-nights of recording in macadamia orchards (orchard edge and centre) on Farms Welgevonden and Laatsgevonden simultaneously. Ad hoc acoustic sampling was also conducted around farm houses on both farms. Discounting data from houses, highest bat activity was recorded on orchard edges at both Welgevonden and Laatsgevonden and a total of 22 insectivorous bat species were reported on both farms. Stinkbugs were sampled on a monthly basis by standard scouting methods by farmers. Activity of bats was positively significantly ($P < 0.05$) related to stinkbug numbers in both cases. Activity index was also significantly related to habitat ($P < 0.01$), crop cycle ($P < 0.01$), temperature ($p < 0.05$) and moon phase ($P < 0.01$). The researcher was unable to test for the relationship between the number of stinkbugs and the proportion of bugs in the diet of *Mops midas* since there was only one data point (sample) from the macadamia study area, while the test between proportion of bugs in the diet of *Nycteris thebaica* and stinkbug numbers showed a slight positive correlation and was not significant ($P = 0.06$). However, bugs were present in the diet of both species throughout the year in both macadamia and urban habitats, at higher proportions than generally found in natural habitats. Foraging activity of bats and higher proportions of bugs in the diet of *Mops midas* and *Nycteris thebaica* in macadamia orchards may be driven by seasonal abundance of pest insects such as stinkbugs. Insectivorous bats forage over macadamia orchards (feeding on bugs assumed to be stinkbugs) during stinkbug (*Bathycoelia natalicola* and *Nezara viridula*) outbreaks, thus integrated pest management technique should be adopted and farmers encouraged in conserving and using bats as biological control agents in macadamia farms.

Keywords: Bats, Macadamia, Stinkbugs, Bat detectors, Activity, Biological Control

© University of Venda

University of Venda
Creating Future Leaders

Acknowledgement

First foremost I am very grateful to my supervisors Prof P.J Taylor, Prof M.C Schoeman and Mr J.N Steyn for their invaluable guidance and helpful comments throughout the study period. I wish to express my gratitude to the late Mr R Baxter for sharing ideas and providing manuals in helping me complete this thesis. I would also like to thank Prof S.H Foord and Dr C Munyai for allowing me to use their Zoology labs and resources.

I am most grateful to the Department of Science & Technology and National Research Foundation through the SARChI Chair scholarship (School of Maths and Natural Sciences), for providing financial support towards this research. Special thanks to Mr Hermann De Jager, Mrs Elsje Joubert and Amana farm management for proving me with stinkbug scouting data.

Finally, I would like to thank my mom (E.M Mashau) and my siblings for their love and support throughout my studies.

© University of Venda

University of Venda
Creating Future Leaders

Table of Contents

Declaration i
Abstract ii
Acknowledgement iiiii
LIST OF FIGURES vi
LIST OF TABLES vii
CHAPTER ONE: INTRODUCTION 1
1.0 Background to the Study 1
1.1 Problem Statement 3
1.2 Research Questions 3
1.3 Objectives 4
1.3.1 Main Objective 4
1.3.2 Specific Objectives 4
1.4 Limitations 4
1.4.1 Weather conditions 4
1.5 Underlying assumptions 5
1.6 Significance of the study 5
CHAPTER TWO: LITERATURE REVIEW 6
2.0 Introduction 6
2.1 Pest Insects of Macadamia 6
2.1.1 Stinkbug 6
2.1.2 Lepidoptera (moths) 11
2.2 Diversity of bats in South Africa 11
2.2.1 Importance of bats 12
2.3 Foraging ecology of bats 12
2.4 Diet of bats 13
2.5 Activity of bats in agroecosystems 14
CHAPTER THREE: DESCRIPTION OF THE STUDY AREA 16
3.0 Introduction 16
3.1 Location of the study areas 16
3.1.1 Farm Laatsgevonden 16

© University of Venda

University of Venda
Creating Future Leaders

3.1.2 Farm Welgevonden 16
3.2 Vegetation of the study areas 18
CHAPTER FOUR: MATERIALS AND METHODS 19
4.0 Introduction 19
4.1 Bat activity monitoring 19
4.2 Bat diet 20
4.2.1 Collection of faecal pellets 20
4.2.2 Microscopic dissection of faecal pellets 21
4.4 Pest insect activity (Scouting or active sweeping) 21
4.5 Data Processing and Statistical Analysis 21
CHAPTER FIVE: RESULTS 22
5.1 Pest insect activity throughout the year 22
5.1.1 Stinkbug scouting for two farms (at Laatsgevonden and Welgevonden) 22
5.2 Bat species richness and composition 24
5.3 Bat activity throughout the year 32
5.4 Dietary variation 37
5.5 Factors explaining variation in bat activity and diet 39
CHAPTER SIX: DISCUSSION, CONCLUSION AND RECOMMENDATION 40
6.1 Discussion 40
6.1.1 Bat species richness and composition 40
6.1.2 Seasonal bat and stinkbug activity 42
6.1.3 Diet variation 43
6.2 Conclusion 45
6.3 Recommendation 45
REFERENCES 46

© University of Venda

University of Venda
Creating Future Leaders

LIST OF FIGURES

Figure 1: (a) Seasonal abundance of *Bathycoelia natalicola* at Nelspruit and Friedenheim between November 2010 to January 2014 (b) Seasonal abundance of two spotted bug and other macadamia bugs in Nelspruit from 2010 to 2015. 8

Figure 2: Spray schedules based on nymph peaks and day-degree models based on stinkbug life cycle. 10

Figure 3: Map showing two study farms (farm Laatsgevonden and Welgevonden). 18

Figure 4: Overall activity (no. bug/month) of stinkbug at Amana farm near Laatsgevonden (a) and Welgevonden (b) during 2014-2015. 22-23

Figure 5: Sample–based rarefaction curves of observed richness (Sobs) vs individuals for different farms and habitat. 27

Figure 6: Regression plots and box and whisper plots for nightly data showing effects of (a) Habitat (orchard centre, orchard edge, houses; n=143), (b) Macadamia crop cycle (flowering, nut drop, nut growth, harvest; n=128), (c) stinkbug density, n=128, (d) Moon phase, n=128, (e) Minimum temperature, n=128 on Species richness (SR). 28-30

Figure 7: Activity of bats throughout the year for different farms and habitats (means and standard errors). 32

Figure 8: Regression plots and box and whisper plots for nightly data showing effects of (a) Habitat (orchard centre, orchard edge, houses; n=143), (b) Macadamia crop cycle (flowering, nut drop, nut growth, harvest; n=128), (c) Stinkbug density, n=128, (d) Moon phase, n=128, (e) Minimum temperature, n=128 on bat activity (AI). 33-35

Figure 9: Percentage Hemiptera in the diet of (a) *Nycteris thebaica* and (b) *Mops midas*. 38

Figure 10. Regression plot showing relationship between % Hemiptera in diet and stinkbug abundance (n=7). 39

© University of Venda

University of Venda
Creating Future Leaders

LIST OF TABLES

Table 1: Summary of activity (AI) of bats in all farms 25

Table 2: Data from Rarefaction analysis .S.hat is the Chao2 (Chao1, 1987) estimator of species richness for each farm habitat (farm house, edge and centre). 26

Table 3: AICc values and results of likelihood ratio (LR) tests between negative binomial generalized linear models. 36

Table 4: summary of the diet of *Mop midas* and *Nycteris thebaica.* 37

© University of Venda

University of Venda
Creating Future Leaders

CHAPTER ONE: INTRODUCTION

1.0 Background to the Study

Bats are flying mammals from the order Chiroptera, with about 1200 species of bats worldwide (Monadjem *et al*., 2010). Bats are long-lived mammals with most females producing one pup per year, resulting in a low reproduction rate (Barclay and Harder, 2003). They occupy a variety of roosts, including underground caves, hollow in trees, and anthropogenic hollows such as roofs and basements of houses, cavities in dam walls and abandoned mine shafts (Kunz and Lumsden, 2003). Insectivorous bats constitute about 70% of all bats worldwide. These feed on a variety of insects and depend on echolocation to forage as well as avoid obstacles (Monadjem *et al*., 2010).

Bats provide crucial ecosystem services in agriculture through consumption of pest insects (Jones *et al*., 2009). In America, molossid bats were documented to feed on pest stinkbugs (Kunz *et al*., 2011). In southern Africa, research on the diet of bats using both microscopic and molecular analysis have determined their potential as predators of pest insects in agro-ecosystems (Bohmann *et al*., 2011; Taylor *et al*., 2013a). Previous microscopic studies conducted in macadamia orchards found fragments of both Hemiptera and Lepidoptera, as well as seven additional insect orders, in culled parts and faecal pellets collected from *Nycteris thebaica* (Taylor *et al*., 2013a). Conventional microscopic analysis of faecal pellets sampled from four species of bat (*Mops condylurus*, *Nycteris thebaica*, *Pipistrellus hesperidus* and *Scotophilus dinganii*) occurring in macadamia orchards, revealed that all species included Hemiptera in their diet 20-50% by volume and 25-92% by occurrence, while molecular studies revealed that *Nycteris thebaica, Scotophilus dinganii, Pipistrellus hesperidus, Chaerephon pumilus* and *Mops midas* specifically ate green stinkbugs from *Nezara* genus (Taylor *et al*., 2013a).

© University of Venda

This study focused on two species of bats *Mops midas* (open-air feeder) and *Nycteris thebaica* (clutter feeder) roosting in macadamia orchards. *Mops midas* can be categorized as a fast flying bat with Coleoptera forming its main prey. On the other hand *Nycteris thebaica* is a slow flying bat, with Orthoptera, Lepidoptera and Coleoptera as primary prey (Seamark and Bogdanowicz, 2002; Schoeman and Jacobs, 2011; Monadjem *et al*., 2010).

© University of Venda

1.1 Problem Statement

Macadamia farmers rely on chemical pesticides to reduce damage caused by major insect pests such as stinkbugs (*Bathycoelia natalicola* and *Nezara viridula*), macadamia nut borer (*Cryptophlebia ombrodelta*) and false coddling moths (*Thaumatotibia* (*Cryptophlebia*) *leucotreta*). However, these measures may result in detrimental environmental effects, including poisoning of pest insects, a decline in population of insectivorous predators such as birds, reptiles and bats, pollution of water bodies and increased pest resistance (Kunz *et al*., 2011). Thus, biological control methods are needed to supplement the use of chemical pesticides. Although the vital role of generalist predators such as bats as agricultural pest controllers is becoming clear in Europe and the New World, more studies in agro-ecosystems, particularly in Africa, are necessary where almost no such research has been conducted (Bohmann *et al*., 2011; Taylor *et al*., 2013a; and Maas *et al*., 2013). Few studies have been conducted on the diet of insectivorous bats especially in agricultural landscapes dominated by macadamia orchards. None of these studies have assessed the diet of *Mops midas*. However, *Nycteris thebaica* and *Mops midas* may be potentially suitable biological control agents of macadamia pests and thus can supplement or even replace the use of synthetic pesticides.

1.2 Research Questions

- Does the proportion of arthropod orders in the diet of *Mops midas* and *Nycteris thebaica* vary during the year?
- Do *Mops midas* and *Nycteris thebaica* feed opportunistically or selectively on the major macadamia insect pests?
- Does variation in the diet of *Mops midas* and *Nycteris thebaica* throughout the year correspond to peaks in abundance of major pest species of Hemiptera (*Nezara viridula*, *Bathycoelia natalicola*)?
- Does activity (relative abundance) of bats correspond with pest insect cycles of *Bathycoelia natalicola* and *Nezara viridula* throughout the year in macadamia orchards?

© University of Venda

1.3 Objectives

1.3.1 Main Objective

To compare the dietary composition of two insectivorous bat species (*Mops midas* and *Nycteris thebaica*) with different foraging behaviour and monitor the activity of bats on two macadamia farms around Levubu, South Africa with a view to understanding their impact on local pest species. The aim of this study was to describe the dietary composition of two species of bats (*Mops midas* and *Nycteris thebaica*), and activities of bats generally roosting on macadamia farms representing different foraging groups. The study also seeks to determine whether bat activity as well as the proportion of Hemiptera in the diet (assuming these mostly represent stinkbugs (*Bathycoelia natalicola* and *Nezara viridula*) based on Taylor *et al*., 2013a) might be correlated with seasonal peaks in the activity of pest stinkbugs.

1.3.2 Specific Objectives

- To estimate activity patterns of all insectivorous bats on two macadamia farms.
- To analyse diets of *Mops midas* and *Nycteris thebaica* from faecal pellets collected from roosts.
- To estimate the abundance of stinkbugs (*Bathycoelia natalicola* and *Nezara viridula*).
- To assess completeness of sampling effort.
- To quantify the correlation between bat activity and insect pest cycles on macadamia farms.
- To relate bat activity to temperature, crop phenology and lunar cycle.

1.4 Limitations

1.4.1 Weather conditions

Bad weather such as heavy rainfall limit access to the sampling sites; however, sampling was done over different seasons to sample different stages of crop cycle and stinkbug cycle.

© University of Venda

University of Venda
Creating Future Leaders

1.5 Underlying assumptions

Other external environmental and anthropogenic factors like habitat transformation, degradation and pollution may have an impact on the activity of bats and their prey. However, these factors were assumed to be less significant than the factors investigated in this study.

1.6 Significance of the study

Insectivorous bats could potentially be an important driving force behind insect pests' suppression in both agricultural and natural vegetation; however this was evident when bats forage selectively over sugarcane plantations in Swaziland (Noer *et al.*, 2012). Dietary analysis and passive monitoring of echolocation calls of bats over agricultural landscapes are necessary to determine if bats are feeding on insect pests. These data, in turn could indicate the likely economic benefits of bats in terms of crop protection. Ideally, by increasing local bat populations (e.g. by introducing bat houses) on agricultural farms, the use of synthetic pesticides may be reduced, while crop damage is decreased and crop yield increased. Bats ecological and economic importance remains to be fully understood yet their populations are declining at an alarming rate due to factors such as habitat loss, bush meat hunting, wind farms and White Nose Syndrome disease that kills large numbers of hibernating bats (Adams and Pedersen, 2013). This study will demonstrate the importance of bats and provide a better understanding of the vital ecosystem services they provide.

