UNIVERSITY OF CAPE COAST

ESTABLISHING LONG-TERM BIOLOGICAL MONITORING PROTOCOLS: COMPARING THREE ARTHROPOD SAMPLING TECHNIQUES IN THE AMURUM FOREST RESERVE, NIGERIA

AGYEMANG OPOKU

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BY

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Thesis submitted to the Department of Conservation Biology and Entomology, College of Agriculture and Natural Sciences, School of Biological Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Wildlife Management

SEPTEMBER 2017

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the results of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ……………………………….. Date …………………

Name: ………………………………………………………………………

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature …………………….. Date …………………

Name: ………………………………………………………………………

Co-Supervisor's Signature …………………………... Date …………………

Name: ………………………………………………………………………

ABSTRACT

Amurum Forest Reserve (AFR), the area around the AP Leventis Ornithological Research Institute is not currently systematically monitored in terms of arthropods, which is fundamental to the bird species of the reserve that has been extensively monitored. Research opportunities to relate the bird data to this biotic factor (food resource) are being lost, particularly as Amurum has been protected for over 14 years and is undergoing regeneration in terms of gallery forest and savanna. This project was to determine the best sampling design and effort to efficiently and accurately determine arthropods abundance and diversity at Amurum forest reserve. In view of this, characteristics such as abundance, richness, average body length, effort and statistical power required for collecting arthropods were compared with sweep net, pitfall trap and sticky trap. Proportions of major taxa and size distribution of arthropods differed significantly between all three methods. Family richness showed no significant difference between sweep net and sticky traps. Sticky traps significantly recorded the highest abundant arthropods and required the least effort in time (236. 63 ±108/sec) to complete sampling. Monitoring arthropods with sweep net had the least statistical power and requires as much as thrice the sampling units required for pitfall trap and sticky trap combined. A combination of pitfall and sticky traps sampled a wider variety of prey taxa and may provide a more accurate estimate of arthropods community in the AFR for avian studies.

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Finally, to John Onah, Clara Cassell, Bright Opoku and all students at APLORI who helped me during my data collection period, I am grateful.

DEDICATION

To my mother, Beatrice Owusu Mensah.

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LIST OF ACRONYMS

AFR	–	Amurum Forest Reserve
APLORI	–	A.P Leventis Ornithological Research Institute
GLM	–	General Linear Model
BS	–	Beating sheet
PT	–	Pitfall trap
SN	–	Sweep netting
ST	–	Sticky trap

CHAPTER ONE

INTRODUCTION

Arthropods represent one of the most successful taxa on earth with a global estimated species richness approaching 10 million (Mora, Tittensor, Adl, Simpson & Worm, 2011). They are essential for ecosystem functioning and have received much attention in biodiversity, conservation and ecological studies (Swart, Pryke & Roets, 2017). On the trophic level, arthropods constitute important food resources for several higher trophic levels, like birds (Norment, 1987; Hollander, Titeux, Walsdorff, Martinage & Van-Dyck, 2015) and has become a major driver regulating bird populations (Galbraith, Beggs, Jones & Stanley, 2015), controlling their abundance and diversity within habitats (Hollander et al.).

Along the Guinea Savanna ecological zone in north-central Nigeria is the Amurum Forest Reserve (AFR), a biodiversity hotspot which boasts of its rich avi-fauna diversity. The AFR has served, and still serves as a study site for many ornithological, ecological and conservation research works by researchers across the globe (Mwansat, Lohdip & Dami, 2011).

However, due to the importance of arthropods in the ecosystem, they are always sampled to answer various ecological questions (Meyer, Ostertag & Cowie, 2011). Arthropods are of different sizes and occupy different habitat types across varied elevation gradient (Buffington & Redak, 1998). For this and other reasons, they are sampled with different sampling methods or techniques. Specific sampling method may target a specific or groups of arthropod taxa bringing into light the advantages and disadvantages associated with various sampling methods (Zou, Feng, Xue, Sang & Axmacher, 2012).

Statement of the Problem

The Amurum Forest Reserve is the home for hundreds of birds including periodic Palearctic and Intra-African migrant visitors (Mwansat et al., 2011; Nwaogu & Cresswell, 2016). Amurum also houses the AP Leventis Ornithological Research Institute (APLORI), the only field station dedicated to ornithological research and conservation training in West Africa. The reserve has been under protection for over 14years and has witnessed significant regeneration in terms of savanna and gallery forest. APLORI has extensively monitored the avifauna in the reserve through its constant effort ringing site (CES) programme (Mwansat et al. 2011; Omotoriogun & Stevens, 2012; Nwaogu & Cresswell, 2016) and other projects (Molokwu, Ottosson & Azi, 2006; Mwansat, Chaskda & Longton, 2006; Molokwu, Ottosson & Olsson, 2007).

However, despite the extensive work done and ongoing on the avifauna of the reserve, Amurum is not currently systematically monitored in terms of arthropods, which is fundamental to the bird species in the reserve. Amurum is heterogeneous in vegetation and any monitoring, especially on arthropods, needs to be fit for purpose in all habitats in both the wet and dry seasons when abundance and diversity will differ profoundly.

Justification

A gap in literature arises due to the lack of standardization of the types of sampling methods used for specific vegetation types, especially in natural systems (Buffington & Redak, 1998; Doxon, Davis & Fuhlendorf, 2011). Assessment of arthropod availability to birds is one of the least understood and conventional areas of sampling methods in animal ecology. Accurate quantification of resource availability is essential to detailed analyses of energy requirements of birds and have direct implications for the evaluation of reproductive success, survival, competitive interactions (Norment, 1987) and helps to understand their distribution, abundance and diversity (Buffingtong & Redak, 1998).

Therefore, establishing a sampling protocol to efficiently and accurately sample arthropods in the AFR through a pilot programme will make available the needed information on resources availability to better complement other bird studies that is currently ongoing in the reserve.

Aim and Objectives

The key aim of this study was to determine the ideal arthropod sampling techniques needed for monitoring intra-annual and therefore inter-annual variation in abundance and diversity across different taxa and how this varied across the three main habitats of the reserve and in the wet and dry seasons.

The specific objectives of this study were to:

1. Determine the arthropod sampling technique that produce the highest taxon diversity and abundance per unit sampling effort.
2. Determine the sampling technique (s) ideal for sampling in the three habitat.
3. Determine the sampling technique (s) ideal for sampling across seasons.
4. Determine the number of samples needed for arthropod collection in the AFR to get a stabilized means.

Null Hypotheses

1. There is no significant difference in the diversity and abundance of arthropods between sampling techniques.
2. There is no significant difference in the diversity and abundance of arthropods between habitats.
3. There is no significant difference in the diversity and abundance of arthropods across seasons.
4. There is no significant difference between sample sizes needed for each sampling technique.

Study Limitations

The goal of a complete arthropod sampling is to capture all arthropods present at a specific area in order to obtain a true reflection of assemblage taxa. However, due to final constraints and availability of equipment, not all arthropod sampling techniques were compared in this study but those that were affordable and available to the researcher. Also, weather data influence arthropods behaviour and useful in their studies but during the period of data collection, the weather station facility in the reserve was not functional so the effect of weather was not included in this study.

The last but not least limitation of this study is fire outbreak. Fire swept across the entire reserve at the course of this study. The fire burnt a lot of vegetation and may have reduced the abundance and diversity of arthropods in the study area.

Figure 1: Picture of the Amurum Forest Reserve showing the three habitat types

CHAPTER TWO

LITERATURE REVIEW

Biodiversity of Arthropods

Arthropods are the most diverse component of terrestrial ecosystems. Globally, they occupy a great scale of functional niche and microhabitats across a wide array of space and in time (Kremen et al., 1993). Moreover, terrestrial arthropods are by far the most diverse group of organisms on our planet, as insects alone account for an estimated 57% of all species living on earth (Millennium Ecosystem Assessment, 2005). Arthropods are present in almost all habitats. In the soil alone, they constitute about 85% of the soil fauna in terms of species richness (Bagyaraj, Nethravathi & Nitin, 2016). In all forms of water bodies and agricultural landscapes (Zhang et al., 2013), backyard gardens (Nagendra, Jaganmohan, & Vailshery, 2013), both disturbed and undisturbed forests bodies (Chumak, Duelli, Rizun, Obrist, & Wirz, 2005), habitat types within and around protected areas (Mulwa, Neuschulz, Bohning-Gaese & Schleuing, 2012), along different elevation gradients (Franzen & Dieker, 2014), arthropods are present. Factually, whether terrestrial ecosystems are measured by species, individuals, or biomass, arthropods dominate all organisms (Stork, 1988; Gaston, 1991).

Arthropods are of different sizes and forms (Greenberg et al., 2000). Small arthropods can be less than 1 mm while large ones can be bigger than 10 mm, especially, some caterpillars, dragonflies etc. (Johnson, 2002). Arthropods are vast diverse and abundant that they provide a rich information to aid efforts in conservation of biodiversity studies as well as the planning and management of nature reserves (Murphy, 1992; Kremen et al., 1993).

Arthropods and Birds

Trophic ecology involving avian species and arthropods have been recorded by many researchers across different ecological systems (e.gs. Ralph, Nagata & Ralph, 1985; Recher, Majer & Ganesh, 1996; Greenberg et al., 2000; Bael et al., 2008; Moorman et al., 2012; Razeng & Watson, 2014). Arthropods are rich in loads of micro and macro nutrients at various life stages (Studier, Keeler & Sevick, 1991; Eva, Hella, Salminen & Hakkarainen, 2010). Birds feed on arthropods for satiation and nutrients. Birds require an essential amount of protein (large molecules of amino acids) in their diet to meet their nitrogen requirements (Koutsos, Matson & Klasing, 2001) for essential growth and reproduction (White, 1993; Klasing, 1998). Birds that meet their proteins requirements grow faster (Bell, 1990; Klasing, 1998) but protein deficiency causes more body fat and greater mortality in birds (Underwood, Polin, O'Handley & Wiggers, 1991).

Moult is critical for fitness for many avian species for several reasons: it allows growth and maintains the function of the integument for protection, thermoregulation and communication but comes with a cost (Danner, Greenberg, Danner & Walters, 2015). Birds require increased amount of amino acids during feathers development (Bruce, 1994) and mating. Feathers contain 85 to 90% protein in the form of keratin and their amino acids composition is considered different from other body proteins (Sales & Janssens, 2003).

With protein being crucial to the survival of birds, most tropical birds rely on insects to obtain their dietary protein (Karr, Robinson, Blake & Bierregaard, 1990).

Birds in the Amurum Forest Reserve

The Amurum Forest Reserve, the area around APLORI, is the only field station in West Africa decided to ornithology and conservation studies (Mwansat et al., 2011). Also, it is one of Nigeria's prestigious biodiversity conservation hotspot (Ezealor, 2002). Over 300 different birds' species have been recorded in the reserve and they serve as study species for the training of young graduates from West Africa in ecology and conservation (Mwansat et al.). Among the birds' species in the reserve are two of Nigeria's endemic bird species, the Rock firefinch *Lagonosticta sanguinodorsalis* and its brood parasite the Jos Plateau indigobird *Virdua maryae* (Payne, 1998). Through APLORI's CES, movements of birds in and out of the reserve have been massively monitored. Several Palearctic migrant species arrive in the reserve at the end of the wet season and depart on spring migration at early April – May (Nwaogu & Cresswell, 2016). Few among the numerous Palearctic migrant visitors in the reserve are Garden warbler *Sylvia borin*, Willow warbler *Phylloscopus trochilus*, Whinchat *Saxicola rubeta*, Tree pipit *Anthus trivalis*. Resident birds' species include Rock loving cisticola *Cisticola aberrans*, Familiar chat *Cercomela familiaris*, Variable sunbird *Cinnyris venustus* and some Intra-African migrant species such as Klaas's cuckoo *Chrysococcyx klaas*, White-throated bee-eater *Merops albicollis*, Violet-backed starling *Cinnyricinclus leucogaster* etc. (Nwaogu & Cresswell, 2016). Omotoriogun & Stevens (2012) have reported the presence of two forest bird species (Yellowbill *Ceuthmochares aerus* and Little greenbul *Andropadus virens*) in Amurum. As it is a common knowledge that birds eat arthropods (Morse, 1971), birds in Amurum are not exceptional.

Arthropods Sampling Techniques

Arthropod populations are sensitive to short-term environmental impacts as well as long-term general ecosystem modifications. They are abundant and can be collected with a variety of techniques without harming their populations. For these reasons, they represent choice organisms for many environmental and conservation monitoring (Kremen et al., 1993).

The enormous importance of terrestrial arthropods have generated long-lasting debates on the best approaches to collect them (Brehm & Axmacher, 2006; Zou et al., 2012). Some researchers have tried to classify the various arthropod sampling methods with or without human influence (Gullan & Cranston, 2005) and/or with or without attractants (Zou et al.). Examples of arthropods sampling methods include sticky traps, suction traps, malaise traps, light traps, pan traps, bait types, pheromone traps, pitfall traps, canopy fogging, sweep netting, soil extraction and leaf litter collection (Morrison, Brennan & Block, 1989; Zou et al.). These have been used to sample arthropods in tropical forests (Sabu, Shiju, Vinod & Nithya, 2011; Cooper et al., 2012), shrub/mixed grass prairie (Doxon et al., 2011) and experimental fields (Evans & Bailey, 1993). The commonly used technique by researchers interested in arthropod abundance or availability relative to the foraging ecology of birds are vacuum sampling, sweep netting, pitfall traps and sticky trap sampling (Norment, 1987; Morrison et al.).

Among the various sampling methods, canopy fogging, sticky traps, window traps and pan traps usually kill specimen and are not required for monitoring rare species (Zou et al., 2012) Researchers use one or combinations of these techniques without understanding the impacts their choice may have on the samples collected and the ability of the methods to meet research objectives (Doxon et al., 2011). Sampling methods have their advantages and limitations (Zou et al.). Sweep netting for instance is the commonly used technique because the equipment is lightweight and simple to use (Buffington & Redak, 1998). Unlike sweep netting, vacuum sampling is difficult to operate because it uses a vacuum sampler (Stewart & Wright, 1995), less effective in collecting large arthropods like grasshoppers but effective in collecting arthropods near the ground and low vegetation (Mommertz, Schauer, Kosters, Lang & Filser, 1996). Pitfall traps, compared to other techniques (e.g. sticky traps) are cost-effective and widely used to collect surface-dwelling arthropods and sometimes even the standard method for selected species assemblages (Rainio & Niemelä, 2003; Sabu & Shiju, 2010). Sticky traps are generally considered passive sampling method, but their colours specially attract certain arthropod taxa and are height dependent (Gillespiel & Vernonz, 1990).

However, no single sampling technique have been said to collect all arthropod taxa but deciding which technique to use under certain circumstances may be difficult (Norment, 1987; Wikars, Sahlin & Ranius, 2005). Morrison, Brennan & Block (1989) opined that Ornithologists seeking to investigate avian feeding ecology must clearly identify their goals in sampling arthropods, and then adequately justify the methods used to achieve the set goals. Other researchers have suggested a combination of two or more sampling methods for this purpose (e.gs. Norment, 1987; Morrison et al.). Some Ornithologists have tried to establish an effective sampling technique to quantify arthropod prey availability for some specific some specific avian species (Southwood, 1980; Poulin & Lefebvre, 1997) but little is known for the sampling techniques ideal to describe arthropods as prey for birds in a community like the AFR.

CHAPTER THREE

MATERIALS AND METHODS

Study Area

The Amurum Forest Reserve (Figure 2) is located about 15 kilometers east of Jos, Plateau state (09° 53ˡN, 08° 59ˡE). The reserve covers a landscape of about 115 hectares (Opoku, 2016) and is one of Nigeria's Important Bird Areas with at least 300 bird species (Daru, Yessoufou, Nuttman & Abalaka, 2015). The reserve is a typical savanna woodland dominated by grasses, with scattered inselbergs outcrop, and strips of riparian forest along streams (Vickery & Jones, 2002). In the grassland savanna, common trees and shrubs include *Dichrostachys cinerea*, *Jasminum dichotomum*, *Combretum fragrans* and *Piliostigma thoningii*. The rocky outcrops are characterised by *Parkia biglobosa*, *Acacia ataxacantha* and several *Ficus* species, whereas the most frequent woody plant species in the forest patches are *Boscia angustifolia*, *Harungana madagascariensis*, *Syzygium guineense* and *Ochna schweinfurthiana* (Gofwen, 2009). Temperatures in the region are 8–15°C during the coldest months (November–February) and rise to 30–38°C during the warm and dry months (March–April). Mean annual rainfall is 1,411 mm, falling mainly between April and October (Payne, 1998). The forest reserve is surrounded by farmlands and has been under protection with little human disturbance for over 10 years (Abalaka, Hudin, Ottosson, Bloomer & Hansson, 2014), however, the reserve experienced a massive fire outbreak the year 2017 which affected about two-thirds of the landscape.

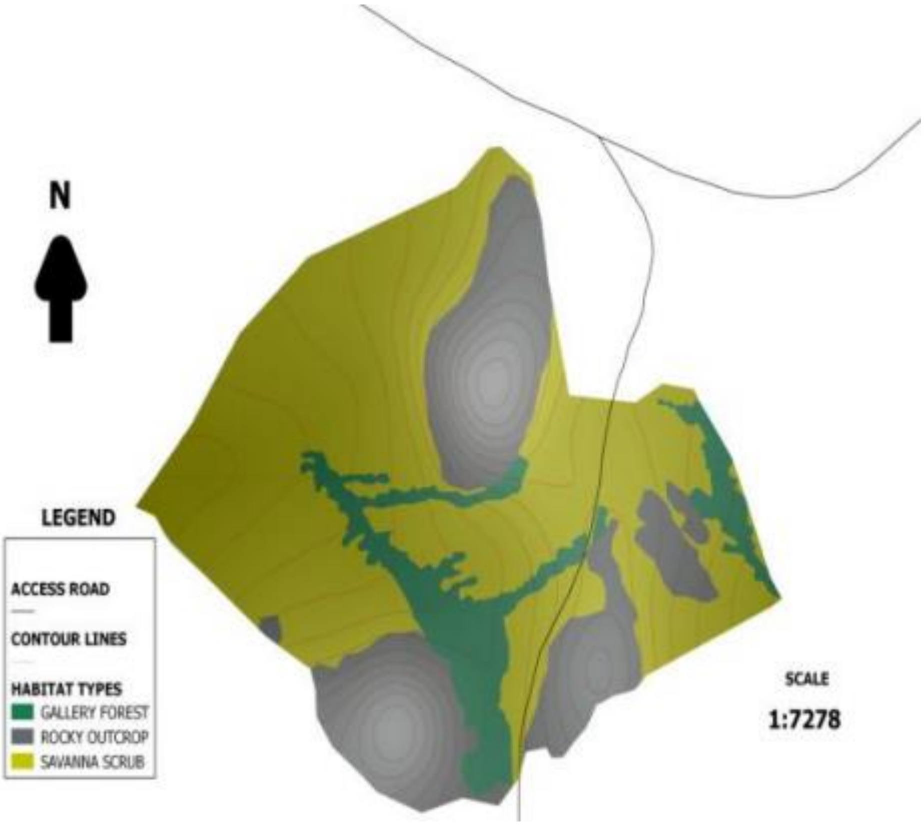

Figure 2: Map of the Amurum Forest Reserve showing the three habitats and distribution

Selection of Sampling Methods

Four sampling methods (sweep netting, pitfall traps, sticky traps and beating sheet) were used for this project. This was because, some birds are primarily surface gleaners, taking arthropods directly from the ground, vegetation substrates such as leaves or branches and some are aerial feeders, therefore, the need to explore multiple arthropods sampling methods. These four methods were selected because of their availability of sampling materials, efficiency and cost (Zou et al., 2012).

Again, the fact that our study site is a protected area, it was advisable to use less destructive methods in order to avoid detrimental effects on the natural community populations (Zaller et al., 2015). Therefore, all four selected sampling techniques are “passive” methods. In that they do not require any attractant sample specimens (Zou et al., 2012).

With pitfall traps, plastic cups (diameter 8cm, depth 15cm) with smooth inner surface were buried in the ground with its rim at the surface. In some instances, liquids such as soapy water or distilled water are usually added in pitfall traps to kill trapped samples (Zou et al., 2012) but in this project, pitfall traps were not filled with preservative liquid in order not to attract birds.

A 1m x 1m white sheet with four ropes joined to the edges were used for beating sheet sampling while sweep net collection were conducted using an 80 cm diameter, 1m long collapsible insect net.

Experimental Design

The three vegetation types in the reserve occupy an unequal area of space. To ensure an unbiased comparison of arthropods sampling techniques between the habitats, nine (9) plots (3 in each habitat) were generated randomly using the Quantum GIS desktop version 2.10.1 (Figure 3). In each plot, four 200 m transects which are 10 m apart were laid parallel to each other. Each of the four transects contained one sampling technique (i.e. sticky traps, pitfall traps, sweeping netting and beating sheet) in a plot. Each of the 200 m transect was split into 20, 10 m apart, for a total of 20 per transect and 80 per plot (Figure 4). The side-by-side placement of the four sampling techniques ensured heterogeneity within habitats did not confound a comparison between these methods.

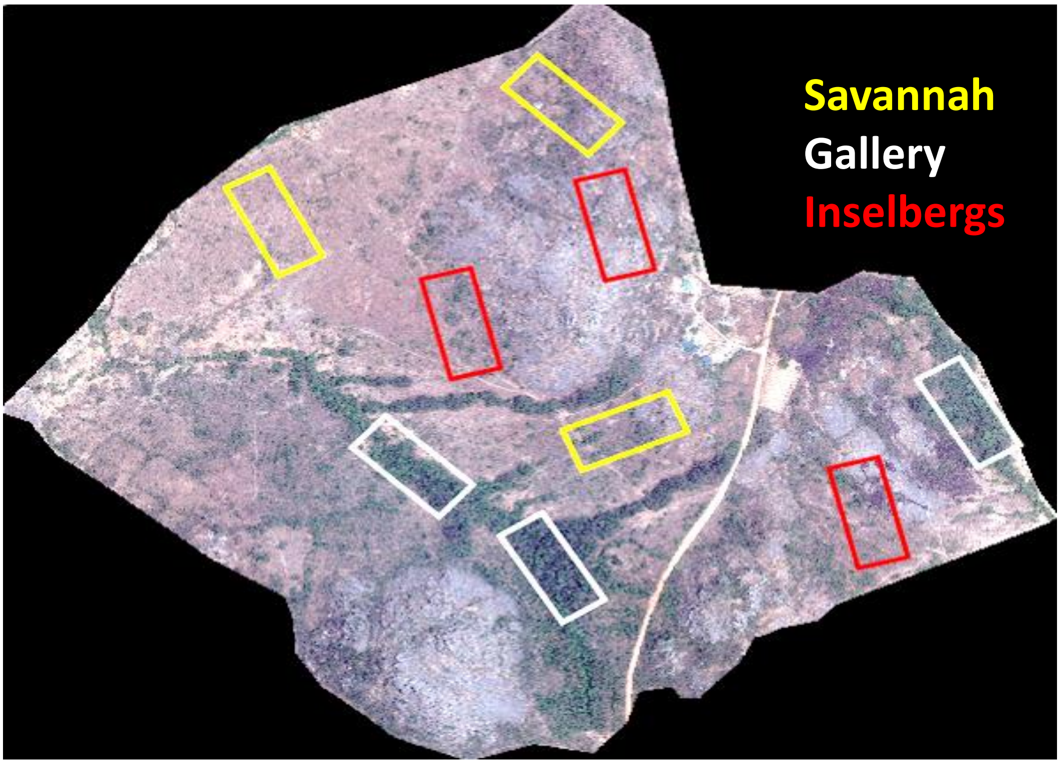

Figure 3: Map of the study area showing the distribution of study plots

Pits were created on the edges of the inselbergs. For this reason, an additional transect was created on the inselbergs where sticky traps were laid on the floor to ascertain if there will be significant difference in arthropods captured by pitfall traps on the boundaries of the rocks and the sticky traps placed on the rocks.

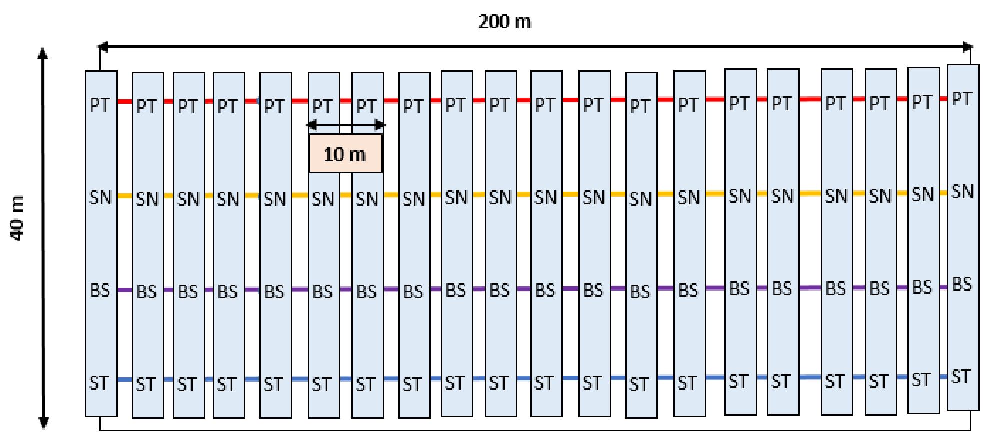

Figure 4: Diagram of a complete experimental design on a plot.

Arthropods Collection and Identification

The research was carried out from 16th February, 2017 to 2nd June, 2017. It was preceded by a one week reconnaissance survey to test sampling materials and their effectiveness. Monitoring was conducted on weekly basis with a set of plots (three plots, one per habitat). This made it possible to sample all nine plots, thus 720 sampling points within a period of one month. Set up of sampling techniques (pitfall and sticky traps) were placed in the field for 24 hours and retrieved thereafter. Sweep netting and beating sheet sampling had 10 sweeps/beats at a sampling point for three times (morning 08-11 hours, afternoon 13-15 hours and evening 16-18 hours) on a sampling day.

Collected arthropod samples from pitfalls, sweep netting and beating sheets were killed using soapy water as killing agent and later transferred into sample bottles while specimens trapped on the sticky traps were identified and recorded on the traps due to the difficulty in removing them from the thick glue. Non scaly specimen were preserved in 70% ethanol while scaly arthropods like butterflies and moths, were kept in envelopes. All specimens were identified to the order and family levels. Specimens were identified using identification guides by Dippernaar-Schoeman et al. (2010); Biondi & D'Alessandro (2012). The length of the collected arthropods were measured by selecting ten specimens from individual group components in the order levels and were separated into small (≤ 0.5 cm), medium (> 0.5 ≤ 2.5 cm) and large (> 3cm) body-length categories (Figure 5).

Time Methods

The time taken to set up and record data for sampling techniques was recorded. For the sweep netting and beating sheets, the period started starts at the beginning of sweeps/beats and ended when specimens are retrieved from sweep nets/beating sheets. With pitfall and sticky traps, the times taken to set up traps as well as the time taken to retrieve traps were recorded as the time taken on a sampling day. The time taken to collect arthropods with each of the methods was to determine the amount of effort required for each of the four sampling methods.

Removal of Ineffective Sampling Techniques Data

Data from the beating sheet sampling technique were not enough for comparison with other methods so it was not included in the analysis. Further, sticky traps that were placed on the inselbergs to sample ground dwelling arthropods for comparison with pitfall traps of designated habitat did not work effectively so it was expunged from the data.

With respect to the beating sheet, it may be as a result of the stratified random sampling experimental design employed in this study. Beating sheet sampling usually requires beating of plants and/or vegetation to collect arthropods. However in this study, most of the sampling points on the inselbergs and savanna habitats did not have enough vegetation needed to apply the beating method. This situation became worse when a fire outbreak occurred in the reserve in the first week of March, wiping the few shrubs and trees on study plots, therefore, making the beating sheet method ineffective. The beating sheet method may have worked using systematic sampling instead of the stratified random experimental design used in this study.

To thoroughly explore crawling arthropods on the inselbergs, sticky traps were placed horizontal on the floor of the rocks in addition to the pitfall traps laid on the boundaries but the latter failed to yield results. Termites consumed almost all the paper outer cover of sticky traps and the glued surface dried up within some few hours making it inactive to trap ground arthropods. Therefore, horizontal placement of sticky traps increases the exposure of the glue surface to air or sun making it dry faster as compared to vertical placements. But generally, the inselbergs recorded the least arthropods compared to the other two habitat types.

Statistical Analyses

All data were entered into Microsoft office Excel 2013 and analyses were done in R statistical software, version 3.3.1 (R Development Core Team, 2016). Normality test for all response variables in the data was conducted to check if they were normally distributed using frequency distribution histogram and model residuals (Appendix A).

The trend in arthropods captured per sampling day, all dates were converted to Julian date. The data for abundance was not normally distributed so they were log transformed. Log of abundance of arthropods was modelled as a function of Julian date (log abundance ~ Julian date). Scatter smooth curve was plotted to show the trend of arthropods abundance against Julian date.

The effectiveness and best sampling design, first of all, the arthropods species richness for each sampling technique was compared using smooth accumulation curves. This was done with the vegan package. Species richness was calculated as the number of unique species recorded for a sampling design per unit sampling effort. Data for all the sampling designs were pooled and separated on habitat basis to compare the differences in species accumulation within the various habitats. Furthermore, Kolmogorov-Smirnov two sample cumulative frequency test was used to compare the calculated frequencies of species from the different sampling techniques to identify how species accumulation functions depend on habitat and sampling techniques.

The diversity of arthropods captured by sampling techniques was calculated per sampling unit using Shannon-Wiener diversity index, below.

H´ = -pi *ln* pi

Where pi = ni/N,

ni = number of individuals of a species,

N = total number of individuals of all secies recorded for a technique per habitat,

ln = natural logarithm (to base) and

H´ = diversity index.

All diversity calculations were done with the vegan package in R. Differences in diversity and abundance of arthropods between the three sampling techniques was analysed using General Linear Models (GLMs). The raw abundance data did not follow the normal distribution pattern and was thus log transformed to improve model fits. Diversity and the log transformed abundance were modeled separately as a function of sampling methods and habitats with an interaction between methods and habitats (Diversity/log abundance ~ method + habitat + method*habitat). The means in body-length of arthropods were determined and compared between sampling techniques.

To evaluate the intra-seasonal differences of diversity and abundance of arthropods between sampling techniques and habitats to give a fair idea of specific technique for a specific season in a habitat, data for wet and dry seasons was analysed using GLMs. Diversity/log abundance ~ habitat +

sampling design + season +habitat*sampling design*season, data =season. This model considered all possible interactions with wet/dry season to determine how any differences in diversity or abundance between habitats or sampling design depend on season.

The effort (time) required in completing sampling per plot for each sampling technique was compared using GLMs. A model comparing the average time taken per transect as a function of method and habitats with interaction was used (Time ~ method + habitat + method*habitat).

To ascertain the correlation between dependent and independent variables or to compare the strength of the effect of each individual independent variable to the dependent variable, the "lm.beta" package in R was used to generate the beta coefficient values in all models.