© University of Venda

University of Venda
Creating Future Leaders

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The aim of this chapter is to give a comprehensive literature review on crucial aspects of macadamia pest insects, diversity of bats, foraging ecology, dietary composition, activity patterns and ecosystem services rendered by bats.

2.1 Pest Insects of Macadamia

2.1.1 Stinkbug

Macadamia (Proteaceae) are attacked by a variety of indigenous pests, such as nut-borer (*Cryptophlebia ombrodelta*) and stinkbug, Pentatomidae (*Bathycoelia natalicola* and *Nezara viridula*) (Bruwer, 1999). Pentatomidae contribute 93.1% of Hemiptera with *Bathycoelia natalicola* as the most abundant species contributing approximately 50.2% (Schoeman, 2013). Stinkbug (*Bathycoelia natalicola* and *Nezara viridula*) and moths (*Cryptophlebia ombrodelta* and *Thaumatotibia* (*Cryptophlebia*) *leucotreta*)) can damage up to 75% of mature nuts if left uncontrolled (Bruwer, 2004).

Bathycoelia natalicola and *Nezara viridula* cause sunken leisions in the kernels, making the nut unfit for export (Schoeman, 2013). A lesser macadamia pest, the coconut bug (*Pseudotheraptus wayi*) has short mouthparts and secretes toxic saliva when feeding on kernels, causing damage to the nut (Joubert, 2001). *Nezara viridula* can cause severe damage of up to 70% of macadamia nut kernels during outbreaks (Wright *et al*., 2007). In South Africa stinkbugs from the family Coreidae and Pentatomidae cause annual crop damage estimated between US$3 and US$7 million in the macadamia and avocado industries (Schoeman, 2013).

© University of Venda

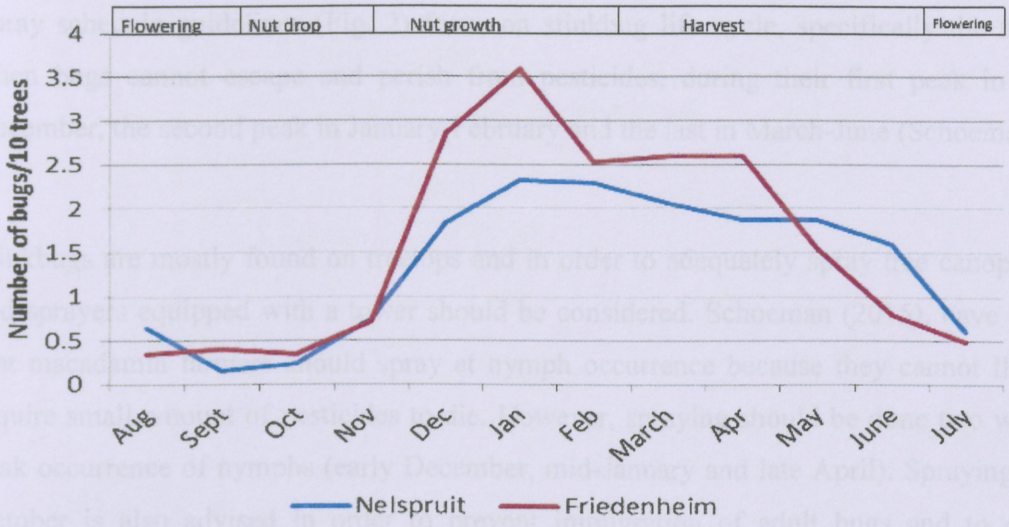
2.1.1.1 Pest Stinkbug Life Cycle in Macadamia Orchards

Schoeman (2015) showed that the stinkbug (*Bathycoelia natalicola*) from two locations (Nelspruit and Friedenheim) feed on young developing nuts with soft shells (Fig. 1), and bugs are restricted to macadamia orchards in summer rather than neighbouring bush. *Bathycoelia natalicola* is more abundant in orchards during seasonal peaks in summer, autumn and winter and it is during this time when macadamia orchards are a biggest source of stinkbug (Fig. 1b).

The adult southern green stinkbug (*Nezara viridula*) is shield-shaped, with a dull green colour and has a malodorous scent. According to Schoeman, (2013) stinkbugs (Pentatomidae) overwinter as adults especially in temperate zones and their nymphs and adults were found to occur throughout winter season (April-August). However, the southern green stinkbug can complete its life cycle in 65 to 70 days, and is known to have up to four generations per year in warm climates (Squitier, 2017). Schoeman, (2013), have shown that the ovipositional period starts during mid-June and ends in the first week of September, while the first generation egg masses are found in the nearby bushes/woods were adults have overwintered and moved into nearby orchards, while the second generation remains in the orchards for their entire life span. Eggs are usually laid under tree leaves, and are barrel shaped and change from light green to yellow and then to light pink before hatching in one week (Squitier, 2017). The egg stage is dependent on the temperature (warmer temperatures speed up the hatching process, while cooler temperatures prolong the hatching process) and as spring temperatures rises stinkbugs moves out of winter cover and start feeding and egg laying (Squitier, 2017).

© University of Venda

(a)



(b)

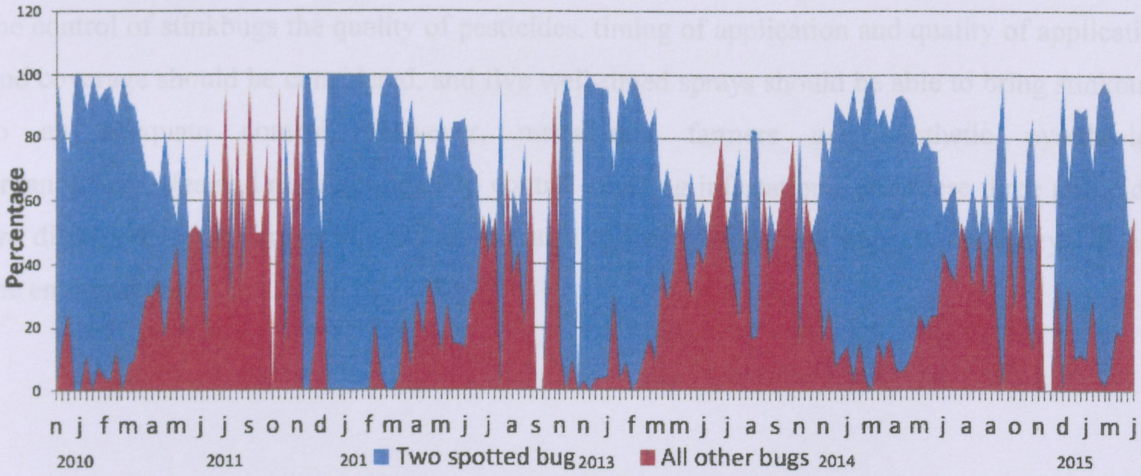


Figure 1: (a) Seasonal abundance of *Bathycoelia natalicola* at Nelspruit and Friedenheim over one year (August-July). (b) Seasonal abundance of two spotted bug and other macadamia bugs in Nelspruit from 2010 to 2015. Taken from Schoeman (2015)

© University of Venda

2.1.1.2 Spray schedule for macadamia pest stinkbug

Spray schedule guidelines (Fig. 2) focus on stinkbug life cycle, specifically the nymph stage when bugs cannot escape and perish from pesticides, during their first peak in November-December, the second peak in January-February and the last in March-June (Schoeman, 2015).

Stinkbugs are mostly found on treetops and in order to adequately spray tree canopies, pruning and sprayers equipped with a tower should be considered. Schoeman (2015), have documented that macadamia farmers should spray at nymph occurrence because they cannot fly away and require small amount of pesticides to die. However, spraying should be done two weeks before peak occurrence of nymphs (early December, mid-January and late April). Spraying during late October is also advised in order to prevent immigration of adult bugs and to delay initial establishment of bugs in macadamias (Schoeman, 2015). Schoeman, (2014), have shown that for the control of stinkbugs the quality of pesticides, timing of application and quality of application and coverage should be considered, and five well-timed sprays should be able to bring stinkbugs to an adequate control. However, macadamia farmers use synthetic pyrethroids, organophosphates and neonicotinoids to control stinkbug infestations, and these three pesticides are discriminated by importing nations because of their detrimental impacts on honeybees and the environment.

© University of Venda

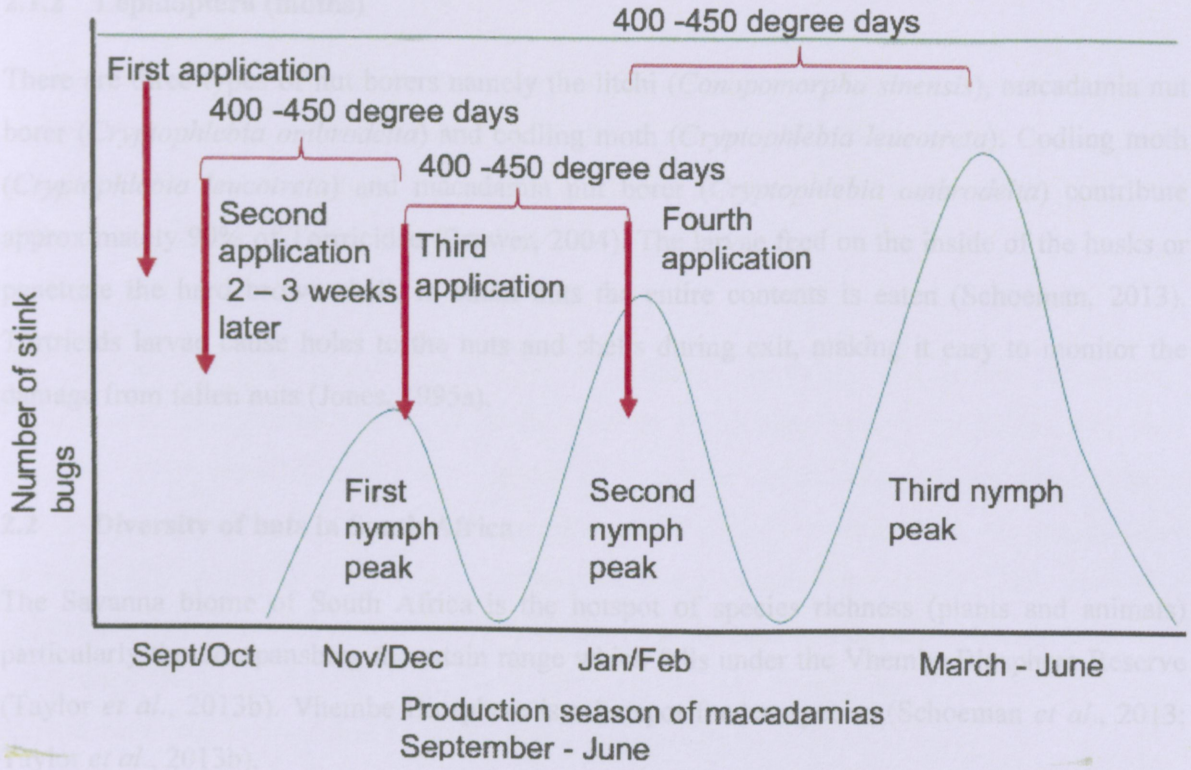


Figure 2. Spray schedules based on nymph peaks and day-degree models based on stinkbug life cycle (Schoeman, 2015).

© University of Venda

2.1.2 Lepidoptera (moths)

There are three types of nut borers namely the litchi (*Conopomorpha sinensis*), macadamia nut borer (*Cryptophlebia ombrodelta*) and codling moth (*Cryptophlebia leucotreta*). Codling moth (*Cryptophlebia leucotreta*) and macadamia nut borer (*Cryptophlebia ombrodelta*) contribute approximately 90% of Tortricidae (Bruwer, 2004). The larvae feed on the inside of the husks or penetrate the hard brown shell. In small nuts the entire contents is eaten (Schoeman, 2013). Tortricids larvae cause holes to the nuts and shells during exit, making it easy to monitor the damage from fallen nuts (Jones, 1995a).

2.2 Diversity of bats in South Africa

The Savanna biome of South Africa is the hotspot of species richness (plants and animals) particularly the Soutpansberg mountain range which falls under the Vhembe Biosphere Reserve (Taylor *et al*., 2013b). Vhembe Biosphere is a hotspot for bat species (Schoeman *et al*., 2013; Taylor *et al*., 2013b).

Insectivorous bats can be divided into three functional foraging groups, open-air foragers that fly above vegetation; clutter foragers that glean insects from the ground and in dense vegetation and clutter-edge foragers that feed at the edges of vegetation (Monadjem *et al*., 2010). Open- air foragers emit narrow band low duty cycle echolocation with low frequency calls and a long duration of call; clutter foragers produce low duty cycle echolocation calls with short duration, high frequency and low intensities (but there are also clutter species that have high duty cycle echolocation calls); clutter edge foragers use echolocation calls at intermediate frequencies (30-70 kHz) of intermediate duration (Monadjem *et al*., 2010).

© University of Venda

2.2.1 Importance of bats

Ecosystem services are conditions and processes through which natural ecosystems together with the species sustain and fulfil human life, maintain biodiversity and production of ecosystem goods such as sea food, forage timber, biomass fuels, natural fiber, pharmaceuticals, industrial productions and their precursors (Kunz *et al*., 2011).