Finally, to establish the minimum sampling frequency to elucidate significant differences between habitats and seasons was determined using power analysis. For each of the techniques, power analyses were carried out using the R package, simr (Green & MacLeod, 2015). First, a mixed effect model with diversity as a function of the total number of sampling points used in this survey with methods and habitats as random effects was used [glmer (diversity ~ total points (1|methods) + (1|habitats)] to accurately predict ≥80% arthropods diversity in the AFR. This model was then simulated 1000 times using the power command in simr and the powerCurve function was used to graphically explore the trade-offs between sampling size and power.

With the number of points needed for each method, a mixed effect model with diversity as a function of number of points and habitat as a random effect was modelled for each sampling technique [glmer(diversity ~ points +

(1|habiat)]. The ‘along’ argument in simr package was used to extend data for both sticky traps and pitfall traps models to 250 and 1,000 points respectively because the 180 sampling points used for the techniques were not enough.

A

B

Figure 5: Measurement of some arthropod specimens in the categories of large (A) and medium (B)

CHAPTER FOUR

RESULTS

General Overview

A total of 19,842 individual arthropods belonging to 72 families, 25 orders and one class were sampled in this project. The orders with the largest numbers of individuals were Hymenoptera (8,296), Diptera (5,390), Hemiptera (2,590), Coleoptera (1,401) and Araneae (529). Together, these orders represented 91.9% of all the specimens collected (Table 1). In terms of family, Formicidae dominated with 39.1% of the total samples. Cicadellidae followed with 12.7% and the least, Daesiidae, with 0.01% (Appendix B). In the three habitat types, majority (37.2%) of the arthropods in the AFR were in the savanna, 34.5% and 28.3% in the gallery and inselbergs respectively.

The number of arthropods captured throughout the study period per sampling day showed no significant difference (GLM: $F_{1, 16}$ =0.894, P =0.35). From figure 6, it can be seen that there was increase from day one (7th March, 2017) to the end (2nd June, 2017) with the peak recorded on day 36 (12th April, 2017) which coincides with the start of the rainy season.

Table 1- *Checklist of arthropod class, orders and families captured by sampling technique. PT, SN and ST stand for pitfall trap, sweep net and sticky trap respectively*

ORDER (%)	FAMILY	PT	SN	ST	ORDER (%)	FAMILY	PT	SN	ST
Araneae (2.7)	Amaurobiidae	✓	✓		**Hemiptera** (13.1)	Aphididae	✓		
	Araneidae	✓	✓	✓		Cicadellidae	✓		
	Clubionidae	✓	✓	✓		Coreidae	✓	✓	✓
	Linyphiidae	✓	✓	✓		Membracidae			
	Lycosidae	✓				Pentatomidae	✓	✓	✓
	Philodromidae	✓	✓	✓		Trombiculidae		✓	✓
Blattodea (0.3)	Blattidae	✓		✓	**Hymenoptera**(41.8)	Apidae	✓	✓	
Chilopoda (0.1)	Lithobiidae	✓		✓		Braconidae		✓	✓
	Scolopendridae	✓				Formicidae	✓		✓
Coleoptera (7.1)	Carabidae	✓	✓	✓		Halictidae		✓	✓
	Cerambycidae		✓			Ichneomonidae	✓	✓	
	Chrysomelidae	✓	✓	✓	**Isopoda** (0.1)	Armadillidiidae	✓	✓	✓
	Coccinellidae	✓	✓	✓	**Isoptera** (1)	Termitidae	✓		✓
	Curculionidae	✓	✓	✓	**Ixodidae** (0.02)	Ixodidae	✓		✓
	Elateridae		✓	✓	**Lepidoptera** (1.3)	Crambidae			✓
	Lampyridae		✓			Eribidae		✓	✓
	Lucanidae	✓	✓	✓		Eupterotidae		✓	✓
	Pseudococcidae			✓		Nymphalidae	✓		✓
	Pyrochroidae	✓	✓			Pieridae		✓	✓
Dermaptera (.3)	Forficulidae	✓	✓	✓	**Mantodea** (0.1)	Mantidae	✓		✓
Diplopoda (0.1)	Julidae	✓						✓	

Table 1 continued

ORDER (%)	FAMILY	PT	SN	ST	ORDER (%)	FAMILY	PT	SN	ST
Diptera (27.2)	Aleyrodidae		✓	✓	**Neuroptera** (0.03)	Chrysopidae	✓	✓	✓
	Anisopodidae		✓		**Odonata** (0.2)	Corsuliidae		✓	
	Asilidae		✓	✓	**Orthoptera** (0.7)	Acrididae		✓	✓
	Calliphoridae		✓	✓		Gryllidae	✓	✓	✓
	Culicidae		✓	✓	**Phasmatodea** (0.2)	Phylliidae	✓	✓	
	Dolichopodidae			✓	**Pscoptera** (0.01)	Lepidopsocidae		✓	✓
	Empididae		✓	✓	**Solifugae** (0.01)	Daesiidae	✓		
	Muscidae	✓	✓	✓	**Thysanoptera** (1.8)	Thripidae	✓	✓	✓
	Psychodidae	✓	✓	✓	**Trichoptera** (1.3)	Hydropsychidae		✓	✓
	Rhagionidae			✓		Hydroptilidae	✓	✓	✓
	Sarcophagidae		✓		**Trombidiforme**(.4)	Tromibidiidae	✓		✓
	Simuliidae		✓		**Zygentoma** (0.2)	Lepismatidae	✓	✓	✓
	Stratiomyidae	✓	✓	✓	**Zygoptera** (0.1)	Lestidae		✓	
	Syrphidae		✓	✓					
	Tenthredinidae		✓	✓					
	Tephritidae		✓	✓					
	Tipulidae		✓	✓					

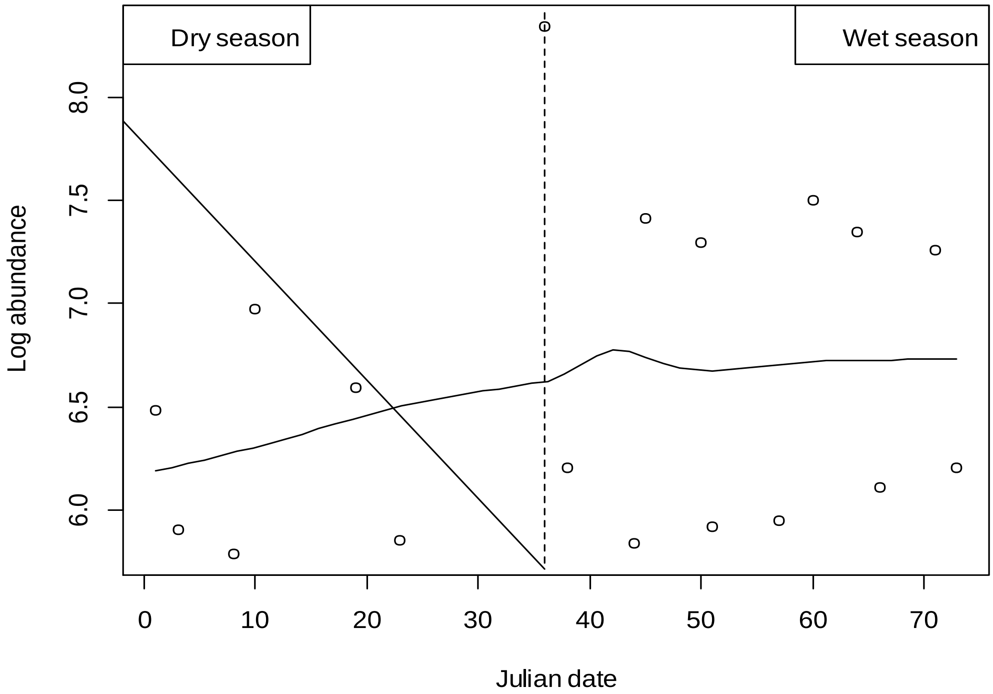

Figure 6: Trends in arthropod abundance with respect to sampling days (Julian date) in the AFR

Sampling Techniques that Produces the Highest Diversity and Abundance

The arthropod accumulation curve expressed in terms of families shows the number and rate at which unique arthropods families were recorded by sampling techniques (Figure 7). Sweep netting recorded a much higher community taxon (52), marginally followed by sticky traps (51) and the least recorded by pitfall traps (40). Accumulation of arthropod families between all sampling techniques almost reached an asymptote; however, majority of arthropod families were recorded within the first four sampling sections. The number and rate at which the three techniques accumulated arthropod families were significantly different for pitfall traps compared to the other two techniques (sticky traps and sweep netting) which accumulated arthropods families at similar rates (Table 2).

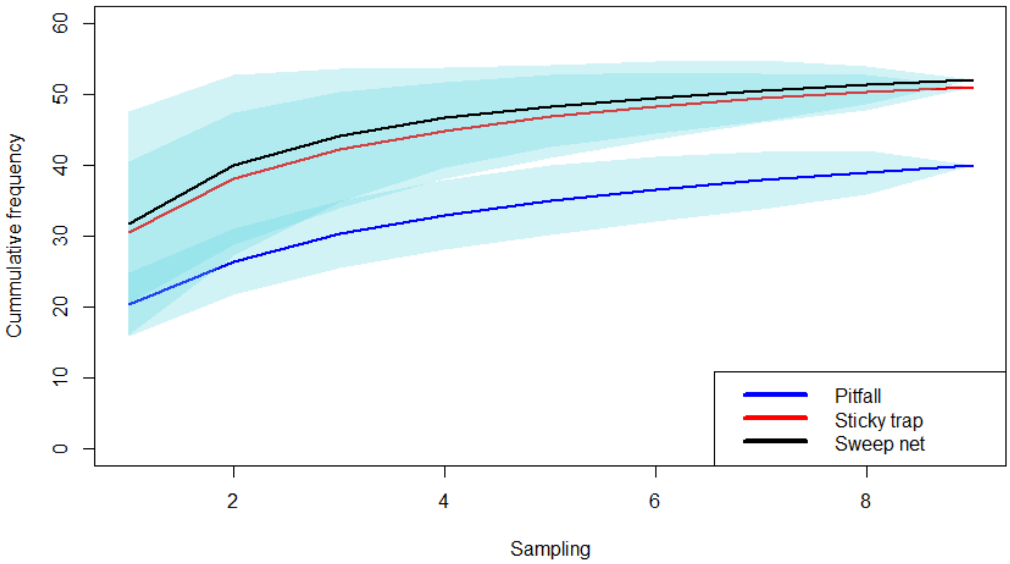

Figure 7: Smoothed arthropods family accumulation curves of three sampling techniques

Figure 8 shows the families accumulation curve of the methods in the three habitat types. Sticky traps accumulated larger number of arthropods in the gallery forest and inselbergs. Sweep netting accumulated more families in the savanna. The rate at which the sampling methods accumulated families in the habitats were found to be significant for all except between pitfall traps and sticky traps that was not significant in the savanna (Table 3).

Table 2- *Two sampled Kolmogorov-Smirnov test results for family accumulation curves between three sampling methods*

Methods	D	P-value
Pitfall vs. Sticky trap	0.67	**0.003**
Pitfall vs. Sweep net	0.67	**0.003**
Sweep net vs. Sticky	0.11	1.0

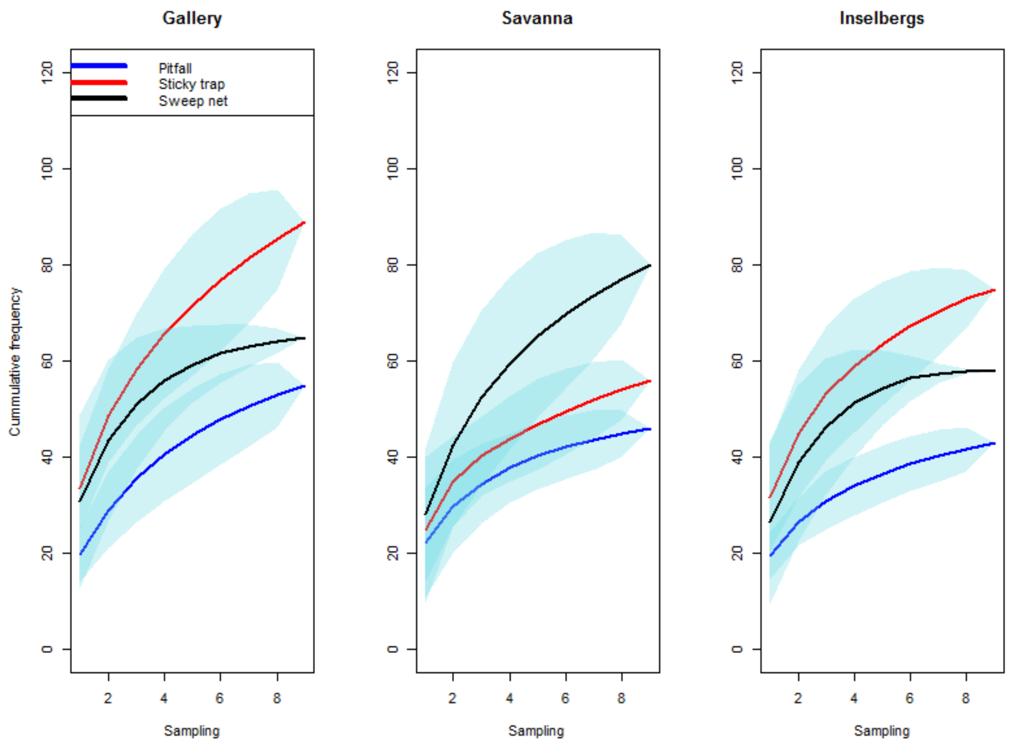

Figure 8: Smoothed families accumulation curves of three arthropods sampling methods in three habitat types

Table 3- *Two sampled Kolmogorov-Smirnov test results for family accumulation curves between sampling methods and habitat types*

Methods	Gallery forest		Savanna		Inselbergs	
	D	P-value	D	P-value	D	P-value
Pitfall vs. Sticky trap	0.78	**0.006**	0.56	0.126	0.89	**<0.001**
Sticky trap vs. Sweep net	0.67	**0.034**	0.67	**0.034**	0.67	**0.034**
Sweep net vs. Pitfall	0.67	**0.034**	0.78	**0.006**	0.78	**0.006**

Figure 9 shows the differences in diversity of arthropods recorded by the sampling methods (GLM: $F_{2:57} = 82.88$, $P < 0.0001$). The highest diversity of arthropods was recorded by sweep netting and the least by pitfall traps but Tukey's post-hoc test analysis indicated that differences in diversity were significant among all methods three methods: sticky traps vs. sweep netting (*P*

= 0.002), pitfall vs. sticky traps (*P* <0.001) and pitfall vs. sweep netting (*P* <0.001) (Figure 10).