Bats provide essential ecosystem services as primary, secondary and tertiary consumers. Fruigivorous bats increase forest diversity through pollination of tropical plants and seed dispersal, while insectivorous bats are important controllers of nocturnal insect populations in agroecosystems and natural ecosystems. Insectivorous bats feed on arthropods which may carry pathogens that could be transmitted to humans and mammals (Kunz *et al*., 2011). Bats also redistribute nutrients and energy through their guano to sustain terrestrial, aquatic and cave ecosystems (Kunz *et al*., 2011). In North America, the loss of bats could lead to agricultural damage estimated at more than $3.7 billion per annum (Boyles *et al*., 2011).

2.3 Foraging ecology of bats

Fruigivorous and nectivorous bats feed on fruits, leaves, flowers and nectar; Carnivorous bats feed on vertebrates such as frogs, fish, mice, birds and other bats, and 70% of bat species are insectivorous that feed on insects and other arthropods (Monadjem *et al*., 2010).

A number of bat species such as *Chaerephon pumilus* and *Mops condylurus* forages in agricultural landscapes dominated by macadamia and sugar cane plantations, particularly when major pest insects are known to occur (Noer *et al*., 2012; Taylor *et al*., 2013b).

© University of Venda

2.4 Diet of bats

Insectivorous bats are opportunistic in their feeding (with other species foraging selectively), consuming different groups of insects depending on body size, skull morphology, wing shape, foraging behaviour, habitat use and echolocation calls (Adams and Pedersen, 2013).Their diets include different insect orders depending on availability and time of the year, thus wing design and echolocation call structure determine insect prey taken by bat (Monadjem *et al*., 2010).

Bat predation of pest insects in agro-ecosystems has an important economic benefit to farmers worldwide (Cleveland *et al*., 2006; Boyles *et al*., 2011; Kunz *et al*., 2011). In Swaziland Noer *et al*., (2012) found that two species of bat (*Chaerephon pumilus* and *Mop condylurus*) roosting near sugarcane plantations foraged selectively over these fields, and preyed on boring moths and stinkbug.

Bats are also important predators of agricultural pests in America where little brown bats (*Myotis lucifugus*) can each consume up to 8 grams of insects per night, thus more than hundred percent its body weight (Boyles *et al*., 2011). In South East Asia, crop damage by insect pests increased by 30% when bats were excluded from the cocoa plantations (Maas *et al*., 2013). Bats also reduced plant herbivory by arthropods during the wet season in Mexican coffee plantations (William-Guillen *et al*., 2008). McCracken (1996) and McCracken *et al.,* (2012) documented that Mexican free-tailed bats feed on migrating populations of corn earworm moths, a major insect pest of maize, tomatoes and beans. In Sacramento, USA insectivorous bats reduced fruit crop damage from corn ear moth by 55% (Long *et al*., 1998).

© University of Venda

2.5 Activity of bats in agroecosystems

Bats habitat use may be influenced by many factors including weather, predation pressure and insect's availability (Downs and Racey, 2006). Some species of bats have recorded higher activity within tree clutter during strong winds (Verboom and Spoelstra, 1999). However, during heavy rains bat activity can be greatly decreased (Eckert, 1982; Tibbels and Kurta, 2003).

In Europe insectivorous bats forage more actively on organic farms with higher numbers of insect prey, than on conventional farms that use chemical pesticides (Wickramasinghe *et al*., 2003). The application of synthetic pesticides by farmers in the United States since 1940s has led to evolved toxicity resistance by pests, elimination of beneficial invertebrate and vertebrate predators, water pollution, decline in population of bats and increased proportion of crops damaged from insect pests by 13% (Kunz *et al*., 2011).

Taylor *et al*., (2013b) showed that 66% of the local bat species forage over agricultural landscapes dominated by macadamia fruits. Molossid bats were most abundant at macadamia orchards during late summer and autumn, when stinkbug numbers reach annual peaks.

Bat activity can be affected by factors such as moon phase, local climatic effects and season (Taylor *et al*., 2013b). Avoidance of moonlight has been recorded in many small mammals including Merriam`s kangaroo rat (*Dipodomys merriami*), southern flying squirrel (*Glaucomys volans*) and many species of bats (Kotler *et al*., 1991). Previous studies have documented that predators such as owls spend longer time hunting on dark nights, thus prey such as bats may feed longer on darker nights due to decreased danger (O`Donnell, 1999; Bork, 2006; Lang *et al*., 2006). Several studies have showed a decrease in bat activity during full moon, while some found no significant effect of moon light on bat feeding patterns (Holland *et al.,* 2011; Taylor *et al*., 2013b).

© University of Venda

Richter and Cumming (2008) documented that bats in temperate and some subtropical regions migrate or even hibernate to warmer areas. Bats can become torpid (lowering of internal body temperature) during lower temperatures in order to save energy and this may result in low bat activity (Monadjem *et al*., 2010). Taylor *et al*., (2013b) also documented a decrease or no activity of bats during cold winter nights in macadamia orchards. Low ambient temperatures decreases night insects activeness as well as bat activity (Swift *et al*., 1985).

© University of Venda

University of Venda
Creating Future Leaders

CHAPTER THREE: DESCRIPTION OF THE STUDY AREA

3.0 Introduction

This study focused on two farms, Laatsgevonden and Welgevonden located in the southern foothills of the Soutpansberg mountain range between Louis Trichardt (previously known as Makhado) and Thohoyandou, in the Levubu Valley, Limpopo, South Africa. This is a subtropical fruit-growing area, which is dominated by extensive monocultures of macadamias, pecan nuts, avocados, bananas, pine and gum plantations.

3.1 Location of the study areas

3.1.1 Farm Laatsgevonden

The Laatsgevonden farm is situated 48 km east of Louis Trichardt town in the Vhembe Biosphere Reserve (30°20'49.30"E and 23°5'13.35"S) Limpopo, South Africa. The area experiences warm wet summers with temperatures between 16-30°C, and cool, dry winters with temperatures between 9-25°C. The area has annual rainfall of 791 mm. Laatsgevonden is situated in the Savanna biome (Desmet *et al.*, 2013), characterized by Tzaneen Sour Bushveld (Mucina and Rutherford, 2006).

3.1.2 Farm Welgevonden

The Welgevonden farm is located 20 km east of Louis Trichardt town, in the Vhembe Biosphere Reserve (30°3'58.53"E and 23°3'25.95"S). The area experiences warm wet summers with temperatures between 14-27°C, and cool dry winters with temperatures between 7-23°C and occasional frost at high altitudes. Annual rainfall is 942 mm. Welgevonden lies in a Savanna biome, characterized by Soutpansberg Mountain Bushveld (Mucina and Rutherford, 2006) and commercial plantation of gums and pines.

© University of Venda

The two study farms (Welgevonden and Laatsgevonden) are dominated by extensive monoculture of commercial macadamia fruit orchards, which consist of approximately 5000 macadamia trees which are about ten to eleven years old, planted at a density of 312 trees per hectare with a 4×8 meters of spacing.

© University of Venda

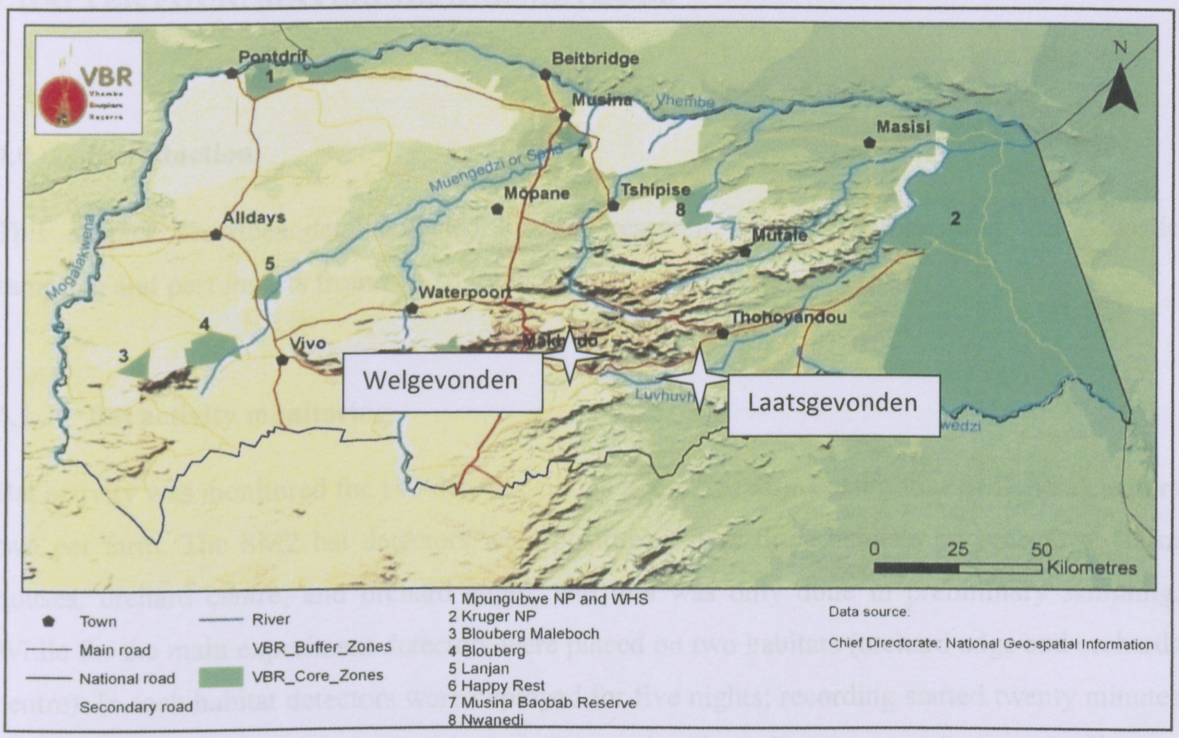


Figure 3: Map showing two study farms (farm Laatsgevonden and Welgevonden)

3.2 Vegetation of the study areas

The Soutpansberg mountain range is situated in the Vhembe biosphere reserve known for rich plant endemism, and a total of 3000 plant species. Important vegetation taxa include the following, Tall trees: *Pterocarpus angolensis, Sclerocarya birrea* subsp *.caffra*. Small trees: *Acacia polyacantha, Albizia versicolor, Ficus sansibarica, Parinari curatellifolia, Piliostigma thonningii, Pterocarpus rotundofolius, Trichilia emetica, Acacia Parinari davyi, A. sieberiana* var.*woodii, Antidesma venosum, Catha edulis, Faurea rochetiana, F. Saligma Ficus burkei, F. petersii, Heteropyxis natalensis, Peltophorum africanum, Terminalia sericea, Vernonia colorata.* Tall shrubs: *Olea europaea*s subsp. *africana, Pseudarthria hookeri* var. *hookeri, Rhus pentheri, Triumfetta pilosa* var. *tomentosa*. Low shrubs: *Agathisanthemum bojeri, Barleria elegans, Dicliptera clinopodia, Flemingia grahamiana, Indigofera filipes, Polygala producta*. Woody climbers: *Bauhinia galpinii, Pterolobium stellatum.* Graminoids: *Cymbopogon caesius, C. nardus, Hyparrhenia cymbaria, H. poecilotricha, Hyperthelia dissoluta, Alloteropsis semialata* subsp. *semialata, Andropogon schirensis, Bothriochloa bladhii, Monocymbium ceresiiforme, Paspalum scrobiculatum, Schizachyrium sanguineum, Themeda trianda*. Herb: *Waltheria indica.*

© University of Venda

CHAPTER FOUR: MATERIALS AND METHODS

4.0 Introduction

This chapter describes data collected for this research; bat diet composition, bat acoustic sampling and pest insects from two study farms.

4.1 Bat activity monitoring

Bat activity was monitored for 143 detector-nights at the two farms using four SM2 bat detectors two per farm. The SM2 bat detectors were positioned over three habitats on each farm (farm houses, orchard centre, and orchard edge), and this was only done in preliminary sampling. While for the main experiment detectors were placed on two habitats (orchard edge and orchards centre). In each habitat detectors were deployed for five nights; recording started twenty minutes prior to sunset and finished twenty minutes after sunrise. Bat calls were stored automatically on a SD memory card in WAV format and later analysed by ANALOOK software (version 0.3.8.13; http//www.hoarybat.com). The WAV files were first converted to ZC format using Kaleidoscope viewer software (version 1.1.15; www.wildlifeacoustics.com).

Two weather variables were recorded and this includes temperature (using SM2 bat detectors temperature sensor) and moon phases (moon phase calendar). Bat activity was never sampled during heavy rains or strong wind as these have negative impacts on the detectors and bat abundance/activity.

Bats calls were identified to family level and when possible down to species level using an existing library of reference calls from the Waterberg, Western Cape, KwaZulu-Natal, Namibia, Swaziland and Mozambique (Taylor *et al*., 2013c).

© University of Venda

Calls were identified to species level based on call duration, band width and frequency at knee (F_k) (Monadjem *et al*., 2010; Taylor *et al*., 2013b, c). Although Taylor *et al*., (2013c) found that some species in the Soutpansberg overlap making species identification hard, Taylor *et al*., (2013b) found that on the subset of bats found at Welgevonden farm, all species could be reliably identified (and they provide a table of key species parameters). Thus to get to functional groups, species were pooled into families. Molossidae (open-air feeders) were identified by low frequency calls (F_k < 30 kHz) of long duration (typically > 10 ms) and narrow bandwidth (< 10 kHz), while bats belonging to Vespertilionidae and Miniopteridae (clutter-edge feeders) were identified by high frequency calls (F_k > 30 kHz) with short durations (< 10 ms) and broad bandwidth (> 20 kHz). Rhinolophidae and Hipposideridae (clutter feeders) were identified through medium to high peak frequency (> 30 kHz), with long durations (10-100 ms).

4.2 Bat diet

4.2.1 Collection of faecal pellets

A total of four samples were obtained from a day roost of *Mops midas* at Welgevonden during early summer on November 2013, before the colony left due to disturbance from owls. To be able to still get some idea of seasonal variation in the diet of this species, further three samples were obtained (in early summer during October and December 2014 and during late summer/autumn in April 2015) from a day roost of this species in a house in the town of Louis Trichardt, some 20 km west of Welgevonden. A total of seven samples were collected from a night roost of *Nycteris thebaica* at Laatsgevonden during summer (December 2013/2014 and January 2014), winter (June and August 2014), spring (September 2014) and during late summer/autumn in April 2015. Pellets were collected on 1×2m boards covered in plastic and placed under roosting bats approximately one week prior to collection. Forty pellets were collected every month; 20 pellets for microscopic analysis and 20 pellets for a separate molecular analysis at the University of Copenhagen, Denmark.

© University of Venda

University of Venda
Creating Future Leaders

4.2.2 Microscopic dissection of faecal pellets

A minimum of 20 pellets were analysed for each sample where possible (Whitaker, 1988; Whitaker *et al*., 2009). Each pellet was separated in 70% ethanol under a dissecting microscope (Carl Zeiss (SCHOTT) Germany; KL 200 LE; S/N 005951 (195-041085). Fragments of arthropod exoskeleton were identified to order (or family if possible) using the keys of Whitaker, (1988) and Whitaker *et al*. (2009), and reference collection of arthropods trapped from light traps and captured stinkbug from active sweeping. For each pellet analysed, the percentage by volume of the different prey order was estimated.

4.4 Pest insect activity (Scouting or active sweeping)

Monthly number of stinkbug (*Bathycoelia natalicola*, and *Nezara viridula*) in macadamia orchards on Welgevonden and Laatsgevonden were obtained using a mechanical knock-down method (Taylor *et al*., 2013b), whereby four large randomly selected macadamia tree branches were shaken vigorously four times each and all ejected stinkbug were captured and identified. Sampling was done by the farmers in early mornings when stinkbugs were immobile, at temperatures below 18°C.

4.5 Data Processing and Statistical Analysis

Models were assessed through determining constancy of error variance, normality, linearity and independence of standardized residuals. The best model was selected based on the Aikaike Information Criterion with the lowest values representing the best model (a conservative AICc estimate was used as a result of low sample sizes). Completeness of species inventories were assessed with sample-based rarefaction curves (Gotelli and Colwell, 2001) using iNEXT, an R package (Hsieh *et al*., 2015). Activity index/relative abundance (AI) was calculated as the occurrence of bat species during one-minute time intervals for each habitat and sample session (Miller, 2001). Since the frequencies histograms for bat activity were skewed, generalized linear models (GzLM) was used in R to calculate the effect of five different predictor variables (habitat, crop cycle, stinkbug density, moon phase and minimum temperature) on both bat activity and species richness.

© University of Venda

University of Venda
Creating Future Leaders

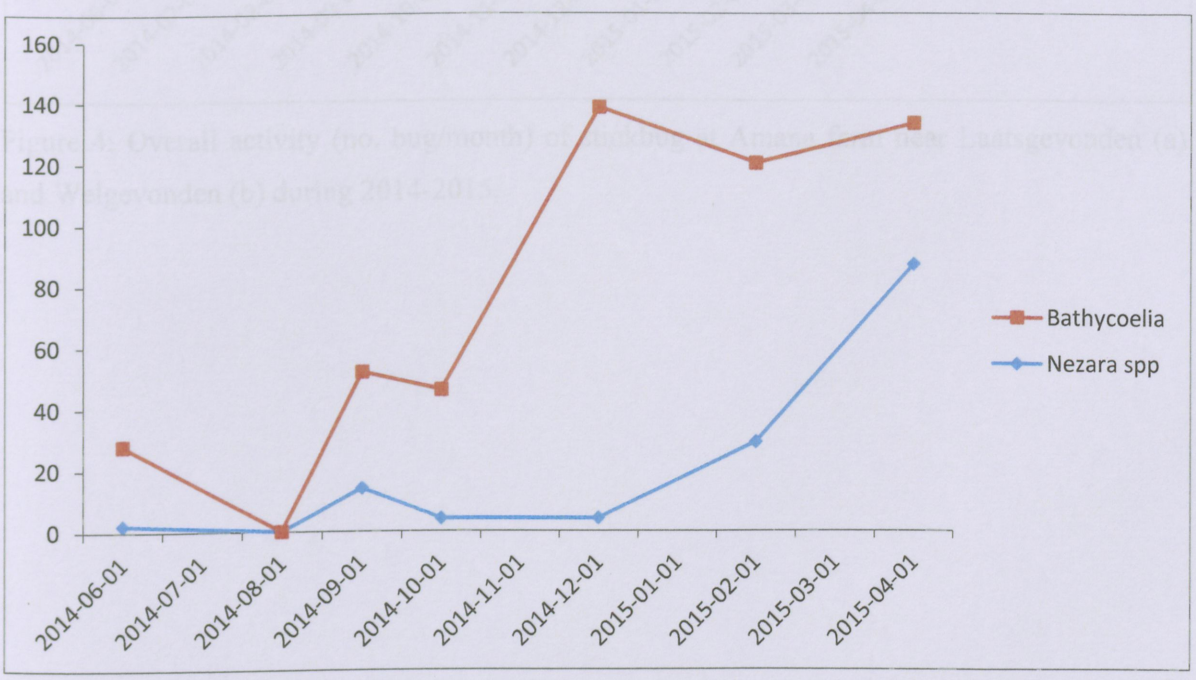
CHAPTER FIVE: RESULTS

5.1 Pest insect activity throughout the year

5.1.1 Stinkbug scouting for two farms (at Laatsgevonden and Welgevonden)

A total of 11 months of scouting for stinkbugs was performed by farmers in 2014 and 2015. At Amana Farms (near Laatsgevonden), stinkbug activity was lowest in winter, with the first peak during late spring followed by two higher peaks in summer and autumn (Fig. 4a). During the course of this study *Bathycoelia natalicola* was more abundant than *Nezara viridula* (Fig. 4a and Fig. 4b). Activity of bugs was highest during late winter, spring and summer for Welgevonden, with no activity during late summer, followed by the last peak in autumn. *Bathycoelia natalicola* dominated during winter to late summer, whereas *Nezara viridula* dominated in autumn.

(a)



UNIVERSITY OF VENDA LIBRARY

© University of Venda

University of Venda
Creating Future Leaders

(b)



Figure 4: Overall activity (no. bug/month) of stinkbug at Amana farm near Laatsgevonden (a) and Welgevonden (b) during 2014-2015.

© University of Venda

University of Venda
Creating Future Leaders

5.2 Bat species richness and composition

Species richness estimators (Table 2) showed that bat assemblages were completely sampled at each farm and habitat (90-100%). However, the data from these two farms showed differences in the observed and expected species richness of different habitats. Macadamia orchards at Laatsgevonden exhibited the highest total bat species richness (S. obs=17) with the lowest richness of 13 species recorded at the farm house at Laatsgevonden (Fig. 5 and Table 2). While species richness varied significantly with habitat (being higher around houses than orchards), it did not differ significantly with stinkbug numbers, crop stage, temperature or moon phase (Table 3, Fig. 6)

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

University of Venda
Creating Future Leaders

Table 1: Summary of activity (AI) of bats in all farms/habitats explanation of abbreviations in text. SM2 bat detectors habitat location on each farm (farm house, orchard edge and centre). *Nycteridae*, regarded as whispering bats, were hardly detected by the detectors.

	Laatsgevonden			**Welgevonden**		
	L-House	L-Edge	L-Centre	W-House	W-Edge	W-Centre
Family Emballonuridae						
Taphozous mauritianus	0	0	0	0	1	0
Family Molossidae						
Chaerephon ansorgei	205	65	62	12	13	1
Chaerephon pumilus	0	707	416	76	1253	516
Mops condylurus	48	68	95	49	142	40
Mops midas	23	90	21	9	21	13
Tadarida aegyptiaca	39	1420	218	46	592	230
Family Vespertilionidae						
Vespertilionidae sp (60 kHz)	0	1	0	3	6	2
Kerivioula sp (100 kHz)	0	10	2	1	0	0
Laephotis botswanae	1	19	30	7	58	6
Myotis tricolor	0	0	3	0	0	0
Myotis welwitschii	1	0	0	0	0	0
Neoromicia capensis	92	23	20	3	23	1
Neoromicia nanus	54	415	773	20	123	14
Neoromicia zuluensis	366	28	22	14	17	20
Pipistrellus hesperidus	292	212	209	40	415	195
Pipistrellus rusticus	0	0	1	0	0	0
Scotophilus dinganii	36	25	18	72	33	18
Eptesicus hottentotus	229	265	245	134	1421	354
Family Rhinolophidae						
Rhinolophus clivosus	0	7	1	2	0	4
Rhinolophus spp (100 kHz)	0	0	1	0	0	0
Rhinolophus simulator	0	2	0	0	0	0
Family Miniopteridae						
Miniopterus natalensis	5	63	117	7	37	11
Total	**1391**	**3420**	**2254**	**495**	**4155**	**1425**

© University of Venda

University of Venda
Creating Future Leaders

Table 2: Data from rarefaction analysis using species abundance (AI). S.hat is the Chao2 (Chao, 1987) estimator of species richness for each farm habitat (farm house, orchard edge and orchard centre).

Farm/habitat	Total no. of observed individuals	S.obs	S.hat	Completeness of sampling S.obs/S.hat x 100
Laats_centre	2254	17	19.93	85.3%
Laats_edge	3420	17	17.18	99.0%
Laats_house	1391	13	13.98	93.0%
Welg_centre	1425	15	16.70	89.8%
Welg_edge	4155	15	15.00	100%
Welg_house	4495	16	16.50	97.0%

© University of Venda

University of Venda
Creating Future Leaders

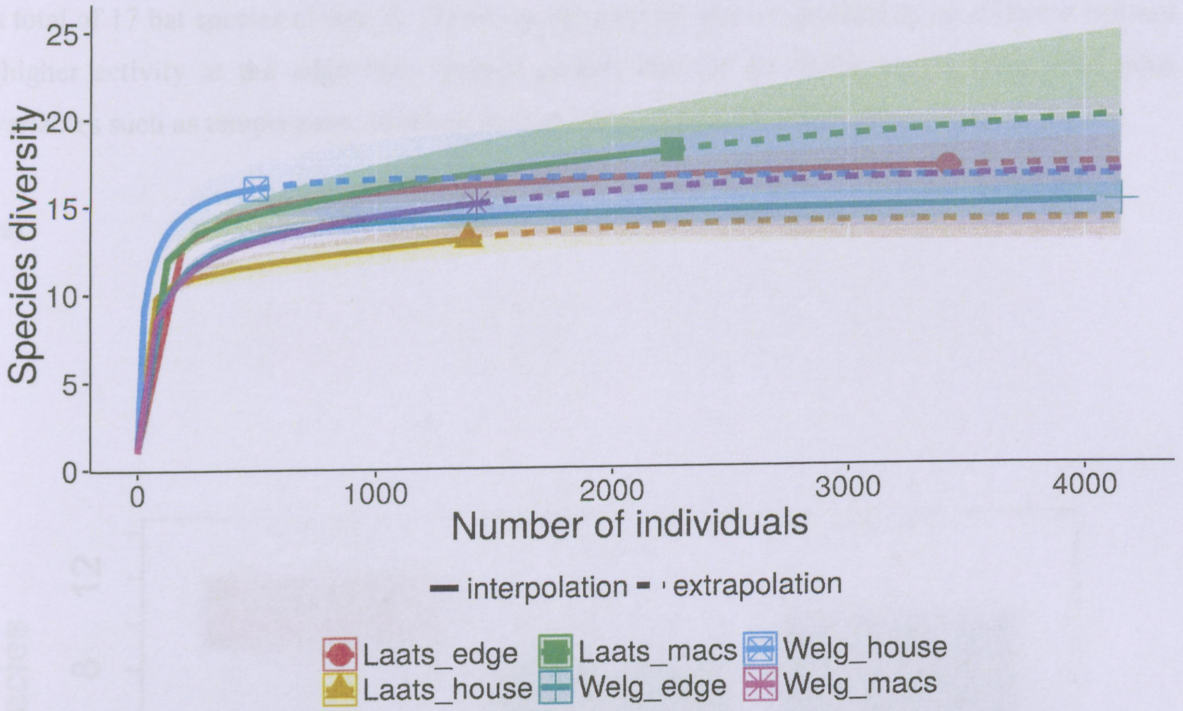
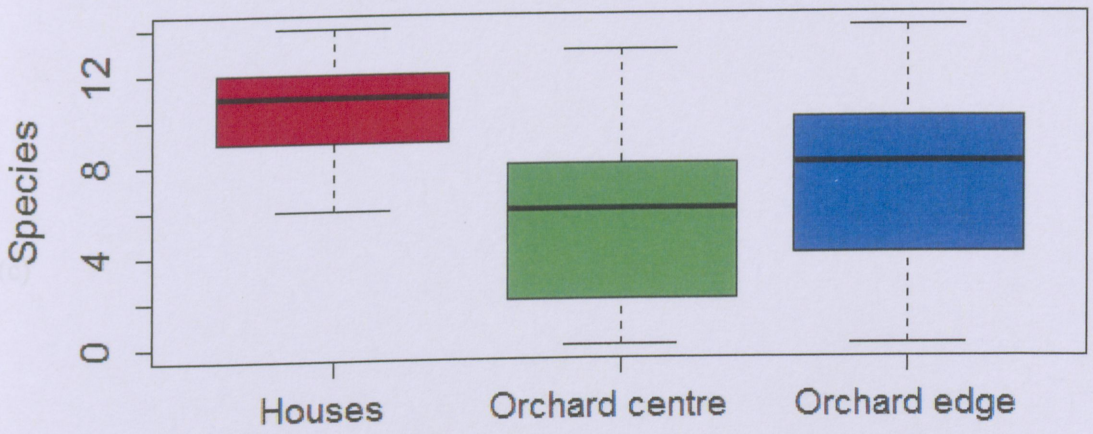


Figure 5: Sample – based rarefaction curves of observed richness (Sobs) vs individuals for different farms and habitat.