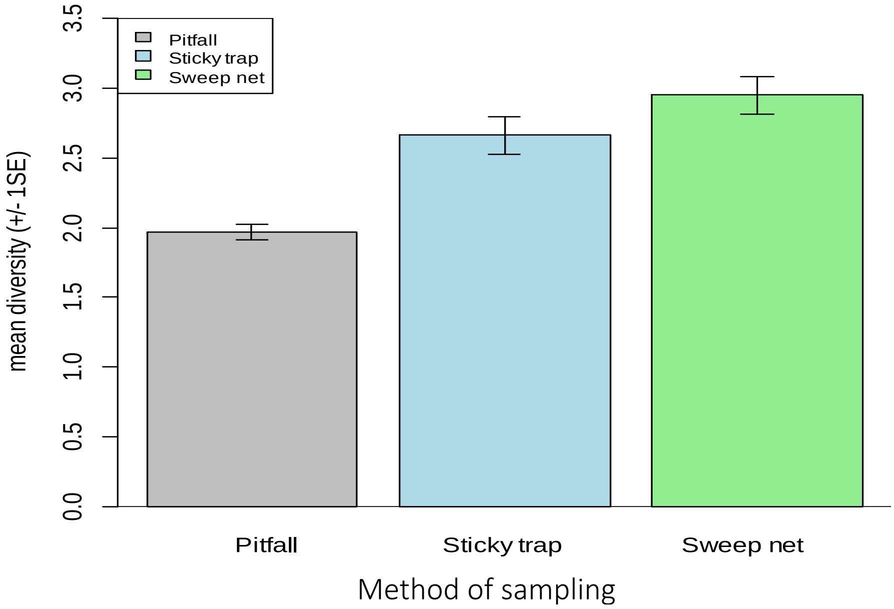

Figure 9: Mean arthropods diversity between three sampling techniques

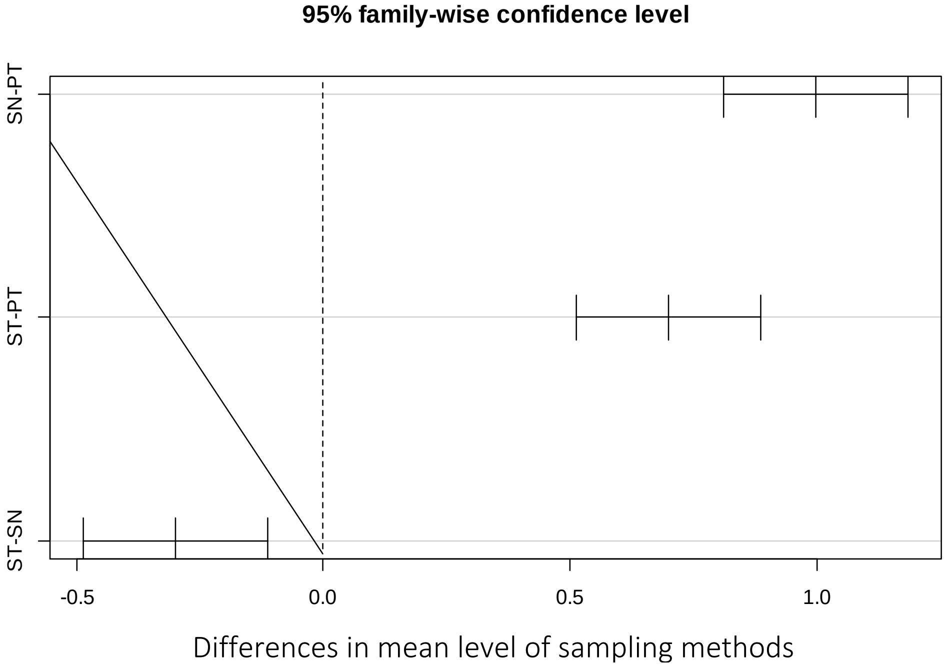

Figure 10: Pairwise post-hoc test showing the differences in mean diversity between methods

Regarding abundance, there was significant differences between the methods (GLM: $F_{2,\ 78}$ =14.47, P <0.001). Sticky trap recorded the highest arthropods abundance followed by sweep netting then pitfall traps (Figure 11). However, the Tukey's post-hoc test showed no significant difference between sweep netting and pitfall traps (P = 0.062) but significant differences between sticky trap vs. pitfall traps (P = 0.002) and sticky trap vs. sweep net (P < 0.001) (Figure 12).

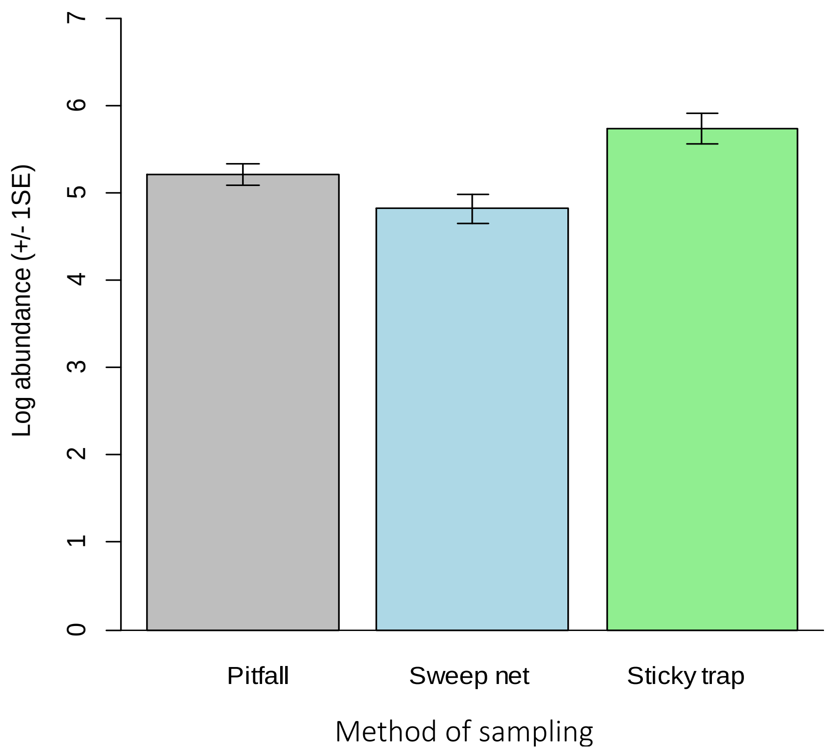

Figure 11: Log abundance of arthropods recorded by sampling techniques

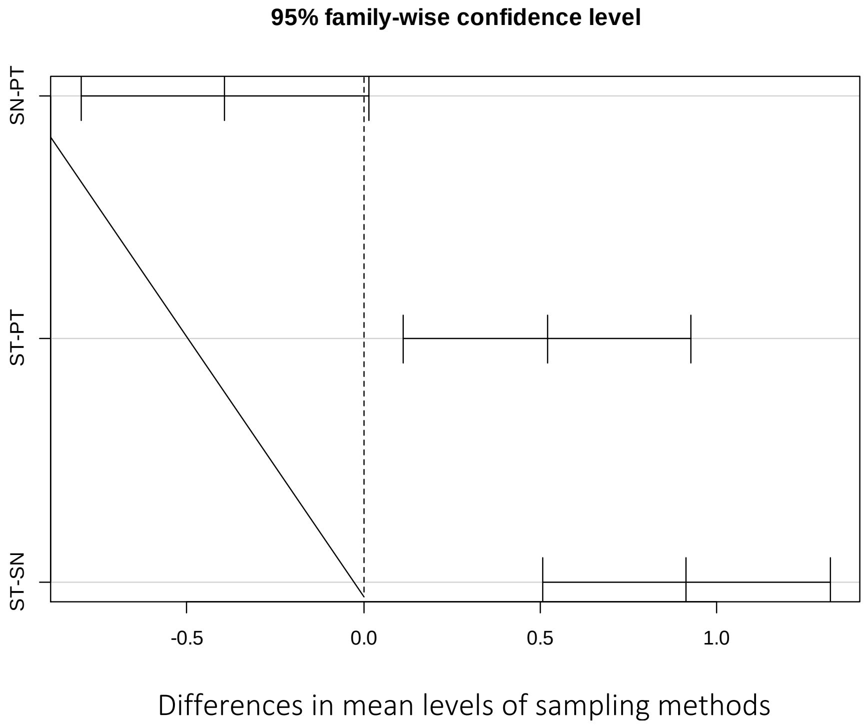

Figure 12: Pairwise post-hoc test showing the differences in arthropods mean abundance between methods

Arthropod Body Length and Sampling Methods

Overall, there was a significant difference in size (in terms of length) of arthropods trapped by the different sampling techniques (GLM: $F_{4, 5349}$=16.52, P < 0.001). Sweep netting recorded the largest arthropods (0.823 ± 0.043 cm) followed by pitfall traps (0.789 ± 0.02 cm) and the least by sticky traps (0.688 ± 0.041 cm).Tukey's HSD test showed no significant difference between body size of arthropods trapped by sweep netting and pitfall traps (P = 0.4203) but between sticky traps vs. pitfall traps (P < 0.001) and sticky traps vs. sweep netting (P < 0.001). Larger arthropods with mean length >4.5 cm were in the classes Diplopoda and Chilopoda, family Odonata and order Solifugae. Smaller arthropods (≤ 0.5 cm) were in the orders Isopoda, Isoptera, Ixodidae, Pscoptera, Trichoptera and Trombidiforme (Table 4).

Table 4- *Mean body length of arthropods orders and sampling techniques. PT, SN and ST represent Pitfall trap, Sticky net and Sticky trap respectively*

Order	Method	Mean length	Sample size
Araneae	PT, SN, ST	0.9	529
Blattodea	PT,ST	2	64
Chilopoda	PT,ST	4.7	24
Coleoptera	PT,SN,ST	0.76	1,404
Dermaptera	PT	1	50
Diplopoda	PT	5	15
Diptera	PT,SN,ST	0.64	5,390
Hemiptera	PT,SN,ST	0.55	2,590
Hymenoptera	PT,SN,ST	0.66	8,296
Isopoda	PT,ST	0.5	20
Isoptera	PT,ST	0.5	208
Ixodida	PT,ST	0.5	3
Lepidoptera	PT,SN,ST	1.68	266
Mantodea	PT,SN	3	15
Neuroptera	PT,SN,ST	0.5	5
Odonata	SN	4.88	42
Orthoptera	PT,SN,ST	2.02	139
Phasmatodea	PT,SN	2.92	37
Pscoptera	SN,ST	0.5	2
Solifugae	PT	5	1
Thysanoptera	PT,SN,ST	0.51	353
Trichoptera	PT,SN,ST	0.5	251
Trombidiforme	PT,ST	0.5	80
Zygentoma	PT,SN,ST	1.17	43
*Zygoptera	SN	1	14
Total			**19,842**

NB: Zygopterans are arthropods in suborder level

Comparing Methods between Habitats

There was significant difference between the diversity of arthropods recorded by the sampling techniques in the three habitat types (GLM: $F_{8:171}$ = 21.52, P < 0.001). Pitfall traps recorded the least diversity in all habitats. Sweep netting recorded significant higher diverse arthropods in the savanna and almost same number of arthropods with sticky traps in the gallery forest. Sticky traps recorded substantially more diverse arthropods than sweep netting on the inselbergs (Figure 13). A post-hoc test shows no significant difference between sweep netting and sticky traps in the gallery (P=0.6) but significant difference (P=0.00) in arthropods diversity between the two methods in the savanna (Figure 14). From appendix C1, the standardized coefficient values shows that sticky traps had the highest positive effect, marginally followed by sweep netting. The two sampling techniques yielded a diverse number of arthropods.

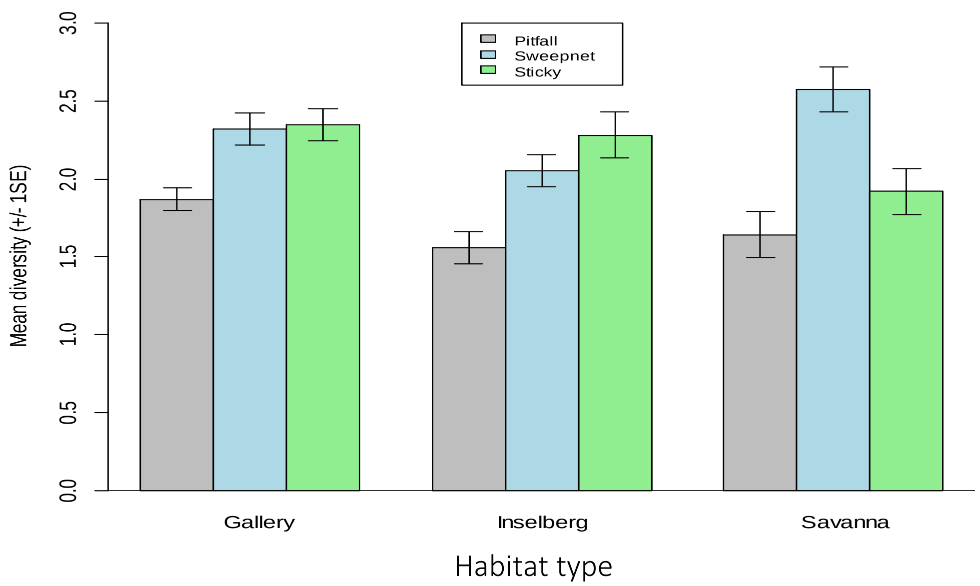

Figure 13: *Mean arthropods diversity among sampling techniques in relation to habitat types*

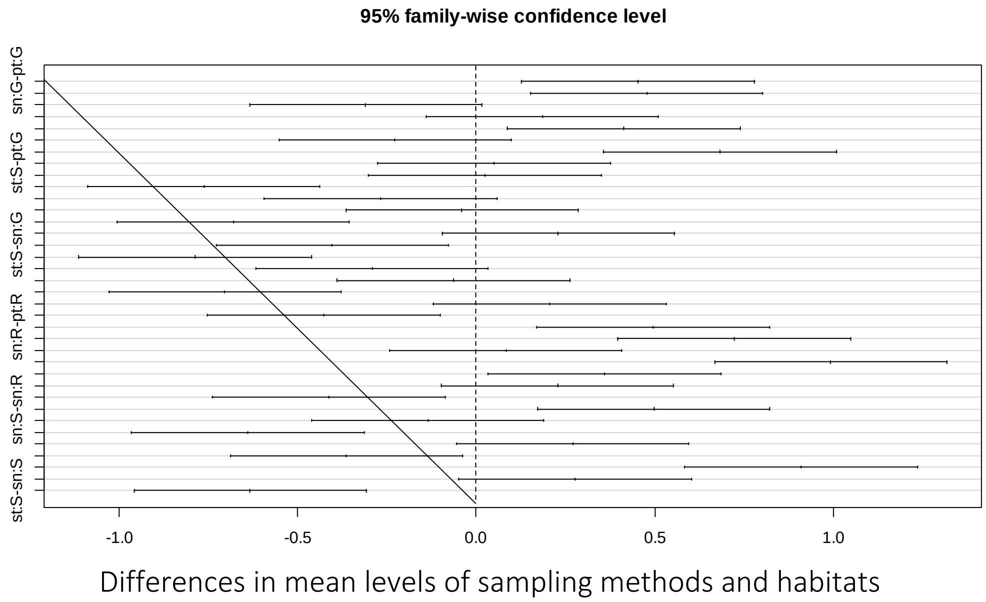

Figure 14: Pairwise post-hoc test showing the differences in mean diversity between methods and habitats

There was a significant difference in abundance of arthropods recorded by the sampling techniques in the three habitat types (GLM: $F_{8,\ 171} = 12.58$, $P < 0.0001$). Sticky traps recorded the largest of arthropods in all habitats except in the savanna. In the inselbergs, pitfall traps recorded a higher abundance of arthropods than the other methods. Sweep netting consistently recorded fewer arthropods than the sticky traps in all habitats (Figure 15). The differences between arthropods abundance recorded by sticky traps and sweep netting in all habitats was statistically significant (Figure 16). Among the sampling methods, the standardized coefficient values showed that generally, sticky traps had the strongest positive effect on the abundance of arthropods. This implies that sticky trap sampling yielded positive increase in arthropods abundance compared to the other sampling techniques. With regards to habitat types, savanna had the highest positive effect on arthropods abundance. It recoded generally the largest number and positively increased with all sampling techniques (Appendix C2).

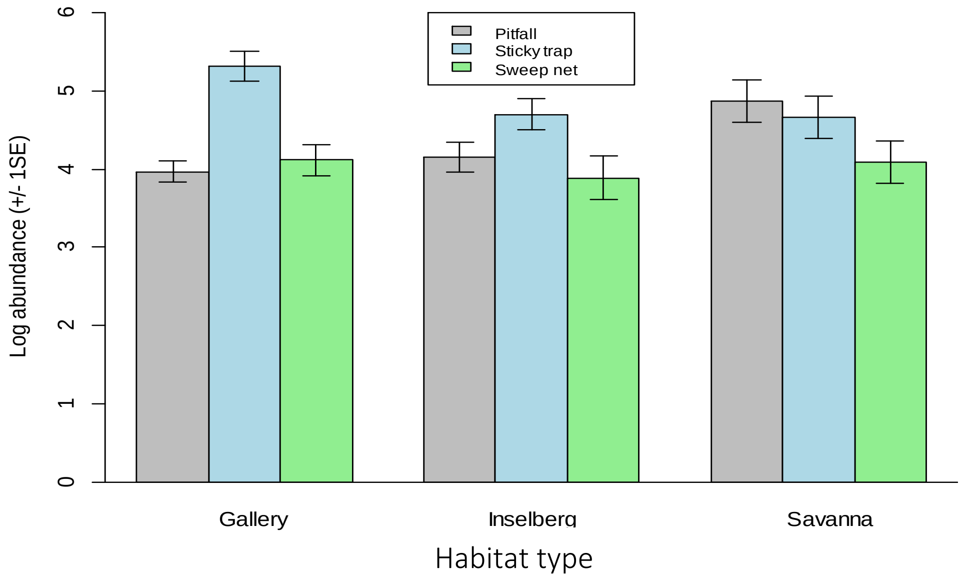

Figure 15: Mean log abundance of arthropods between sampling techniques with respect to habitat type

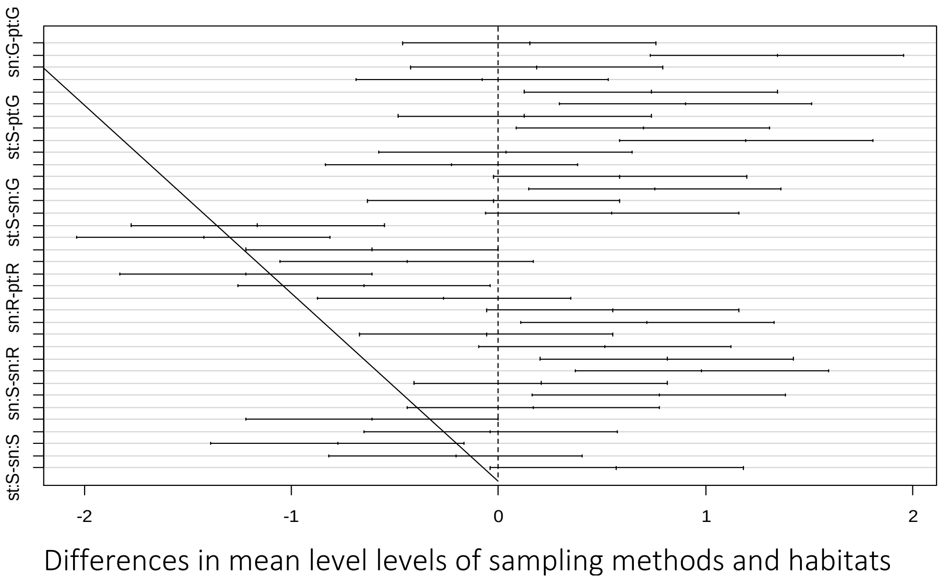

Figure 16: Pairwise post-hoc test showing the differences in mean abundance between methods and habitats

Comparing Techniques across Seasons

Generally, the pattern of arthropods diversity recorded by the sampling methods were the same for both seasons (Figure 17). Sweep netting recorded the highest arthropod diversity, followed by sticky traps then pitfall traps. This pattern was consistent between seasons (GLM: $F_{5,\ 114}$ = 37.67, P <0.001).

Tukey's post-hoc test (Figure 18) showed that interaction between seasons were significant for all methods but pitfall traps (*P* = 0.91). There was no significant difference in the diversity of arthropods recorded by sweep netting and sticky trap for both wet and dry seasons. The wet season had stronger positive effect on arthropods diversity while the sticky traps and sweep netting also had the strongest positive and negative effects respectively on arthropods diversity across seasons (Appendix C3).

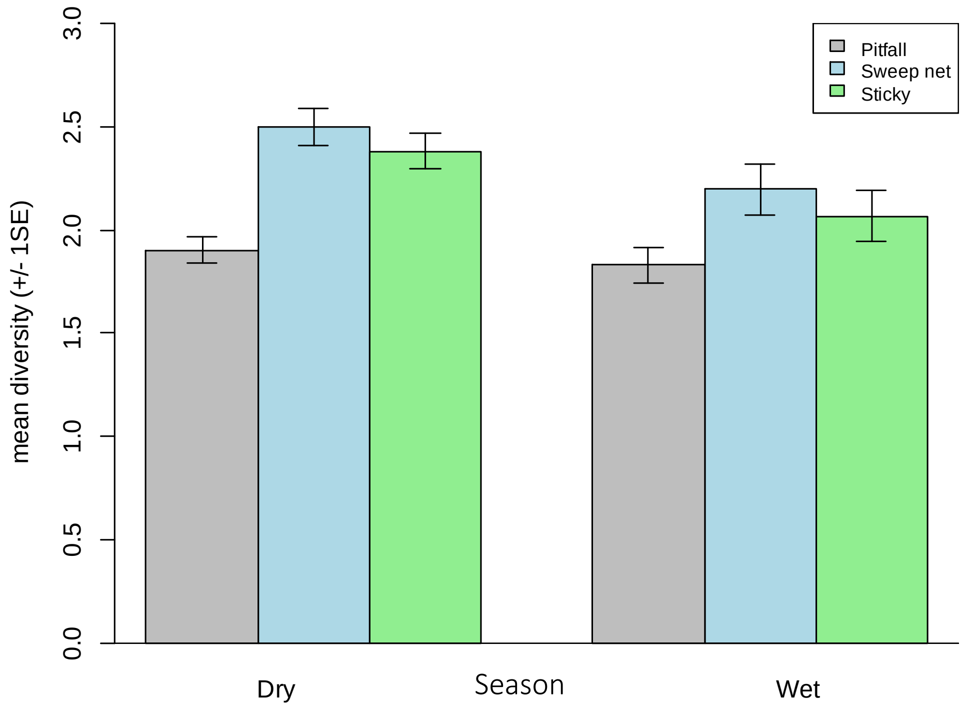

Figure 17: Mean diversity of arthropods captured by three sampling techniques in both dry and wet seasons

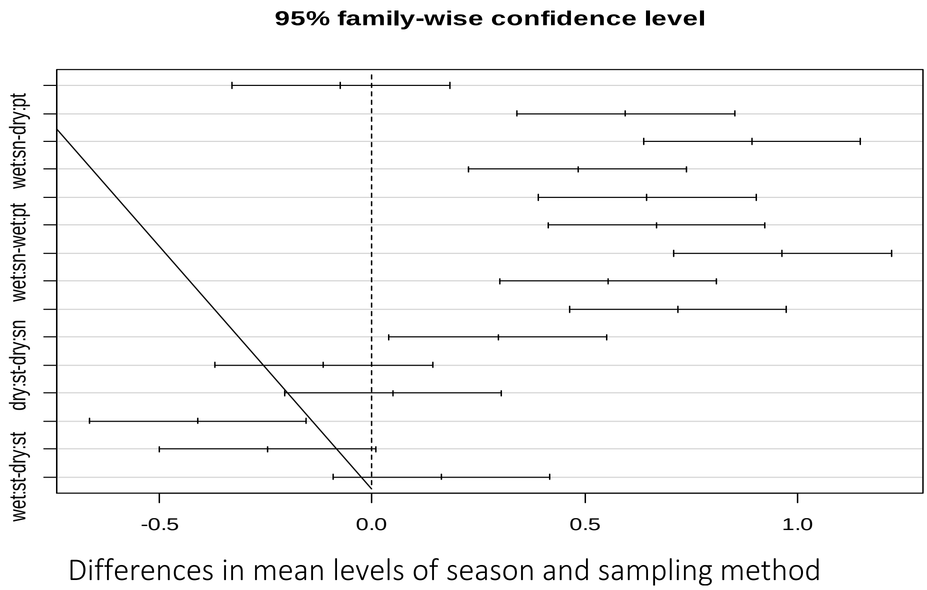

Figure 18: Pairwise post-hoc test showing the differences in mean diversity between methods in dry and wet seasons.

Among the sampling techniques in two seasons, the wet season and sticky traps had the strongest positive effects while sweep netting and its sampling in the wet season recorded the strongest negative effects on abundance of arthropods in the AFR (Appendix C4). A similar trend was seen in the abundance of arthropods recorded. Sticky traps sampling in the wet season had a stronger positive effect on arthropods abundance.

Figure 19 shows the number of arthropods captured by the three sampling methods in both dry and wet seasons. Sticky traps recorded large number of arthropods while pitfall traps recorded the least abundance (GLM: $F_{3, 116} = 83.7$, $P < 0.001$). There was significant differences between ($P < 0.01$) and within (sweep netting vs. pitfall traps, $P = 0.02$; sticky trap vs. pitfall traps, $P < 0.001$; sticky trap vs. sweep netting, $P < 0.001$) (Figure 20).

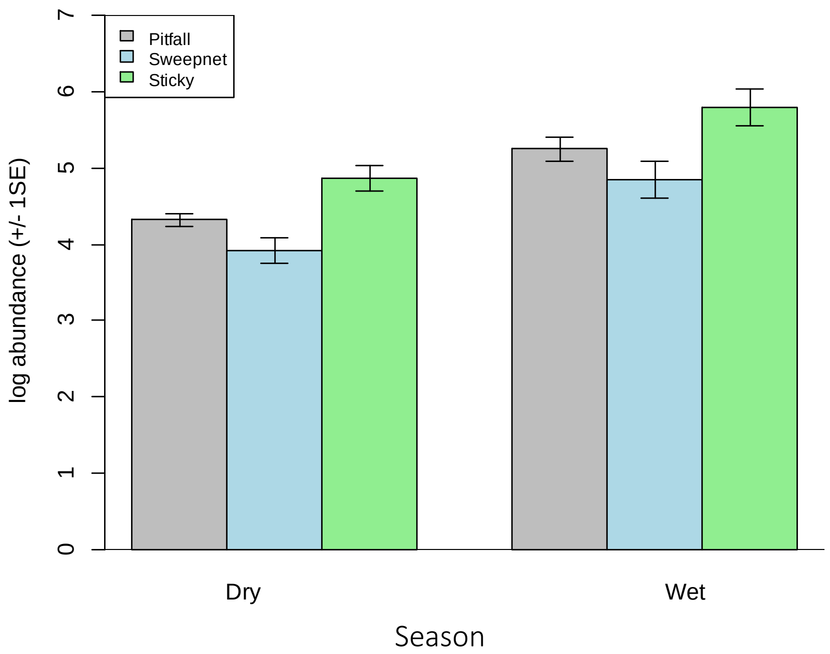

Figure 19: Mean log abundance of arthropods captured by three sampling methods in both dry and wet seasons

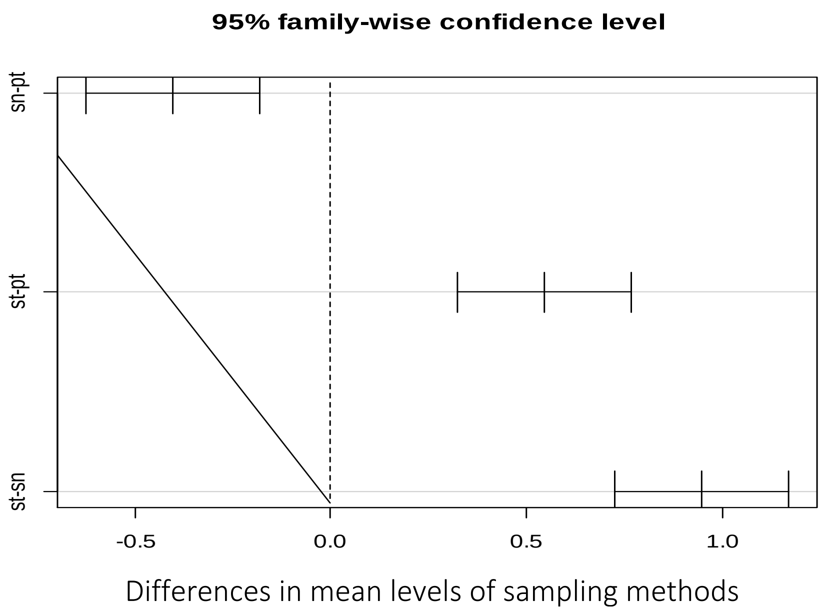

Figure 20: Pairwise post-hoc test showing the differences in abundance between methods in dry and wet seasons

Time Taken to Complete Sampling on a Transect

In terms of time taken to complete sampling per transect (Figure 21), generally, sticky traps were approximately as fast as pitfall traps (236.63 ± 108 seconds versus 342.22 ± 76 seconds respectively) while sweep netting took the longest time to complete sampling per plot (1623.22 ± 108 seconds). Between habitats, the trend in time taken to complete sampling between methods was same. Sweep netting took the longest time in each habitat while stick traps recorded the least time. With respect to time taken to sample in each habitat, the post-hoc test (Figure 22) showed that there was no significant difference in the sampling time when using pitfall and sticky traps irrespective of habitat. However, sampling time for sweep netting was significantly longer in the gallery forest compared to the sampling time for this technique in the other two habitats.

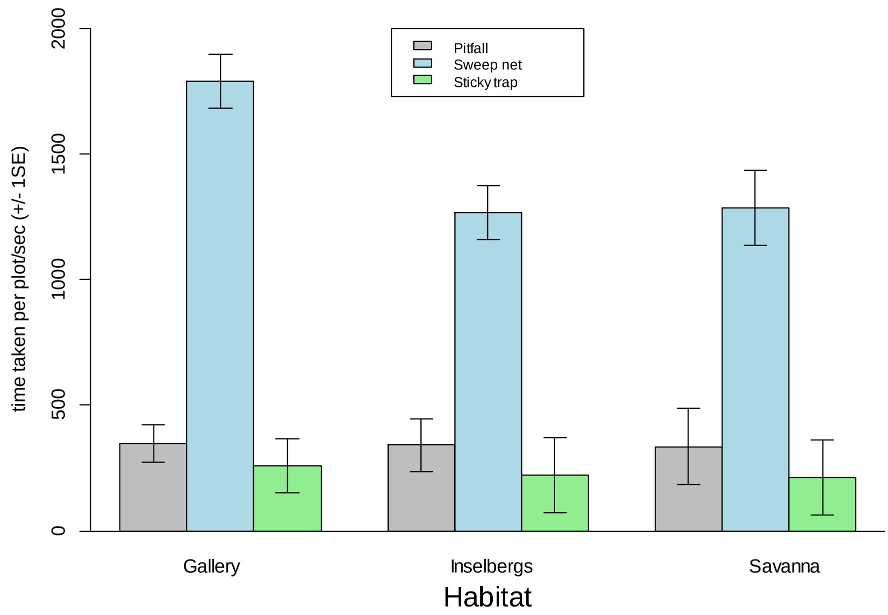

Figure 21: Mean time taken to complete sampling on transects within habitats.