© University of Venda

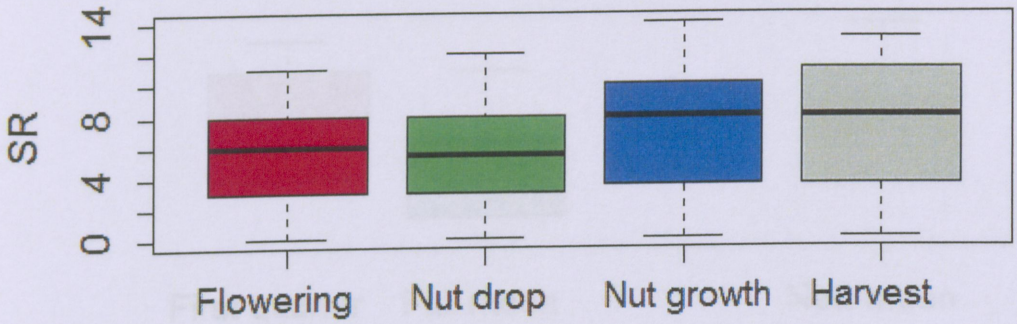
Macadamia orchards in both Welgevonden and Laatsgevonden recorded highest bat activity and a total of 17 bat species (Table 2). However, bat activity varies significantly on different habitats (higher activity at the edge than orchard centre) but did not differ significantly with other variables such as temperature, stinkbug density, crop cycle and moon phase (Table 3, Fig. 6).

(a)

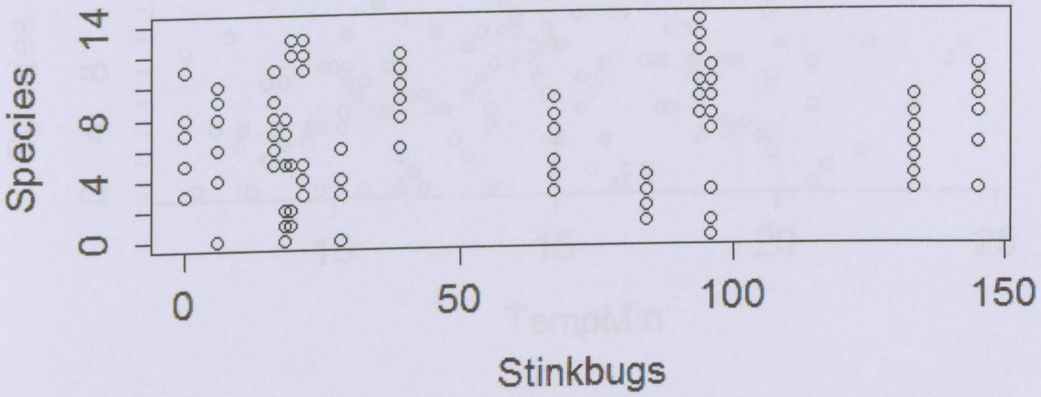


© University of Venda

(b)

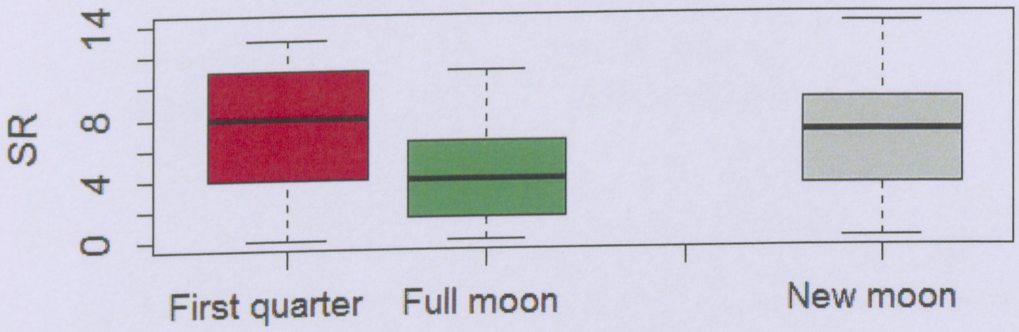


(c)

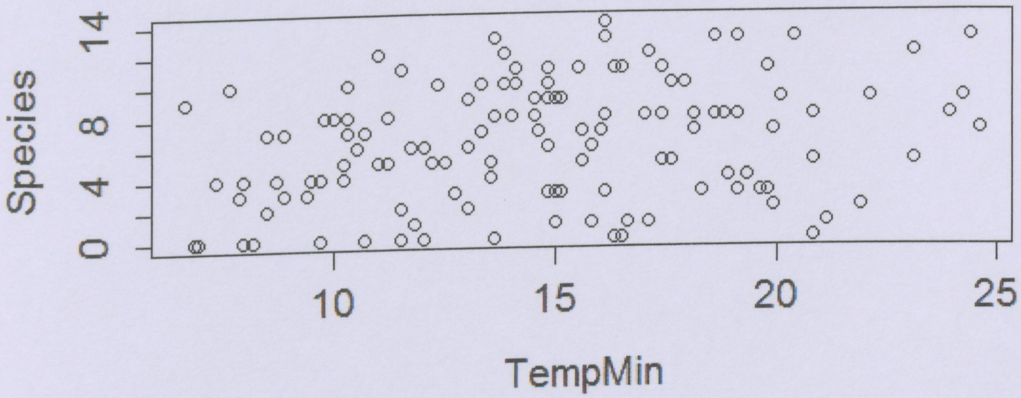


© University of Venda

(d)



(e)



© University of Venda

Figure 6: Regression plots and box and whisper plots for nightly data showing effects of (a) Habitat (orchard centre, orchard edge, houses; n=143), (b) Macadamia crop cycle (flowering, nut drop, nut growth, harvest; n=128), (c) stinkbug density, n=128, (d) Moon phase, n=128, (e) Minimum temperature, n=128 on Species richness (SR).

© University of Venda

5.3 Bat activity throughout the year

Bat activity at Laatsgevonden was highest during summer (nut growth season when stinkbug are found to occur) and lowest in winter (Fig. 7). Bat activity at Welgevonden was highest during spring during nut drop season towards nut growth season when stinkbugs are known to occur.

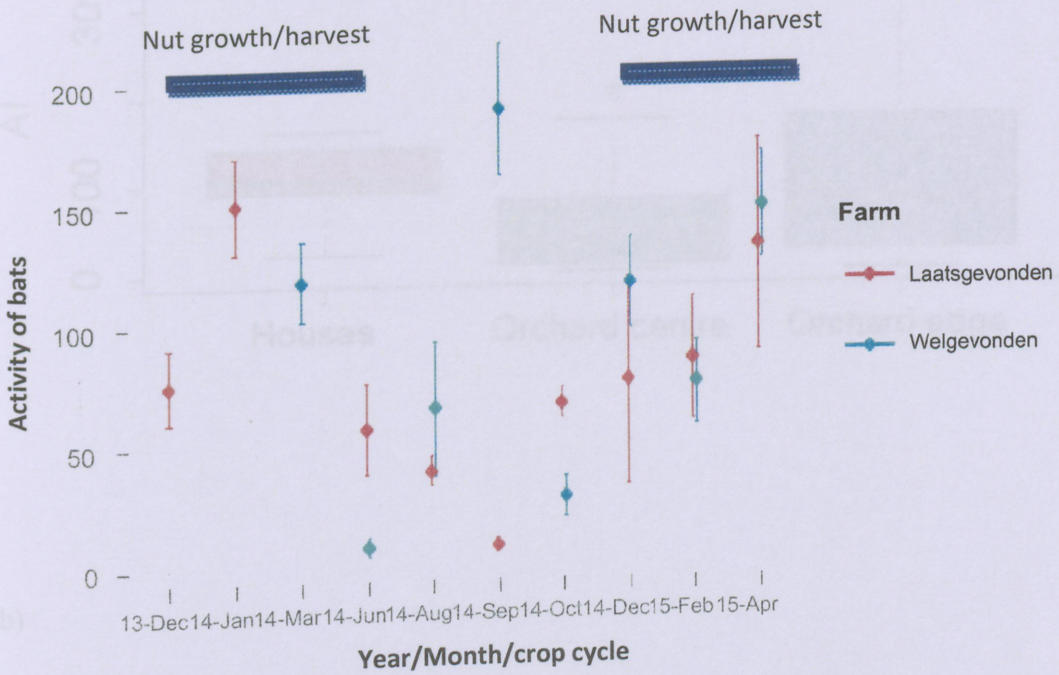
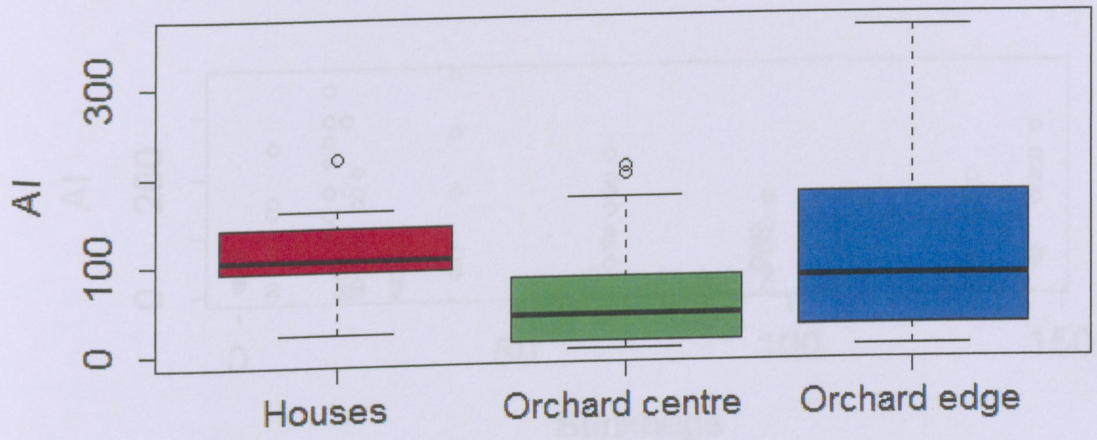


Figure 7: Activity of bats throughout the year for different farms and habitats (means and standard errors).

© University of Venda

University of Venda
Creating Future Leaders

(a)

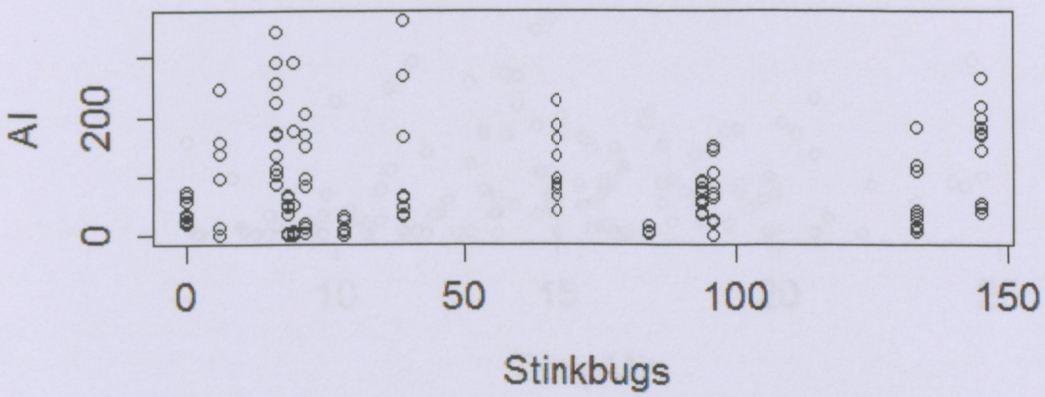


(b)

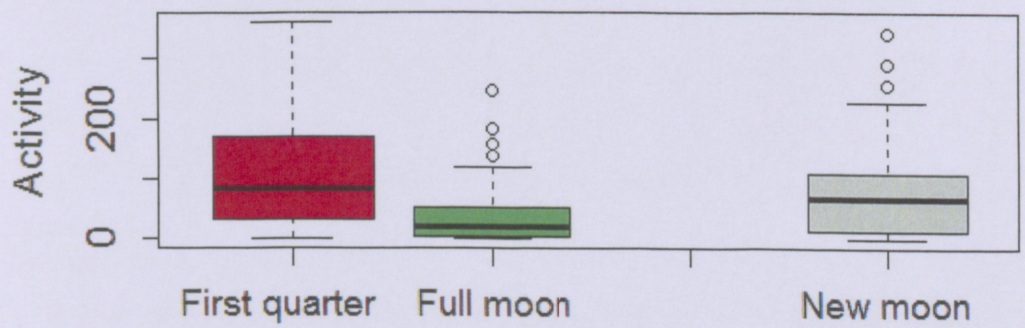


© University of Venda

(c)



(d)



© University of Venda

(e)

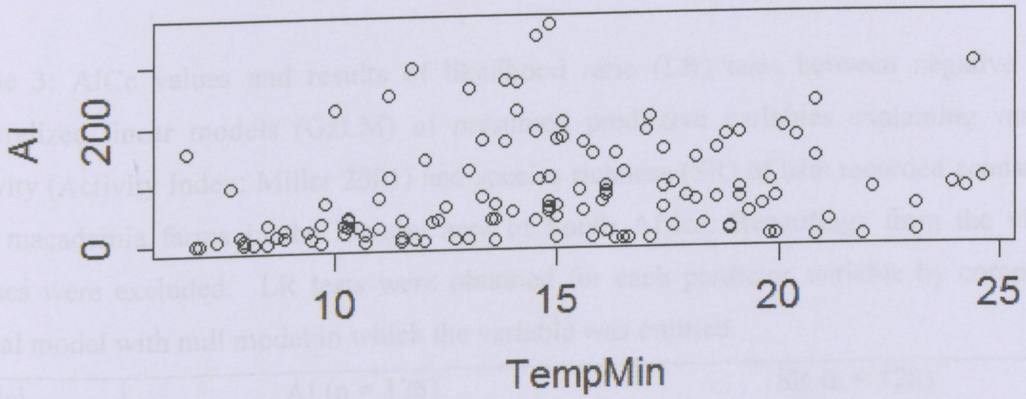


Figure 8: Regression plots and box and whisper plots for nightly data showing effects of (a) Habitat (orchard centre, orchard edge, houses; n=143), (b) Macadamia crop cycle (flowering, nut drop, nut growth, harvest; n=128), (c) Stinkbug density, n=128, (d) Moon phase, n=128, (e) Minimum temperature, n=128 on bat activity (AI).