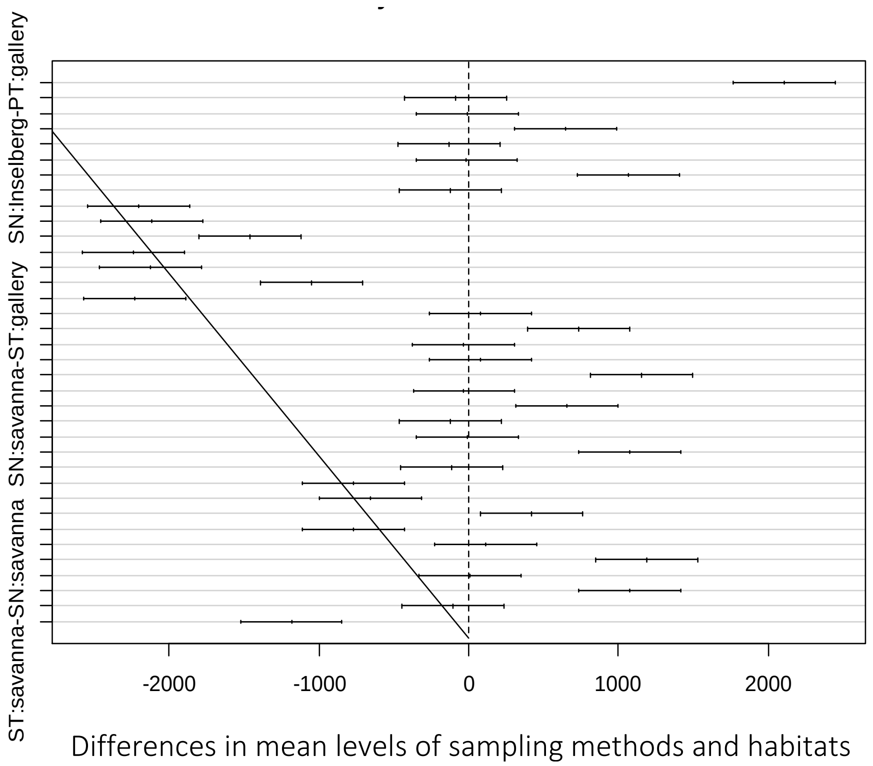

Figure 22: Pairwise post-hoc test showing the mean diversity differences between methods and habitats

Sample Size Needed for Arthropods Sampling in the AFR

For the total number of sampling points needed to accurately predict ≥80% arthropod diversity in the AFR, figure 23 shows that after 1,000 simulations, lower survey points of 450 out of the 540 used in this project are needed for future arthropods sampling in the Amurum Forest Reserve. Any arthropod survey that is conducted with 540 or more sampling points will reflect a representation of the reserve.

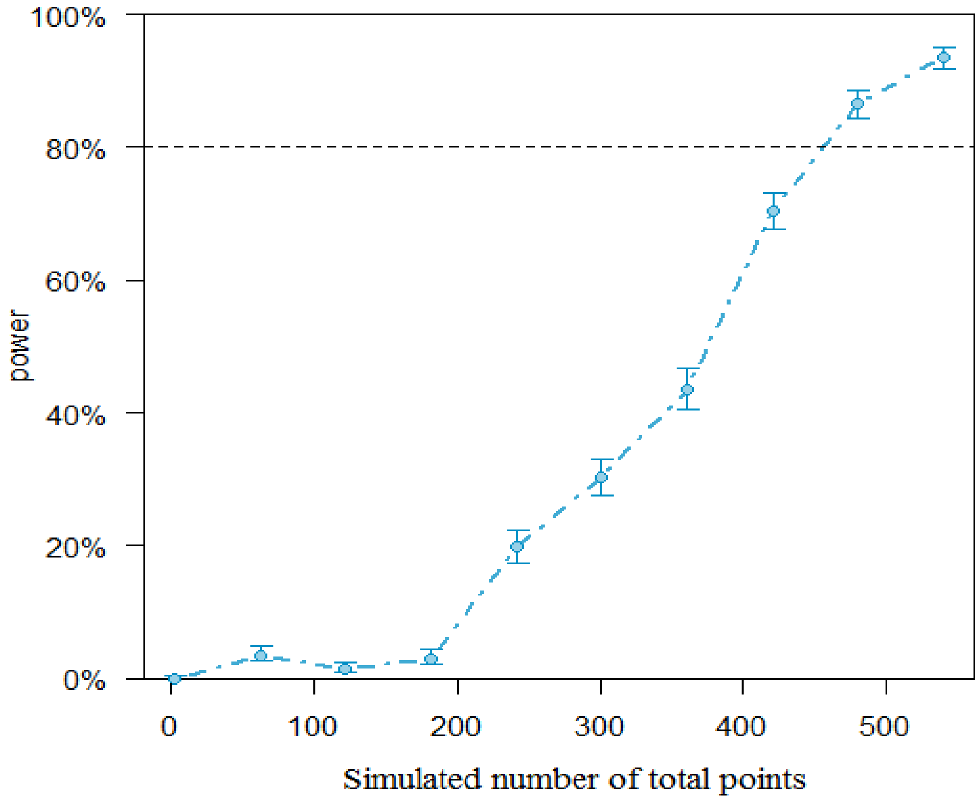

Figure 23: Power to detect the required total number of sampling points needed for arthropods sampling in the AFR

In terms of the number of sampling points needed to accurately predict ≥80% ground dwelling arthropods diversity in the AFR using pitfall traps, figure 24 shows that at least 130 sampling points (72% of the total points used in this study) would be sufficient, thus reducing the required effort by about 28%.

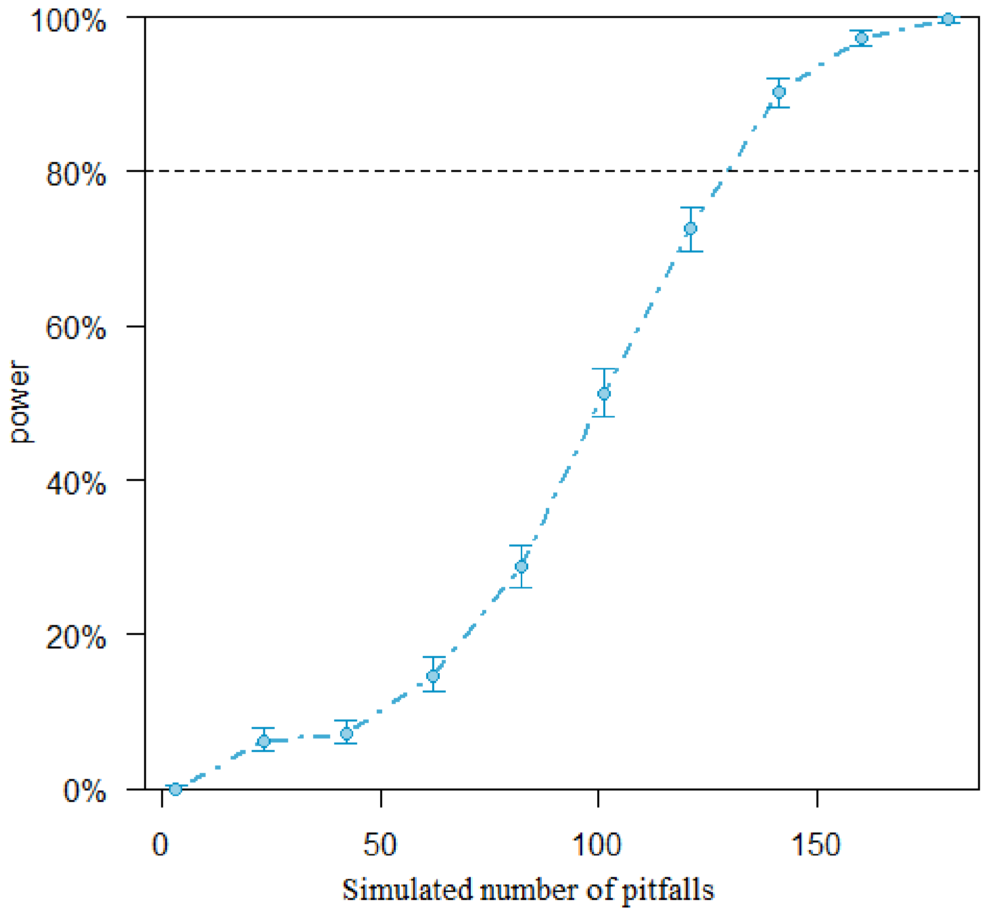

Figure 24: Power to detect the required number of sampling points needed for pitfall trap sampling in the AFR

The total number of sampling points (180) used in this survey for sticky traps was not sufficient. More effort (survey points) was typically needed to provide ≥80% power to detect the diversity of arthropods in the AFR using sticky traps as sampling method (Figure 25). However, increasing the sampling points from 180 to 250 with 1,000 simulations showed that at least 205 sampling points are needed (Figure 26).

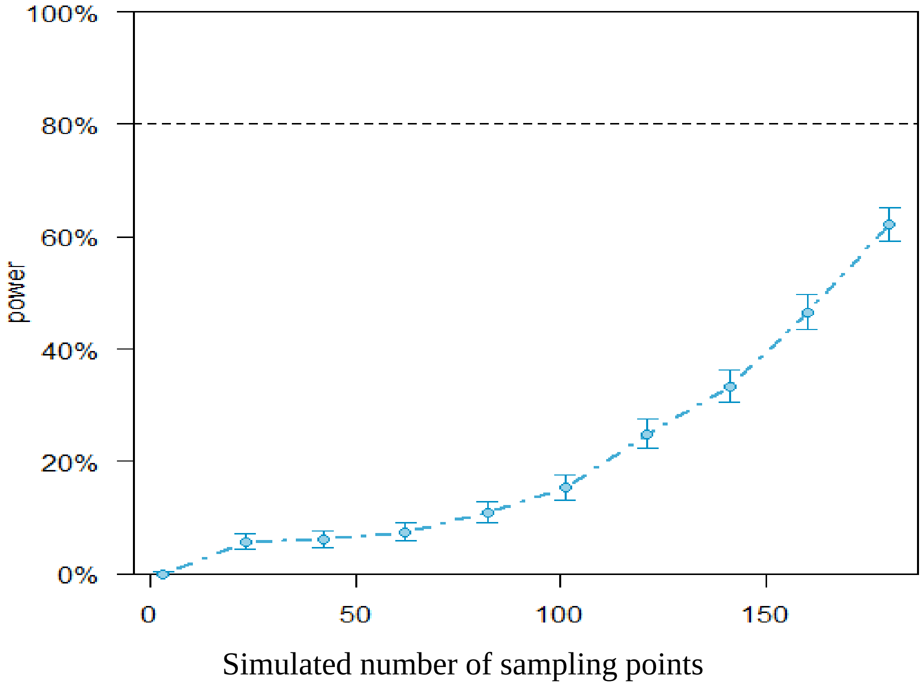

Figure 25: Power to detect the required number of sampling points needed for sticky trap sampling in the AFR

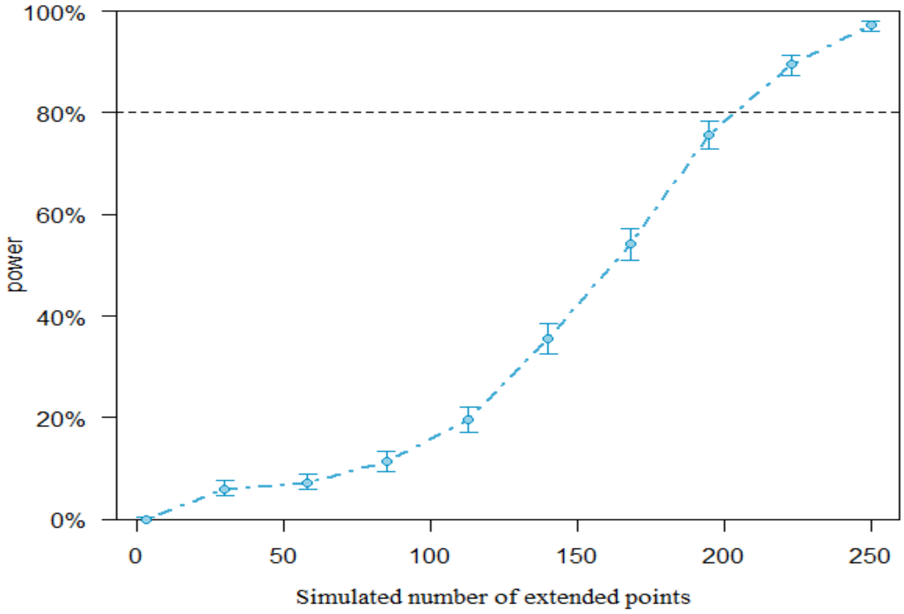

Figure 26: Power to detect the required number of sampling points needed for sticky trap sampling in the AFR after an extension of data points from 180 to 250

With sweep netting, figure 27 shows that the 180 sampling points used in this project was not enough to predict ≥80% power of arthropods diversity in the AFR. When the sampling points were increased from 180 to 1,000, figure 28 shows that more than the extended 1,000 points are needed for arthropods samplings with sweep netting as a sampling technique. This means, sweep netting sampling requires more than more twice the total number of points used in this study.

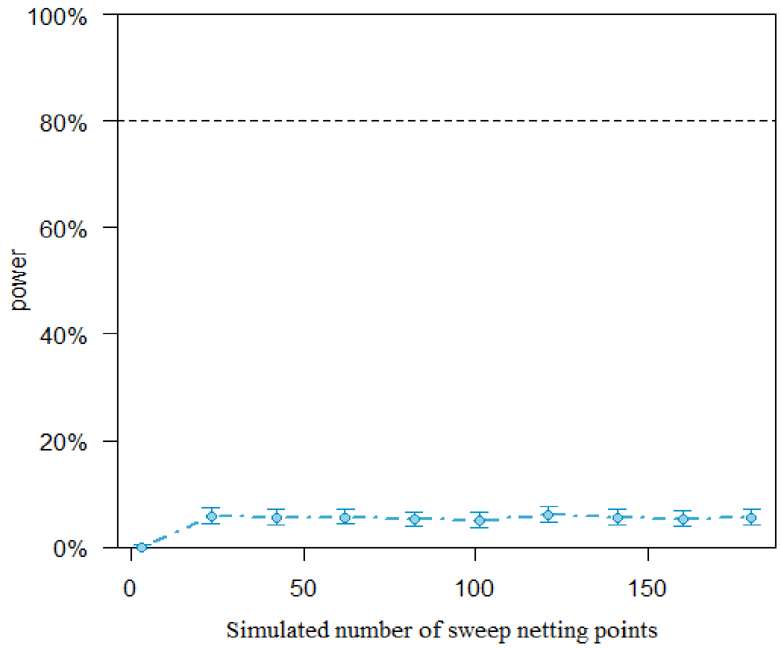

Figure 27: Power to detect the required number of sampling points needed for sweep netting sampling in the AFR using 180 sampling points

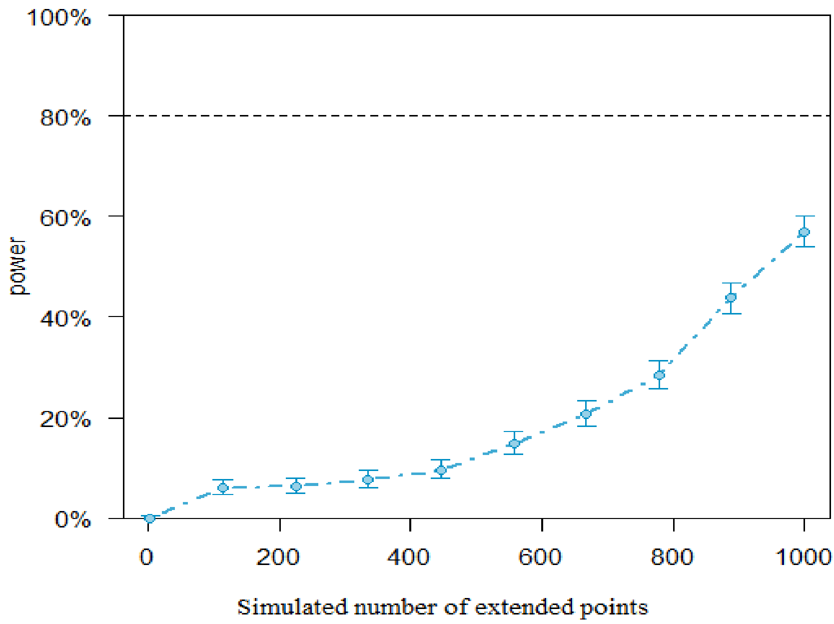

Figure 28: Power to detect the required number of sampling points needed for sweep netting sampling in the AFR after an extension of data points from 180 to 1,000

CHAPTER FIVE

DISCUSSION

Trends and Seasonal Abundance of Arthropods in the AFR

The large number of arthropods recorded in this survey is an indication of the rich fauna and flora of the forest reserve. Over the years, available land cover satellite images of AFR indicate significant regeneration in terms of gallery forest and savanna. A major contributing factor to regeneration in the forest reserve could be attributed to the large number of arthropods in the reserve as it is well known that arthropods are key players in forest regeneration (Schowalter, 2006) through ecosystem services such as pollination and provision of nutrients to the forest floor for eventual uptake by plants (Pyle, Bentzien & Opler, 1981; Schowalter, 2016).

In the three habitat types, savanna and gallery forest recorded more arthropods compared to the inselbergs. Savanna and gallery forests are on lower altitudes compared to the inselbergs and this may be a contributing factor for the differences in arthropods abundance in the three habitat types. Arthropods abundance decreases with increasing altitudes (Hoiss, Krauss, Potts, Roberts & Steffan-Dwewenter, 2012; Franzen & Dieker, 2014) because climatic conditions such as temperature, rainfall and humidity which are contributing factors to arthropod assemblages, differ with increasing altitudinal gradient (Hoiss et al.). Ecologically, high abundance of any biodiversity has a lot to do with availability of resources such as food and water (Janes, 1994). The differences in the abundance of arthropods between habitat types in this study may also be as a result of differences in richness and diversity of plants distribution in the AFR reserve (Barde & Abiem, 2015).

Although, this study of arthropods community in the AFR did not cover a long period of time, it was observed that arthropods in the reserve have seasonal patterns in their abundance during the year. All recorded taxa showed a clustered distribution with highest abundance in the transition period from the end of the dry season to the start of the rainy season. Larger numbers of arthropods were collected in the rainy season (72.8%). The trend seen in the abundance of arthropods supports the works of Wolda (1988) and Silva, Frizzas & Oliveira (2011) where first rains in the year acted as a trigger for resumption of arthropods activities and abundance. One of the important factors in many regions is the change from the dry season to the rainy season (Wolda, 1988) especially the tropics where climate conditions affects the seasonal pattern of arthropods (Wolda & Fisk, 1981). Rainfall generally brings out new leaves with lower toxins levels and higher nutrient content (Feeny, 1970) which are more suitable for arthropod sap feeders (Ott, Azevedo-Filho, Ferrari & Carvalho, 2006) and explains the reasons for many arthropods abundance in the wet season. Some arthropod especially Coleopterans spend the dry season underground, in larval diapause and then change into adults in the second half or end of the dry season. Adults only abandon the soil to mate and disperse when temperature rises and the first rain begin (Oliveira, Morón & Frezzas, 2008). This can also be one of the reasons for the high number of arthropods starting with first rains in the AFR.

Sweep Net, Sticky and Pitfall Traps Sampling

Sweep netting, sticky traps and pitfall trap sampling are the three most used sampling methods in arthropod-birds surveys (Morrison et al., 1989). In this study, it was found that the three sampling techniques produced different results. Trapping efforts by the three methods yielded results similar to those from earlier studies carried out on the subject matter (Norment, 1987; Morrison et al.). Although, family richness was similar between sweep netting and sticky traps, different taxa were collected. Seasonal abundance and size classes varied using the three methods. These results have important implications.

For instance, Ornithologists and Wildlife biologists often measure habitat quality for insectivorous birds based on arthropods abundance (Cederbaum, Carroll & Cooper, 2004; Doxon & Carroll, 2007). However, abundance estimates may be biased if the sampling method used does not take into factor these sampling differences (Palmer, Lane & Bromley, 2001). Because the sizes and prey of arthropods consumed by birds differ (Maher, 1979; Doxon & Carroll, 2007). Knowledge of these differences is essential for determining the most appropriate sampling method(s).

The sizes of arthropods selected by a bird species aid in determining which sampling technique to use. In this study, the mean length of arthropods collected by sweep netting was 0.823 cm, whereas that for pitfall traps and sticky traps were 0.789 cm and 0.688 cm respectively, including individuals as long as 5cm. In the Amurum forest reserve, ground-foraging game birds such as African thrush (*Turdus pelios*), Double-spurred francolin (*Francolinus bicalcaratus*), Sun lark (*Galerida modesta*), Crested lark (*Galerida cristata*) and Stone partridge (*Ptilopachus petrosus*), pitfall trap sampling will collect arthropods in size class and taxa typically eaten by the above avian predators. However, other bird species like the Red-throated bee-eater (*Merops bulocki*), White-throated bee-eater (*Merops albicollis*), Fanti saw-wing (*Psalidoprocne *obsura*), Rock martin (*Ptyonoprogne fuligula*) and other specialized aerial avian predators that prey on large arthropods will be better sampled using sweep netting and sticky traps. Maher (1979) determined that nestlings of several grassland avian species consumed varied sizes of arthropods in length. In such cases, using multiple sampling methods to adequately sample all size classes and taxa of arthropods would be most appropriate.

New (1998) work has shown that climatic variables (temperature, humidity, cloud cover and wind speed and direction) can influence the types of arthropods collected using a particular sampling method. But in this study, because paired transects sampling was used in habitats within minutes from each other, the possible effect or influence of climate conditions were minimized, and therefore, differences found are likely due to differences between the sampling techniques. Some studies have shown that vegetation height and density may influence the types and numbers of arthropods collected (Duffy, 1980; Hand, 1986). But particularly in this work, differences between sampling techniques were likely not because of either vegetation structure or density because transects were laid parallel to each other across all habitats. Therefore, differences detected between sweep netting, pitfall trap and sticky trap sampling were likely due to differences in arthropods behaviour and activity and their location.

Differences between sampling techniques can also be attributed to the spatial distribution of arthropods within vegetation and habitats (Mommertz et al., 1996). With sweep netting, only the outer portions of vegetation/plants are sampled, because sweep nets cannot penetrate the vegetation. As a result, sweep nets are less effective at collecting arthropods within dense vegetation structures (Buffington & Redak, 1998). The use of sweep netting seem to be the least effective compared to sticky traps. Total number of capture was low and some orders of ground-dwelling arthropods were missed almost entirely, but a good amount of ground-dwellers and crawling arthropods were captured by sticky traps. One reason to this may be the difficulty with sweep net sampling in the gallery forest where the vegetation are clustered, making it difficult to swing the net, hence, requiring more effort (time) and less capture. As explained by Zaller et al. (2015), the success of sweep net sampling is explained by its practical use and the fact that it can only be employed in almost all habitats except on dense vegetation.

Sweep net sampling is also more vulnerable to disruption by short-time changes in weather conditions than either pitfall or sticky traps which operate for 24hr periods. Unlike sticky and pitfall traps sampling, sweep netting has one clear disadvantage over spatial and temporal differences. Sticky and pitfall traps collect both nocturnal and diurnal guilds of taxa. In addition, the experience of the collector may be influenced by the results obtained by sweep net sampling (Norment, 1987; Cooper & Whitmore, 1990). Sweep net sampling may not catch arthropods that live close to the soil surface. It is also likely to miss many large and faster arthropod species which are alerted by the collector's vigorous progress through the habitat. Moreover, sweep netting records species that are active at a short time period or present in the presence of the collector. During the course of sampling, it was observed that sweep netting cause significant damage to plants. Damage caused by sweep nets could be similar to that caused by herbivores and may therefore decrease plants fitness (Marquis, 1995). Low fitness in some plants species which are resources to birds as a result of sweep netting could be detrimental to the bird species that feeds on them. These limitations make sweep net sampling an unreliable sampling tool for estimating arthropods activity, although, it is the most used sampling method (Zou et al., 2012). This was affirmed by the standardized coefficient figures which showed that sweep netting in most cases had the strongest negative effect on arthropod indices in the AFR especially, in the wet season.

Sticky traps are known to be very effective, low cost and require less skilled labour (Atakan & Canhilal, 2004; Wallis & Shaw, 2008; Bashir, Alvi & Hina-Naz, 2014). It produced a higher total abundance of arthropods, which would likely translate to a larger total biomass although dry-weight of arthropods was not measured in the present study. However, it may also be biased because of its colours which serve as attractants to arthropods (Child, 1998). Some studies suggests specific taxa are attracted to specific colours (Straw, Williams, & Green, 2011; Atakan & Pehlivan, 2015) but yellow and blue are the most common and successful colours that have been used in several arthropod sampling (e.g. Atakan & Canhilal, 2004; Hassan & Mohammed, 2004; Wallis & Shaw, 2008; Thein, Jamjanya & Hanboonsong, 2011; Lu, Bei & Zhang, 2012). The yellow colour used in this research may be a contribution factor to its success. In contrast, the advantage of sticky trap over sweep netting is that flying arthropods can be trapped with the shortest possible time. Considering that there is little time to spend performing arthropods assessments, sticky traps seem to be a valid method for getting a snapshot impression of arthropods community in protected areas. Unlike sweep netting, sticky traps do not cause damage to plants. It was the sampling technique that had most positive effects on arthropod indices recorded. Aside the success in sticky trap sampling in this study, it was found that preserving and analyzing specimen was difficult as the records had to be done on the traps, any attempt to remove it caused damage. Unlike sweep netting and other sampling techniques, identification of specimen with sticky traps cannot be done to the lowest taxonomic level (Górska-drabik, Golan & Ûwikliĕska, 2011).

Pitfall traps capture mostly ground-dwelling arthropods and are useful in illustrating seasonal variations in activity of different taxa of surface active dwellers (Higaar, Ostbye & Melen, 1978), it is subject to interpretational errors. Thus, it was not surprising that spiders (Araneae), ants (Formicidae) and beetles (Coleopterans) were captured frequently in pitfall traps in this study. It yielded little results on flying arthropods. However, few Lepidopterans and Hymenopterans were recorded using this method, even though, both taxa and many flying arthropods constitute an important component in the diet of many avian species. The type and size of pitfall traps used in monitoring arthropods have influence on the results or catch as some specimens are able to escape from the trap either by hopping or crawling out from the trap. The types of plastic cups used in this survey were deep and had smooth inner layer which was able to prevent specimens from escape, including a slug (Appendix D). Pitfalls trapping non arthropods have been recorded in other studies (Zou et al., 2012).

Legg & Nagy (2006) experiment reveals that results from any inadequate biological monitoring are misleading for the information quality and also very dangerous because they create the illusion that something useful has been done. It is with this view that a guided design for arthropods monitoring in the AFR has been provided through this project to ensure that future monitoring work findings are accurate and meaningful in terms of sample size. In broad terms, the results shows that the power to detect the optimum diversity of arthropods in the AFR require less survey efforts with pitfall and sticky trap samplings but sweep netting requires high level of relative survey effort to detect with confidence. The low power in sweep net sampling may be as a result of collector biases, partial operation in habitat types, especially, gallery forest and failure to sample nocturnal arthropods.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Arthropods are a major component in the diet of almost all global bird species. It is an undeniable fact that birds eat arthropods and, arthropods aid in forest regeneration through ecosystem services. In view of this, the project sought to establish an efficient and accurate sampling protocol for arthropods sampling in the Amurum Forest Reserve, the forest that is situated in the center of A.P. Leventis Ornithological Research Institute, the only field station dedicated to birds' research and conservation training in West Africa.

This study aimed at establishing;

- The sampling technique that produces the highest taxon of arthropods
- The technique to use in the three habitat types.
- The technique to use across seasons.
- The sample size required for arthropods monitoring in the AFR.

A stratified random sampling approach was used to generate nine plots (three in each habitat type) and 200 x 4 parallel transects within each plot.

The results showed that arthropods from the order Hymenopteran dominated the recorded samples. The overall family accumulation curve showed no significant difference between the sticky trap and sweep netting sampling. In total, sticky traps recorded abundant species than the other two sampling techniques and also, across seasons and between habitats. Sweep net sampling requires more than thrice the effort (time) needed for pitfall and sticky traps combined surveys. The results also showed that, a total of about 450 sampling points in total are needed for arthropods sampling in the reserve.

Conclusions

In conclusion, it was evident from this work that:

1. No single sampling technique can adequately characterize the arthropods community in the AFR and/or savanna habitats.
2. Pitfall and sticky traps as the preferred sampling techniques for arthropods monitoring in the AFR, especially as it requires less effort, have high statistical powers to collect arthropods with reasonable sampling units and will remove any bias associated with sampling survey.
3. Arthropods resources are available for birds in the AFR throughout the seasons with the majority in the rainy season.
4. All four hypotheses stated in this study are rejected based on the fact that there were significant differences in arthropods abundance between sampling techniques, habitats and across seasons.

Recommendations

From the above results, the following recommendations can be made. Ornithologists seeking to estimate arthropod prey activity should use more than one relative method. Considering the lack of significance difference in the overall family richness accumulated between the sticky traps and sweep netting which surveys mostly flying arthropods, and fewer sampling points required for sticky, it is recommended that sticky traps sweep netting be used for arthropods survey in the AFR. However, pitfall trap sampling should never be ignored in any arthropod surveys as sticky trap and sweep netting will not record ground-dwelling arthropods which form a vital component in the diet of the birds in the reserve. So therefore, if the aim of monitoring is to sample ground dwelling arthropods, pitfall sampling should be used. Again, from the findings in this project, it is evident that a combination of sticky traps and pitfall traps will probably give an accurate estimate of the relative abundance of both adults and immature arthropods which are important component of some savanna avian species, therefore, highly recommended. But for studies with budgetary constraints, investigators should take into consideration cost involved in sampling before choosing a sampling method.

Arthropods decline have been said to occur globally. In order not to take much resource (arthropods) from the AFR which would have a dire consequence on the avian community that depend on these resources, it is recommended that future monitoring be conducted on bi-weekly and/or monthly basis.