© University of Venda

University of Venda
Creating Future Leaders

Macadamia orchards in both Welgevonden and Laatsgevonden recorded highest bat activity (Table 1). However, bat activity varies significantly on different habitats (higher activity at the edge than orchard centre) but did not differ significantly with other variables such as temperature, stinkbug density, crop cycle and moon phase (Table 3, Fig. 6).

Table 3: AICc values and results of likelihood ratio (LR) tests between negative binomial generalized linear models (GzLM) of presumed predictive variables explaining variation in activity (Activity Index: Miller 2001) and species richness (SR) of bats recorded acoustically on two macadamia farms in the Levubu area of South Africa. Recordings from the vicinity of houses were excluded. LR tests were obtained for each predictor variable by comparing the global model with null model in which the variable was omitted.

Model	AI (n = 128)				SR (n = 128)			
	AICc	LR statistic	D.F	P	AICc	LR statistic	D.F.	P
1. Global	1336.6	-	-	-	706.7	-		-
2. Omit Stinkbug density	1338.7	4.019	1	0.044	705.3	0.592	1	NS
3. Omit Habitat	1354.4	19.772	1	<0.001	715.2	10.468	1	0.001
4. Omit Crop cycle	1343.0	12.334	3	0.006	704.6	3.938	3	NS
5. Omit Moon phase	1345.6	12.983	2	0.002	710.6	7.896	2	0.02
6. Omit Minimum temperature	1340.2	5.557	1	0.018	706.7	1.947	1	NS

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

5.4 Dietary variation

Summary of the proportions (%) and standard deviation (± SD) of different insect orders in the diet of *Mops midas* and *Nycteris thebaica* for all habitats (Welgevonden, 71 Kameel Street and Laatsgevonden).

Table 4: summarizes the diet of *Mop midas* and *Nycteris thebaica*. Coleoptera dominated the diet of both species, followed by moths. Hemiptera is present in low proportions in almost every sample, yet was more prevalent in the diet of *Mops midas* than *Nycteris thebaica*. Small quantities of Hymenoptera, Isoptera and Orthoptera were also recorded.

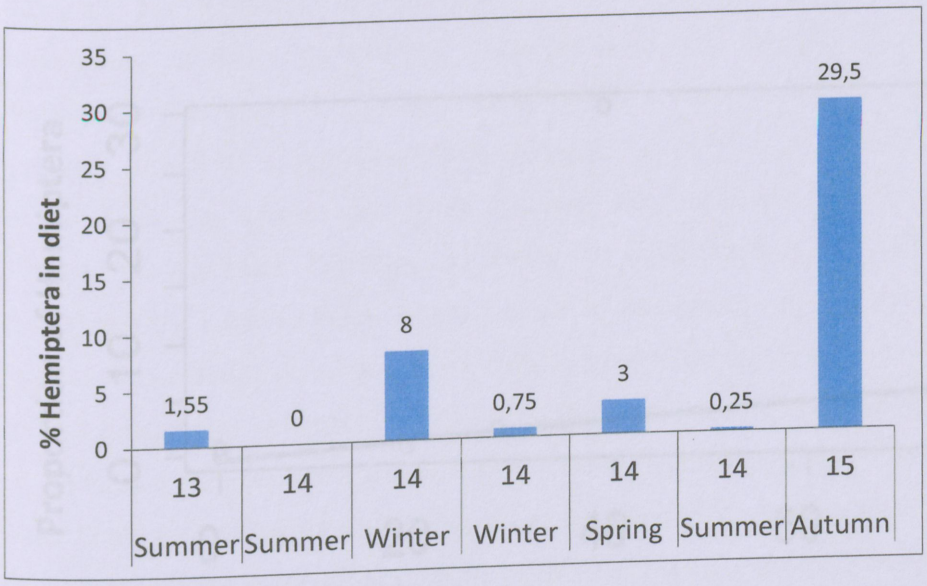
Locality	Date	Coleoptera	Hemiptera	Hymnoptera	Isoptera	Lepidoptera	Orthoptera	Trichoptera	Total
M. midas									
Welgevonden	30/11/2013	88.9±11.9	4.3±6.4	0	0	6.8±12.3	0	0	100
71 Kameel St	20/10/2014	75.0±24.4	12.2±14.2	0	0	12.9±16.4	0	0	100
71 Kameel St	30/12/2014	74.6+-22.7	19.4±21.7	0	0	6.0±9.0	0	0	100
72 Kameel St	9/4/2015	79.7±20.1	15.9±17.1	0	0	4.5±8.1	0	0	100
N. thebaica									
Laatsgevonden	21/12/2013	56.6±27.5	1.6±3.5	0	0	41.8±28.7	0.1±0.5	0	100
	7/1/2014	87.2±13.8	0	0	0.2±0.7	12.7±13.9	0	0	100
	12/6/2014	80.3±27.2	8.0±16.0	0	0	11.7±18.5	0	0	100
	9/8/2014	67.2±27.7	0.75±2.5	0	0	32.1±27.6	0	0	100
	25/9/2014	74.3±27.9	3.0±5.5	0.5±2.2	0	21.3±25.3	0	0.8±3.4	100
	23/12/2014	76.9±25.4	0.3±1.1	0	0	22.8±25.7	0	0	100
	26/4/2015	45.5±28.1	29.5±24.5	0	0	25±13.5	0	0	100

© University of Venda

The highest proportion of bugs in the diet of *Nycteris thebaica* was during autumn (Fig. 9a). Hemiptera was present in low proportion during summer.

Mops midas had low proportions of bugs in its diet during summer at Welgevonden (Fig. 9b). Higher quantities of bugs were recorded at Louis Trichardt (LTT urban) during summer and autumn.

(a)



(b)

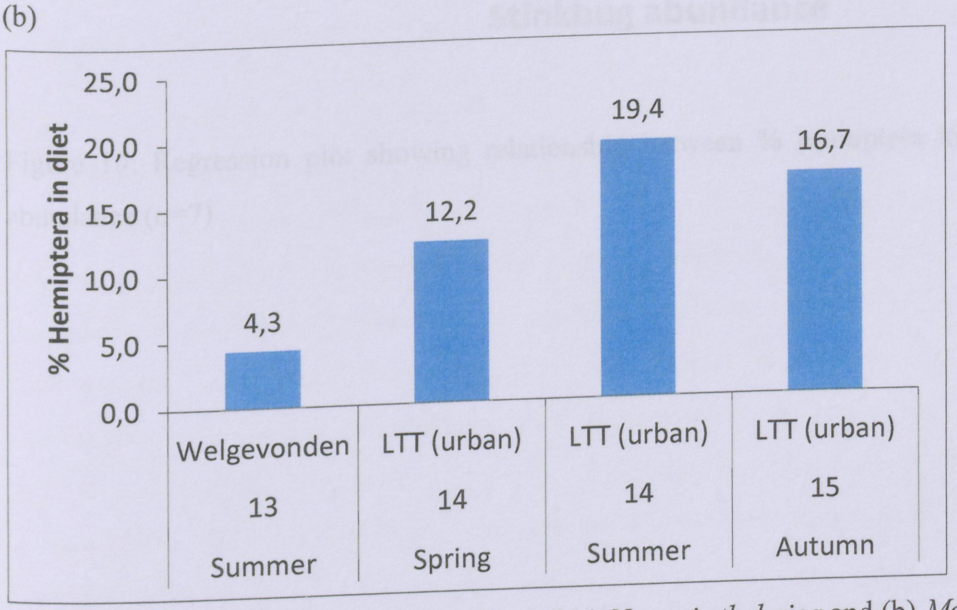


Figure 9: Percentage Hemiptera in the diet of (a) *Nycteris thebaica* and (b) *Mops midas*.

© University of Venda

5.5 Factors explaining variation in bat activity and diet

Based on a generalized linear model with log-normal distribution, for the data from Laatsgevonden for *Nycteris thebaica*, there was a weak positive correlation (r=0.06), albeit not statistically significant, between proportions of Hemiptera in diet of bats and stinkbug abundance from scouting (Fig. 10).

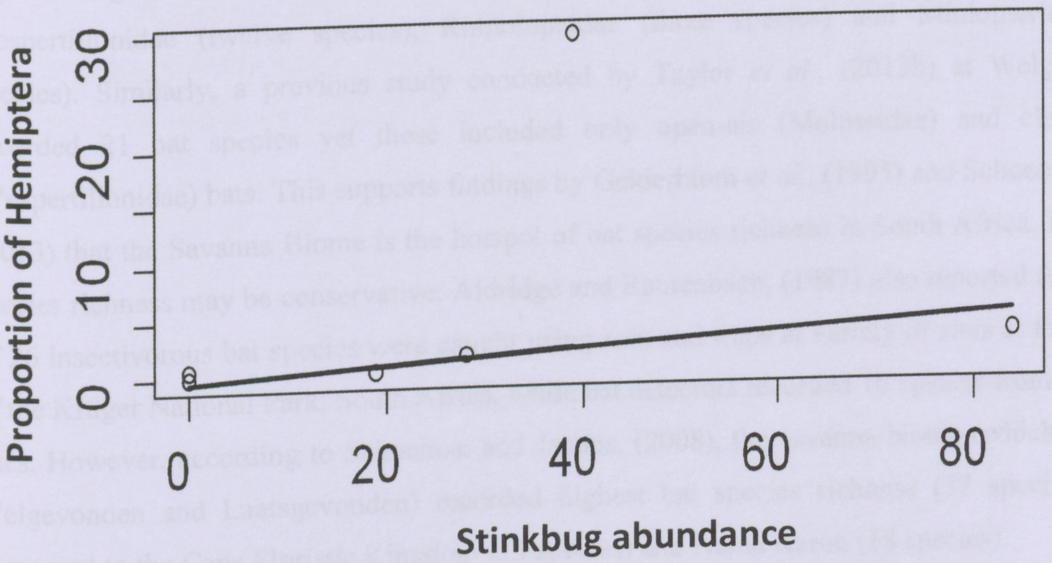


Figure 10: Regression plot showing relationship between % Hemiptera in diet and stinkbug abundance (n=7)

© University of Venda

University of Venda
Creating Future Leaders

CHAPTER SIX: DISCUSSION, CONCLUSION AND RECOMMENDATION

6.1 Discussion

6.1.1 Bat species richness and composition

In this study, 21 bat species were recorded at Laatsgevonden and 17 at Welgevonden, reporting all three bat functional groups (open-air feeder, clutter feeder and clutter-edge feeder), representing at least five families, Emballanuridae (one species), Molossidae (five species), Vespertilionidae (twelve species), Rhinolophidae (three species) and Miniopteridae (one species). Similarly, a previous study conducted by Taylor *et al.*, (2013b) at Welgevonden, recorded 21 bat species yet these included only open-air (Molossidae) and clutter-edge (Vespertilionidae) bats. This supports findings by Gelderblom *et al.*, (1995) and Schoeman *et al.*, (2013) that the Savanna Biome is the hotspot of bat species richness in South Africa. However, species richness may be conservative. Aldridge and Rautenbach, (1987) also reported that a total of 26 insectivorous bat species were caught using nets and traps at variety of sites at Pafuri area of the Kruger National Park, South Africa, while bat detectors recorded 16 species from the same sites. However, according to Schoeman and Jacobs, (2008), the savanna biome (which includes Welgevonden and Laatsgevonden) recorded highest bat species richness (37 species) when compared to the Cape Floristic Kingdom (13 species) and Nama Karoo (18 species).

A total of 16 species were common and generally found at Welgevonden and Laatsgevonden (*Chaerephon ansorgei*, *Chaerephon pumilus*, *Mops condylurus*, *Mops midas*, *Tadarida aegyptiaca*, *Laephotis botswanae*, *Neoromicia capensis*, *Neoromicia nanus*, *Neoromicia zuluensis*, *Pipistrellus hesperidus*, *Scotophilus dinganii*, *Eptesicus hottentotus*, unknown *Kerivoula*100, unknown *Vespertilionidae* (60 kHz), *Rhinolophus clivosus*, *Miniopterus natalensis*). Five species were absent from Welgevonden and these include *Myotis tricolor*, *Myotis welwitschii*, *Pipistrellus hesperidus*, *Rhinolophus simulator*, unknown *Rhinolophus species* (100 kHz), while only one species (*Taphozous mauritianus*) did not occur at Laatsgevonden.

© University of Venda

University of Venda
Creating Future Leaders

The occurrence of the Mauritian tomb bat (*Taphozous mauritianus*) at farm Welgevonden was in agreement with Taylor *et al*., (2011) who reported relatively high number of *Taphozous mauritianus* calls close to the farm house and assuming that it may be due to individuals roosting on the outside walls of the house or on the bark of nearby palm trees a common roost site for this species (Monadjem *et al*., 2010), but surprisingly during this study it was only recorded once.

Laatsgevonden habitats recorded higher species richness than Welgevonden habitats and this could be due to the close presence of the Luvuvhu River that runs through the farm. This was in agreement with Sirami *et al*., (2013) who documented higher bat species richness in riverine than other habitats probably due to insect abundance, while findings by Stahlschmidt *et al*., (2012), reported that construction of artificial wetlands provide foraging habitats and an increase in bat activity.

Previous studies also depicts that certain agricultural landscapes are important foraging habitats for bats species (Medina *et al*., 2007; Bhagwat *et al*., 2008; Taylor *et al*., 2013b. Wickramasinghe *et al*., (2003) reported significantly higher bat activity over organic farms than conventional farms due to insects' diversity and abundance on organic farms.

Habitat affects species richness because houses record more species probably as these are emerging from roosts (many houses are used by bats as roost). Agroforests provide heterogeneity and enhanced biodiversity and it may sometimes offer higher diversity of bats than the surrounding forests (Bhagwat *et al*., 2008). Faria *et al*., (2006) also reported that agricultural landscapes can support higher species richness of bats but this depends on the broader landscape matrix.

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

University of Venda
Creating Future Leaders

6.1.2 Seasonal bat and stinkbug activity

This study assumed that bat activity in this study will correspond with seasonal peaks in insect numbers especially of the two major macadamia pests (*Bathycoelia natalicola* and *Nezara viridula*). This study found strong temporal changes in activity patterns by bats, with Welgevonden depicting highest peak in activity during autumn and summer and lowest in winter, while Laatsgevonden reported higher activity during autumn (nut harvest stage) yet lower in spring (macadamia flowering season). Consistent with stinkbug abundance from Schoeman (2015), at Amana the highest numbers of bugs were collected during nut growth and harvest stage, whereas at Welgevonden there was an outbreak of bugs during spring (flowering season). This correlates with the unusual September (spring) peak in bat activity at Welgevonden. Agricultural areas may have high bat activity during pest insects' outbreaks (Shiel *et al.*, 1999). For example, in sugarcane plantation pest insect abundance was correlated with habitat selection by *Chaerephon pumilus* and *Mops condylurus* (Noer *et al.*, 2012). McCracken *et al.*, (2012), also documented Brazilian free-tailed bat (*Tadarida brasiliensis*) tracking the abundance of corn earworm moths (*Helicoverpa zea*). However, results from current study agrees with Taylor *et al.*, (2013b) who reported a significant increase in molossid bats activity during late summer and autumn when stinkbug numbers reach their annual peaks in macadamia orchards. Previous studies have found that Molossid bats feed on major macadamia pest such as stinkbugs (Kunz *et al.*, 2011; Bohmann *et al.*, 2011).

Bat activity was the highest on orchard edges at both Laatsgevonden and Welgevonden. Habitat structure and prey availability influence habitat selection by insectivorous bats (Brigham *et al.*, 1997). The findings by Grindal *et al.*, (1999) reported significantly greater foraging activity by insectivorous bats between edges, and this agrees with the results of the current study.

© University of Venda

Bathycoelia natalicola was more abundant than *Nezara viridula* at Amana during nut growth and harvest season (summer to autumn). Similarly, Taylor *et al*., (2013b) found stinkbug populations (in Welgevonden macadamia orchards) peaks during middle and late summer (November to February). *Nezara viridula* dominated during the last peak (nut growth/harvest) at Welgevonden. In contrast, Schoeman and Mohlala (2012) and Schoeman (2015) found that *Bathycoelia natalicola* dominates macadamia orchards during autumn (April). Ideally this could be the best time to apply environmental friendly pesticides (that does not poison beneficial insect predators) together with introduction of predators such as birds and bats in agroecosystems.

6.1.3 Diet variation

Interestingly, this was the first formal study to assess the diet of *Mops midas* using microscopic analysis apart from Archer (1977) who found mostly beetles in few stomachs. However, *Nycteris thebaica* in the current study consumed proportions of Hemiptera much higher than many other studies conducted from natural habitats. Hemiptera have not previously been recorded to be a major component in the diet of *Nycteris thebaica* from culled parts (Laval and Laval, 1980; Seamark and Bogdanowicz, 2002), stomach contents (Whitaker and Black, 1976) and faecal pellets (Bowie *et al.,* 1999; Schoeman, 2006). Based on microscopic analysis of samples from the same night roost used in the current study, Taylor *et al*., (2011) found proportion (20%) of Hemiptera in faecal pellets but not culled parts. The findings from the current study agrees with Taylor *et al*., (2011) reporting the highest proportion (29.5%) of Hemiptera in the diet of *Nycteris thebaica*.

The proportions of Hemiptera in the diet of *Mops midas* and *Nycteris thebaica* vary during different crop cycles, while other arthropods orders (Coleoptera, Lepidoptera, Isoptera, Hymnoptera, Orthoptera and Trichoptera) did not. Molossid bats showed an increase in activity during stinkbug outbreaks in macadamia farms (Taylor *et al*., 2013b), while Taylor *et al*., (2013a) reported higher proportions of green vegetable stinkbug (*Nezara viridula*) in the diet of *Mops midas* and *Nycteris thebaica* and this agrees with the findings of the current study on the variation of Hemiptera in the diet of this species which could be an act of opportunistic feeding on stinkbugs during seasonal outbreaks. Hemiptera also vary dramatically during different crop

© University of Venda

University of Venda
Creating Future Leaders

seasons at Laatsgevonden when the diet of *Nycteris thebaica* was assessed using a dissecting microscope (Taylor *et al*., 2011).

The current study could not really conclude whether *Mops midas* and *Nycteris thebaica* feed selectively or opportunistically since invertebrates were not sampled. However, the high proportion of Hemiptera relative to other studies is an indication of selective feeding. *Mops midas* might be more opportunistic and flexible when foraging since Taylor *et al*., (2013a) reported that the presence of stinkbugs in all foraging groups is an indication of flexible and opportunistic feeding strategy of bats in macadamia orchards. Lee and McCracken (2005) reported that free-tailed bats (*Tadarida brasiliensis*) frequently fed on migrating populations of insect pests from orders Coleoptera, Lepidoptera and Hemiptera. Similarly, *Mops midas* and *Nycteris thebaica* fed primarily on Coleoptera, Lepidoptera and Hemiptera.

Nycteris thebaica consumed higher proportions of Hemiptera in their diet during the seasons when stinkbugs reach their annual peaks (nut growth/harvest), although there was no significant correlation between the proportions of Hemiptera in the diet of *Nycteris thebaica* and season or crop cycle and this may be because bats are opportunistic feeders and other insect orders may be available at different times of the year. However only few monthly dietary samples were collected for this study and for practical reasons there was only one agricultural sample for *Mops midas* and the rest were from an urban situation, therefore this study could not test for the association between the diet of *Mops midas* and crop cycle. In agricultural landscapes, Whitaker, (1995) also reported bats feeding on Hemiptera especially from Family Pentatomidae. In another study conducted in agricultural farms during an outbreak of pest insects, Clare *et al*., (2011) documented Hemiptera in the diet of *Myotis lucifugus* foraging over such landscapes. McCracken *et al*., 2012 also reported higher proportions of insects in the diet of bats foraging over corn and cotton farms. In another study by Braun (2014) various species of bats were reported to forage over agricultural landscapes dominated by pecan nuts during pest insects' outbreak. Faecal pellets collected when bats return to Texas bat cave comprised of about 96% of corn earworm moth during their outbreak (Whitaker *et al*., 1996).

UNIVERSITY OF VENDA
LIBRARY

© University of Venda

6.2 Conclusion

Acoustic surveys recorded 22 species of bats on two study farms (Laatsgevonden and Welgevonden) in habitat types: orchard centre and orchard edge. Overall, activity patterns and species richness did not vary significantly between the two habitats. Bat activity was highest during stinkbug pest outbreaks during nut growth and harvest stages at both Welgevonden and Laatsgevonden. Notable was the unusual peak in bat activity at Welgevonden during September feeding opportunistically on available stinkbug prey. Nevertheless, bat and stinkbug activity showed local spatial variation. Bat species richness was higher at Laatsgevonden than Welgevonden which could be due to the close proximity of the Luvuvhu River at Laatsgevonden. Alternatively, there was highest species richness around farm houses probably because certain bat species use roofs of farm houses as roosts.

Bat activity was highest in both farms during the time of the year when stinkbug reach annual peaks and this correlate to the highest proportions of bugs (assumed to be stinkbug) in the diet of both *Mops midas* and *Nycteris thebaica*. However, dietary data did not strongly reflect stinkbug abundance data. Temperature and moon phases did not have a significant effect on the feeding patterns of bats, while

6.3 Recommendation

Future studies should trap nocturnal insect in parallel with bat acoustic recording. Ideally, faecal pellets should be collected at the same time to assess insect availability and selectivity of bats foraging in macadamia orchards and other accessible habitats. Additionally, dietary data from bats at additional bat roosts are necessary to estimate a full dietary sample using both microscopic and molecular analyses during different crop cycles. Quantifying economic benefits of bats is very important (Boyles *et al.*, 2011). This can be achieved through avoided cost models (Wanger *et al.*, 2014), and through bat exclusion experiments (Maas *et al.*, 2013 and Maas *et al.*, 2015). The Department of Agriculture and Environmental Affairs should encourage the use integrated pest control and thus includes conservation of potential insect predators such as bats in agroecosystems, through workshops and conferences held in macadamia farms.

© University of Venda

University of Venda
Creating Future Leaders

REFERENCES

ADAMS, R. A. and PEDERSEN, S. C. (2013) Bats Evolution Ecology and Conservation. *New York, Springer*.

ALDRIDGE, H.D.J.N. and RAUTENBACH, I.L. (1987) Morphology, echolocation and resource partitioning in insectivorous bats. *Journal of animal ecology* 56, 763-778.

ARCHER, A.L. (1977) Results of Winifred T. Carter expedition 1975 to Botswana mammals-Chiroptera. *Botswana society* 9, 145-154.

BHAGWAT, S.A., WILLIS, K.J., BIRKS, H.J.B. and WHITTAKER, R.J. (2008) Agroforestry: A refuge for tropical biodiversity? *Trends in Ecology and Evolution* 23, 261-267.

BARCLAY, R.M.R., and HARDER, L.D. (2003) Life histories of bats. Life in the slow lane. *In* Kunz, T.H. and Fenton M.B. (eds) *Bat Ecology*. University of Chicago Press.

BOHMANN, K., MONAJEM, A,. NOER, C.L., RASMUSSEN, M., ZEALE, M.R.K., CLARE, E., JONES, G., WILLERSLEV, E. and GILBERT, M.T.P. (2011) Molecular diet analysis of two African free-tailed bats (Molossidae) using high throughput sequencing. *PLoS ONE* 6, e21441. doi:10.1371/journal.pone.0021441.

BORK, K.S. (2006) Lunar Phobic in the Greater Fishing Bat *Noctilio leporinus* (Chiroptera: Noctilionidae). USA: University of Kansas.

BOWIE, R. C. K., JACOBS, D. S. and TAYLOR, P. J. (1999) Resource use by two morphologically similar insectivorous bats *(Nycteris thebaica* and *Hipposideros caffer). South African Journal of Zoology* 34, 27–33.

© University of Venda

University of Venda
Creating Future Leaders

BOYLES, J.G., CRYAN, P.M., MCCRACKEN, G.F. and KUNZ, T.H. (2011) Economic importance of bats in agriculture. *Science* 332, 41-42.

BRAUN DE TORREZ, E. (2014) Bats, insects and pecans: habitat use and ecosystem services of insectivorous bats in a pecan agroecosystem in central Texas. Boston University, Boston.

BRIGHAM, R.M., GRINDAL, S.D., FIRMAN, M.C. and MORISSETTE, J.L. (1997) The influence of structural clutter on activity patterns of insectivorous bats. *Canadian Journal of Zoology*. doi:10,1139/z97-017.

BRUWER, I.J. (1999) Integrated pest management on macadamia in South Africa. Proceedings of the first International Macadamia Symposium in Africa. 28-30 September, Nelspruit, 292-295.

BRUWER, I.J. (2004) Evaluation of integrated pest management programmes for the control of various insect pests on macadamias in South Africa. *Yearbook of the Southern African Macadamia Growers Association* 11, 22-27.

CLARE, E.L., BARBER, B.R., SWEENEY, B.W., HEBERT, P.D.N. and FENTON, M. B. (2011) Eating local: influences of habitat on the diet of little brown bats (*Myotis lucifugus*). *Molecular Ecology* 20, 1772-1870.

CLEVELAND, C.J., BETKE, M., FEDERICO, P., FRANK, J. D., HALLAM, T. G., HORN, J., LOPEZ, J.D., MACCRACKEN, J. D., MEDELLIN, R. A., MORENO-VALDEZ, A., SANSONE, C. G., WESTBROOK., J. K. and KUNZ, T. H. (2006) Economic value of the pest control services provided by Brazilian free-tailed bat in south-central Texas. *Frontier in Ecology and the Environment* 4(5), 238-243.

© University of Venda

University of Venda
Creating Future Leaders

DESMET, P. G., HOLNESS, S., SKOWNO, A. and EGAN, V. T. (2013) Limpopo conservation plan v.2: Tactical report. Contract number EDET/2216/2012. Report for Limpopo Department of Economic Development Environment and Tourism (LEDET) by ECOSOL GIS.

DOWNS, N.C. and RACEY, P.A. (2006) The use by bats of habitat features in mixed farmland in Scotland. *Acta Chiropterologica* 8(1), 169-185.

ECKERT, H. G. (1982) Ecological aspects of bat activity rhythms. 201-242 in T. H. Kunz, editor. Ecology of bats. *Plenum Press*, New York, New York, USA.

FARIA, D., LAPS, R. R., BAUMGARTEN, J. and CETRA, M. (2006) Bat and bird assemblages from forests and shade cacao plantations in two contrasting landscapes in the Atlantic Forest of southern Bahia, Brazil. *Biodiversity and Conservation* 15, 587-612.

GELDERBLOM, C. M., BRONNER, G. N., LOMBARD, A. T. and TAYLOR, P. J. (1995) Patterns of distribution and current protection status of the Carnivora, Chiroptera and Insectivora in South Africa. *South African Journal of Zoology* 30, 103-114.

GRINDAL, S.D., MORISSETTE, J.L. and BRIGHAM, R.M. (1999) Concentration of bat activity in riparian habitats over an elevational gradient. *Canadian Journal of Zoology* 77, 972-977.

GOTELLI, N.J. AND COLWELL, R.K. (2001) Quantifying biodiversity: Procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4, 379-391.

© University of Venda

University of Venda
Creating Future Leaders

HOLLAND, R.A., MEYER, C.F.J. KALKO, E.K.V. KAYS, R AND WIKELSKI, M. (2011) Emergence Time and Foraging Activity in Pallas' Mastiff Bat, *Molossus molossus* (Chiroptera: Molossidae) in Relation to Sunset/Sunrise and Phase of the Moon. *Acta Chiropterologica*: *Museum and Institute of Zoology PAS* 13(2), 399-404.

HSIEH, T.C., MA, K.H. and CHAO, A. (2015) iNEXT: An R package for interpolation and extrapolation of species diversity (Hill numbers).

JONES, V.P. (1995a) Sampling plans for *Cryptophlebia* spp. (Lepidoptera: Tortricidae) attacking macadamia and litchi in Hawaii. *Journal of economic entomology* 88(5), 1337-1342.

JONES, G., JACOBS, D.S., KUNZ, T.H., WILLIG, M.R. and RACEY, P.A. (2009) Carpe noctem: the importance of bats as bioindicators. *Endang Species Res*. 8, 93-115.

JOUBERT, P.H. (2001) *Pseudotheraptus wayi* Brown Coconut bug. In: VAN DEN BERG, M.A., DE VILLIERS, E.A. and JOUBERT, P.H. (Eds). *Pests and Beneficial Arthropods of Tropical and Non-Citrus Subtropical Crops in South Africa*. Ad Dynamics, Nelspruit, 525.

KOTLER, B.P., BROWN, J.S. and HASSON, O. (1991) Factors affecting gerbil foraging behavior and rates of owl predation. *Ecology* 72, 2249-2260.

KUNZ, T.H. and LUMSDEN, L.F. (2003) Ecology of cavity and foliage roosting bats. In: *Bat Ecology* (Kunz, T.H. and Fenton, M.B., eds.). 3-89. University of Chicago Press, Chicago.

KUNZ, T.H., DE TORREZ, E.B., BAUER, D., LOBOVA, T. and FLEMING, T.H. (2011) Ecosystem services provided by bats. *New York Academy of Science* 1223, 1-38.

© University of Venda

University of Venda
Creating Future Leaders

LANG, A.B., KALKO, E.K.V., ROMER, H., BOCKHOLDT, C. and DECHMANN, D.K.N. (2006) Activity Level of Bats and Katydids in Relation to the Lunar Cycle. *Oecologia* 146, 659-666.

LAVAL, R.K. and LAVAL, M.L. (1980) Prey selection by slit-faced bat *Nycteris thebaica* (Chiroptera: Nycteridae) in Natal, South Africa. *Biotropica* 12, 241-246.

LEE, Y. and MCCRACKEN, G.F. (2005) Dietary variation of Brazilian free-tailed bats links to migratory populations of pest insects. *Journal of mammology* 86 (1), 67-76.

LONG, R., SIMPSON, T., DING, J., HEYDON, S. and REILL, R. (1998) Bats feed on crop pests in Sacramento Valley. *California Agriculture* 52, 8-10.

MAAS, B., CLOUGH, Y. and TSCHARNTKE, T. (2013) Bats and birds increase crop yield in tropical agroforestry landscapes. *Ecology Letters* 16, 1480- 1487.

MAAS, B., DANIEL, S. K., BUMRUNGSRI, S., DARRAS, K., GONTHIER, D., HUANG, J. C. C., LINDELL, C. A., MAINE, J. J., MESTRE, L., MICHEL, N. L., MORRISON, E. B., PERFECTO, I., PHILPOTTI, S. M., CAGAN, H. S., GLU, E., SILVA, R. M., TAYLOR, P. J., TSCHARNTKE, T., VAN BAEL, S. A., WHELAN, C. J. and GUILLEN, K. W. (2015) Bird and bat predation services in tropical and Agroforestry landscapes. *Biological reviews* (2015), 00-00.

MCCRACKEN, G.F. (1996) Bats aloft: A study of high-altitude feeding. *Bats* 14(3), 7-10.

MCCRACKEN, G.F., WESTBROOK, J.K., BROWN, V.A., ELDRIDGE, M., FEDERIKO, P. and KUNZ, T. H. (2012) Bats track and exploit changes in insect pest populations. *PloS* ONE 7 (8), e43839.

© University of Venda

MEDINA, A., HARVEY, C. A., MERLO, D. A., VILCHEZ, S., and HERNANDEZ, B. (2007) Bat Diversity and Movement in an Agricultural Landscape in Matiguas, Nicaragua. *Biotropica* 39(1), 120–128.

MILLER, W.B. (2001) A method for determining relative activity of free-flying bats using a new activity index for acoustic monitoring. *Acta Chiropterologica* 3(1), 93-105.

MONAJEM, A., TAYLOR, P.J., COTERRILL, F.P.D. and SCHOEMAN, M.C. (2010b) Bats of Southern and Central Africa: A Biogeographic and Taxonomic Synthesis. University of Witwatersrand Press, Johannesburg.

MUCINA, L. and RUTHERFORD, M.C. (2006) The vegetation of South Africa, Lesotho and Swaziland. 19. South African National Biodiversity Institute, Pretoria.

NOER, C.L., DABELSTEEN, T., BOHMANN, K. and MONAJEM, A. (2012) Molossid bats in an African agro-ecosystem select sugarcane fields as foraging habitat. *African Zoology* 47, 1-11.

O`DONNELL, R.P. (1999) The Effect of Moon Phase and Moonlight Intensity on the Activity of Barred Owl and Great Horned Owl. Poster Meeting of the Northeast Regional Animal Behaviour Society.

RICHTER, H. V. and CUMMING, G. S. (2008) First application of satellite telemetry to track African straw-coloured fruit bat migration. *Journal of Zoology*, 275, 172–176.

SEAMARK, E.C.J. and BOGDANOWICZ, W. (2002) Feeding ecology of the common slit-faced bat (*Nycteris thebaica*) in Kwazulu-Natal, South Africa. *Acta Chiropterologica* 4 (1), 49-54.

© University of Venda

University of Venda
Creating Future Leaders

SCHOEMAN, M.C. (2006) The relative influence of competition and coevolution on the community structure of insectivorous bats in southern Africa. PhD thesis, university of Cape Town.

SCHOEMAN, M.C. and JACOBS, D.S. (2008) The relative influence of competition and prey defences on the phenotypic structure of insectivorous bat ensembles in southern Africa. *PLoS ONE* 3, e3715. doi:10.1371/journal.pone.0003715.

SCHOEMAN, M.C. and JACOBS, D.S. (2011) The relative influence of competition and prey defences on the trophic structure of animalivorous bat ensembles. *Oecologia* 166, 493–501.

SCHOEMAN, M.C., COTTERILL, F.P.D., TAYLOR, P.J. and MONADJEM, A. (2013) Using potential distributions to explore environmental correlates of bat species richness in southern Africa: effects of model selection and taxonomy. *Current Zoology*. 59.

SCHOEMAN, P.S. and MOHLALA, R. (2012) Prediction of ideal spraying dates for the stink bug and nut borer complexes. *South African Macadamia Association* Yearbook 20.

SCHOEMAN, P.S. (2013) Phytophagous stink bugs (Hemiptera: Pentatomidae; Coreidae) associated with macadamia in South Africa. *Open Journal of Animal Sciences* 3, 179-183.

SCHOEMAN, P.S. (2015) Stink bug IPM on macadamias in South Africa: Current status and the road ahead. *Southern African Macadamia Association Yearbook* 22, 69-75.

SHIEL, C.B., SHIEL, R.E, FAIRLEY, J.S. (1999) Seasonal changes in the foraging behaviour of Leisler's bats (Nyctalus leisleri) in Ireland as revealed by radio-telemetry. *Journal of Zoology* 249, 347-358.

© University of Venda

University of Venda
Creating Future Leaders

SIRAMI, C., JACOBS, D. S, CUMMING, G. S. (2013) Artificial wetlands and surrounding habitats provide important foraging habitat for bats in agricultural landscapes in the Western Cape, South Africa. *Biological Conservation* 164, 30–38

SQUITER, J. M. (2017) Southern green stinkbug, *Nezara viridula* (Linnaeus) (Insecta: Hemiptera: Pentatomidae). IFAS Extension, University of Florida.

STAHLSCHMIDT, P., PATZOLD, A., RESSL, L., SCHULZ, R., BRUHL, C. A. (2012) Constructed wetlands support bats in agricultural landscapes. *Basic Applied Ecolology* 13, 196-203.

SWIFT, S.M., RACEY, P.A. and AVERY, M.I. (1985) Feeding ecology of *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) during pregnancy and lactation. II. Diet. *Journal of Animal Ecology* 54, 217–225.

TAYLOR, P.J., MKHARI, D., MUKWEVHO, T., MONADJEM, A., SCHOEMAN, M.C., SCHOEMAN, C. and STEYN, J.N. (2011) Bats as potential biocontrol agents in an agricultural landscape, Levubu Valley, Limpopo Province: diet, activity and species composition of bats in macadamia orchards and neighbouring natural habitats. *SAAGA Yearbook* 34, 51-61.

TAYLOR, P.J., BOHMANN, K., STEYN, J.N., SCHOEMAN, M.C., MATAMBA, E., ZEPEDA-MENDOZA, M., NANGAMMBI, T. and GILBERT, M.T.P. (2013a) Bats eat pest green vegetable stink bugs (*Nezara viridula*): Diet analysis of seven insectivorous species of bats roosting and foraging in macadamia orchards. *South African Macadamia Association Yearbook* 21.

© University of Venda

University of Venda
Creating Future Leaders

TAYLOR, P.J., STEYN, J.N. and MONAJEM, A. (2013b) Seasonal patterns of habitat use by insectivorous bats in a subtropical African agro-ecosystem dominated by macadamia orchards. *African Journal of Ecology*.doi: 10.1111/aje.12066.

TAYLOR, P.J., SOWLER, S., SHOEMAN, M.C. and MONAJEM, A. (2013c) Diversity of bats in the Soutpansberg and Blouberg Mountains of northern South Africa: complementarity of acoustic and non-acoustic survey methods. *South African Journal of Wildlife Research* 43(1), 12-26.

TIBBELS, A. E., and KURTA, A. (2003) Bat activity in low and unthinned stands of red pine. *Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere* 33, 2436-2442.

VERBOOM, B. and SPOELSTRA, K. (1999) Effects of food abundance and wind on the use of tree-lines by an insectivorous bat, *Pipistrellus pipistrellus*. *Canadian Journal of Zoology* 77, 1393–1401.

WANGER, T.C., DARRAS, K., BUMRUNGSRI, S., TSCHARNTKE, T. & KLEIN, A.M. (2014). Bat pest control contributes to food security in Thailand. *Biological Conservation* 171, 220-223.

WHITAKER, J.O. Jr. and BLACKS, H. (1976) Food habits of cave bats from Zambia, Africa. *J. Mammal*. 57, 199-204.

WHITAKER, J.O. Jr. (1988) Food habits analysis of insectivorous bats. In: Kunz TH (ed) Ecological and behavioral methods for the study of bats. *Smithsonian Institution Press*, Washington, DC.171-189.

© University of Venda

University of Venda
Creating Future Leaders

WHITAKER, J. O., Jr. (1995) Food of the big brown bat, *Eptesicus fuscus,* from maternity colonies in Indiana and Illinois. *American Midland Naturalist* 134, 346-360.

WHITAKER, J. O., Jr, NEEFUS, C. and KUNZ, T.H. (1996) Dietary Variation in the Mexican Free-tailed Bat (*Tadarida brasiliensis mexicana*). *J. Mammal*. 77(3), 716-724.

WHITAKER, J.O. Jr., MCCRACKEN, G.F. and SIEMERS, B.M. (2009) Food habits analysis of insectivorous bats. In: Kunz TH, and Parsons, S (eds) Ecological and behavioral methods for the study of bats 2nd edition. *The John Hopkins University Press*, Baltimore. 567-592.

WICKRAMASINGHE, L.P., HARRIS, S., JONES, G. and VAUGHAN , N. (2003) Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *Journal of Applied Ecology* 40, 984-993.

WILLIAM-GUILLEN, K., PERFECTO, I. and VENDERMEER, J. (2008) Bats limit insects in a Neotropical Agroforestry System. *Science*. 320 70.

WRIGHT, M.G., FOLLETT, P.A. and GOLDEN, M. (2007) Long-term patterns and feeding sites of southern green stinkbug (Hemiptera: Pentatomidae) in Hawaii macadamia orchards, and sampling for management decisions. *Bulletin of Entomological Research* 97, 569-576.

© University of Venda