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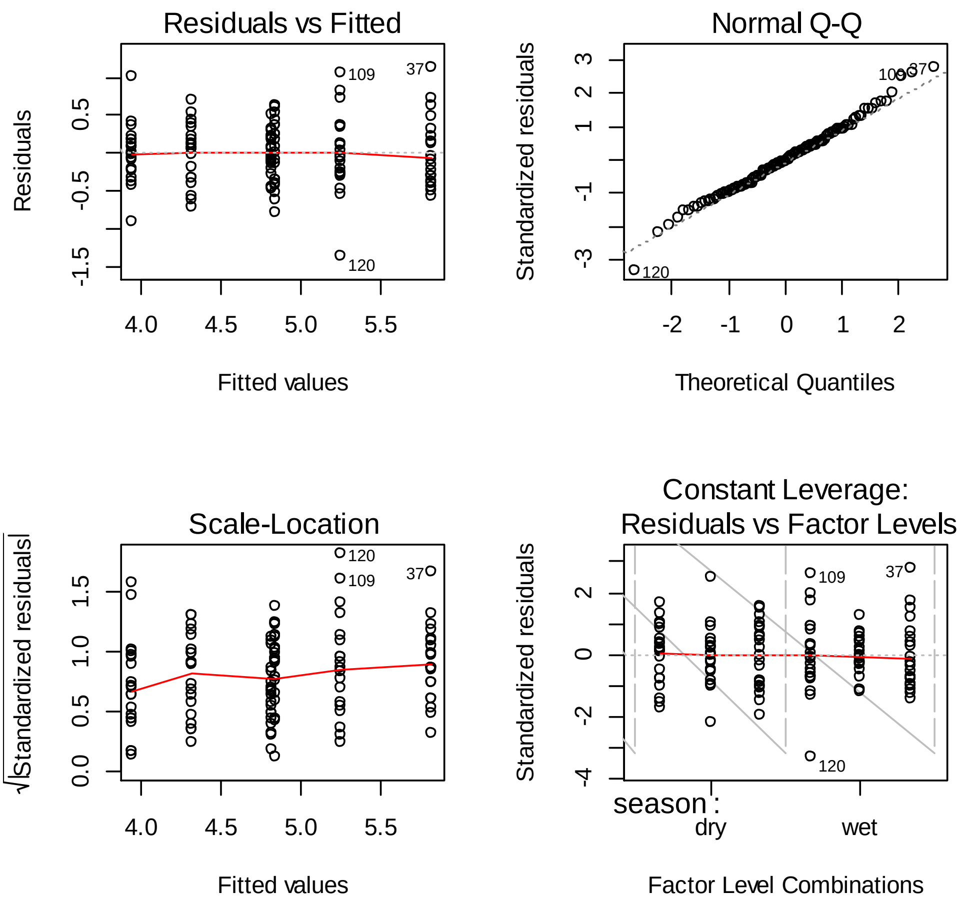
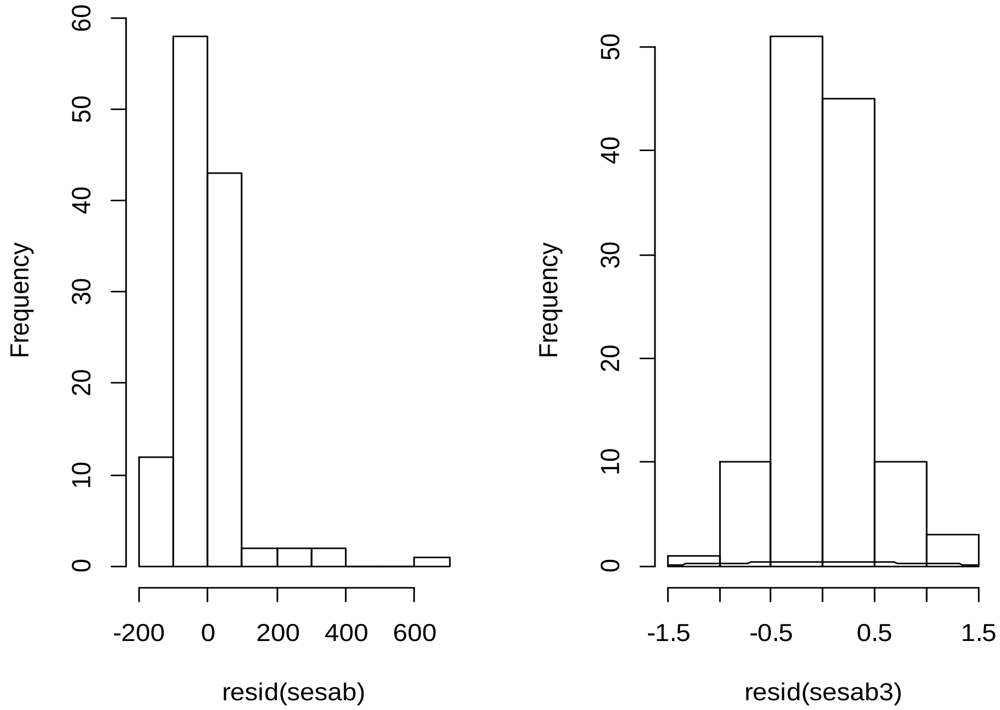
APPENDICES

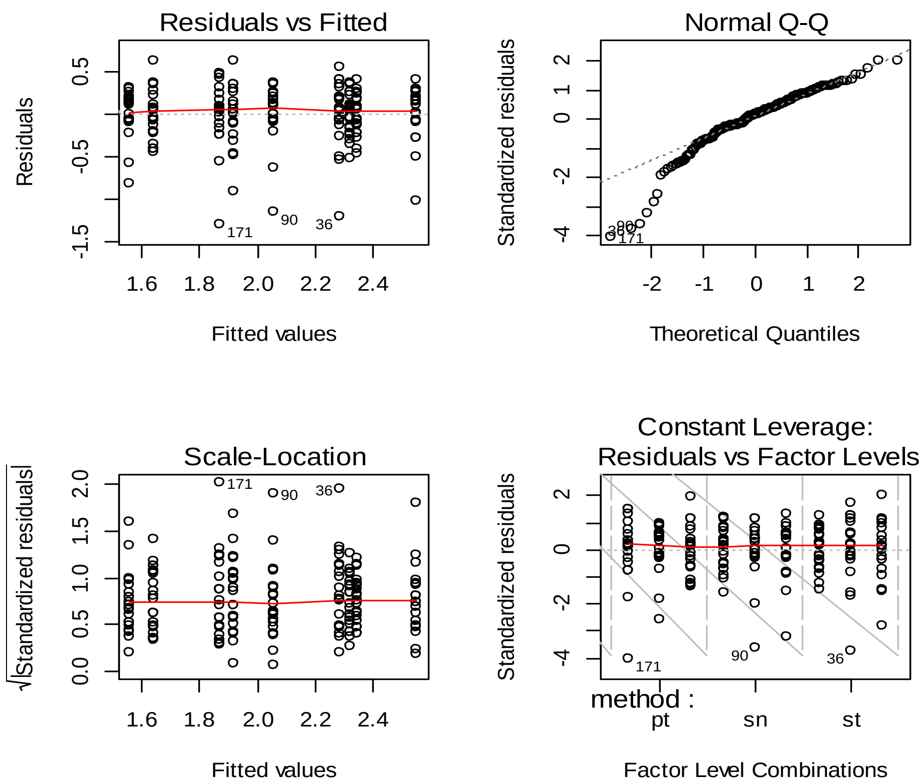
(A)



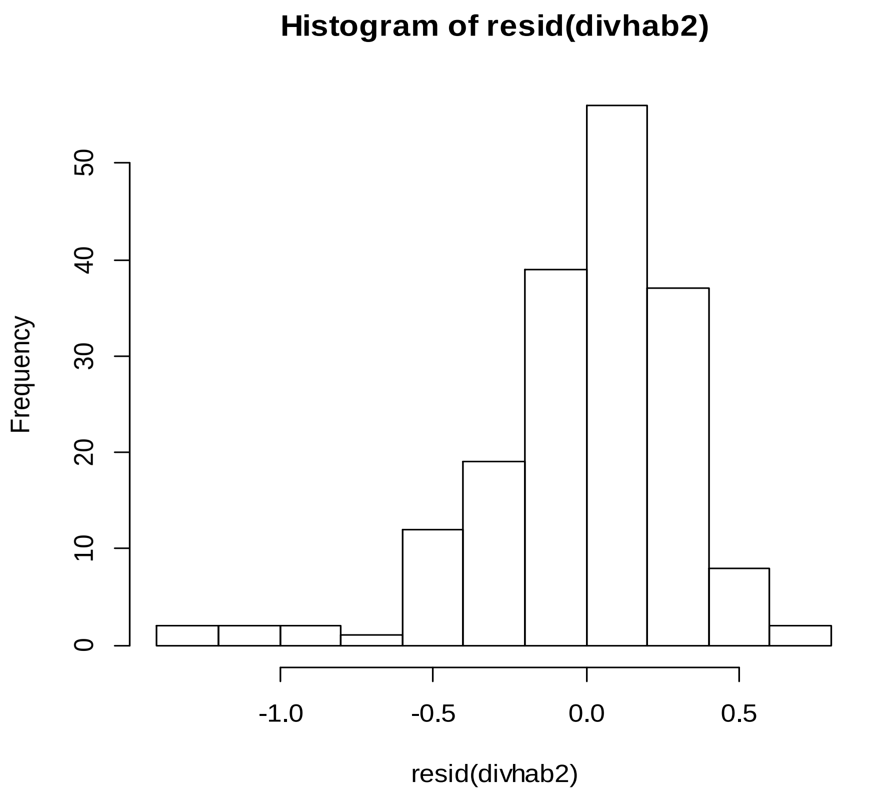
Model residuals for seasonal abundance



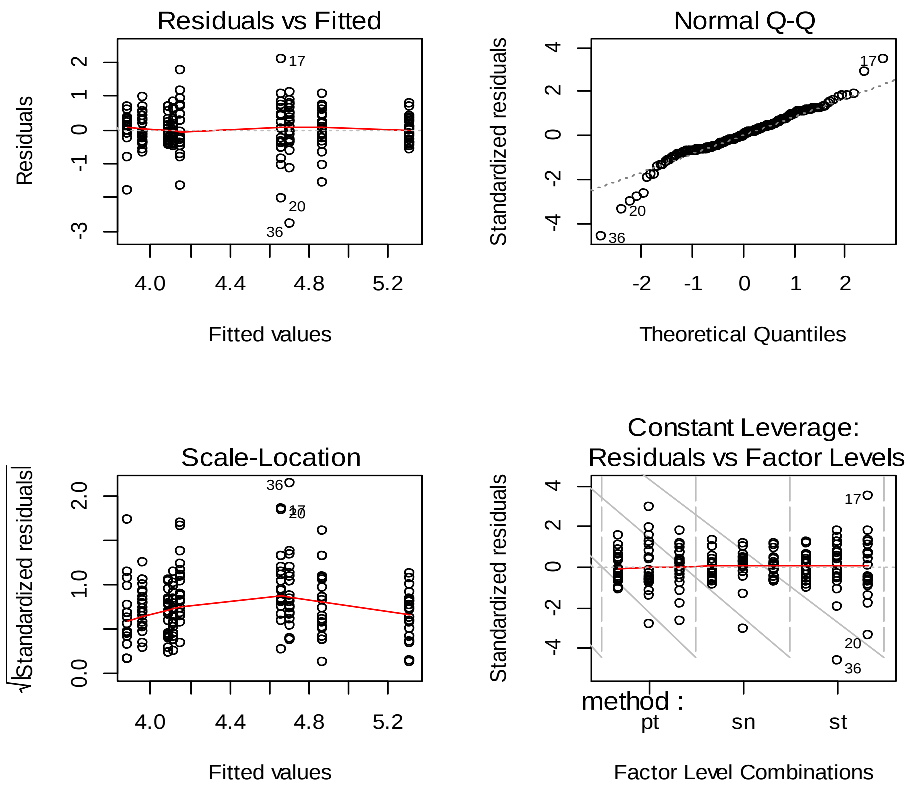
Histogram of raw data (L) and model residual (R) for seasonal abundance



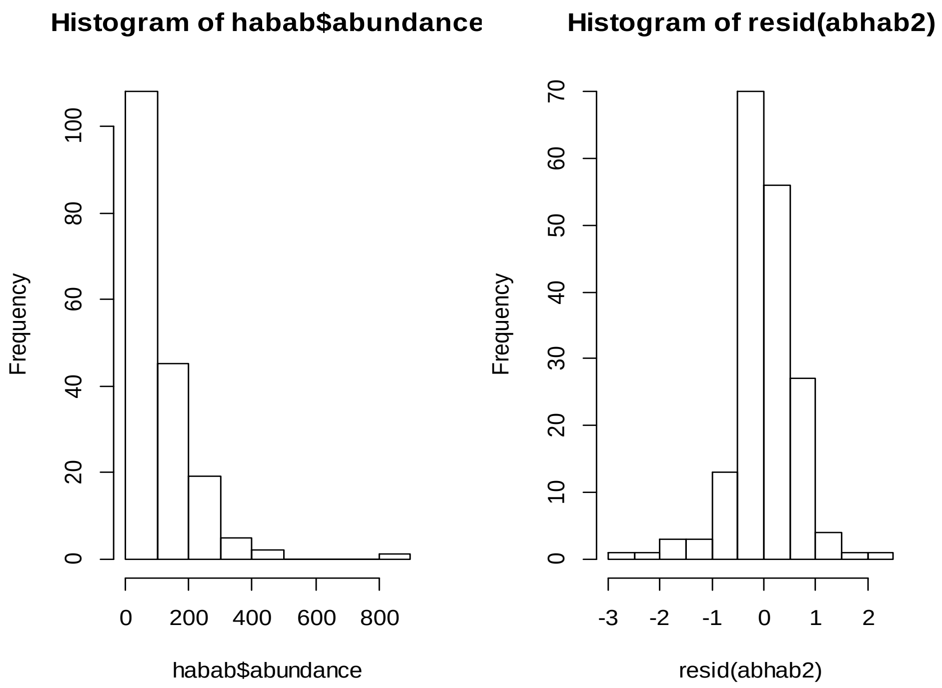
Model residual for seasonal diversity and habitats



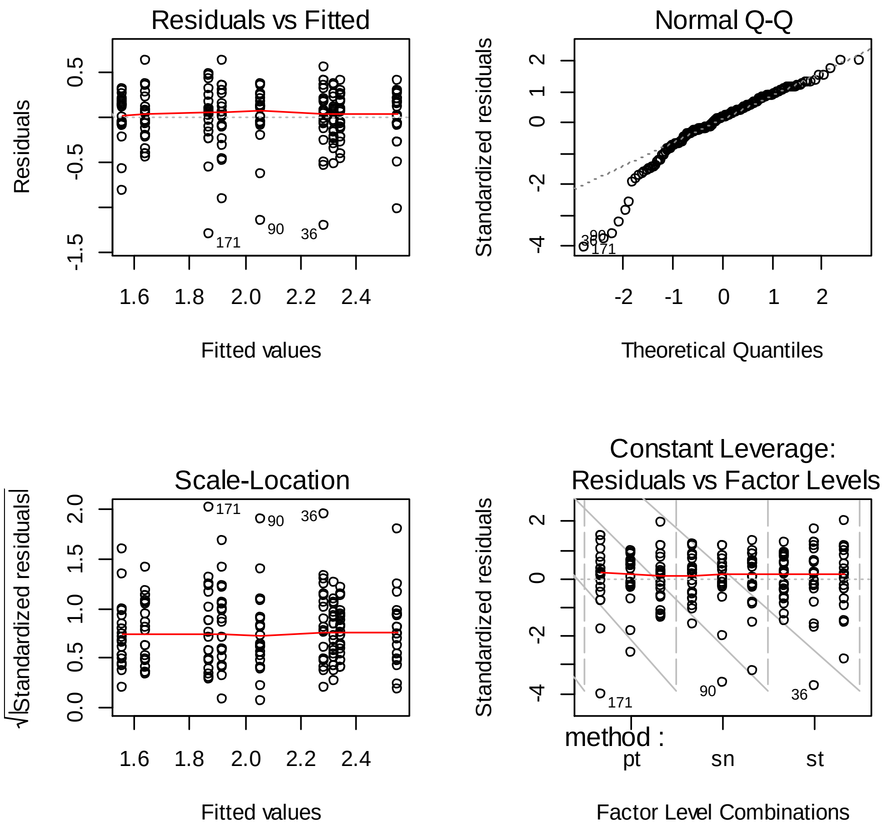
Histogram for diversity of arthropods in habitat types



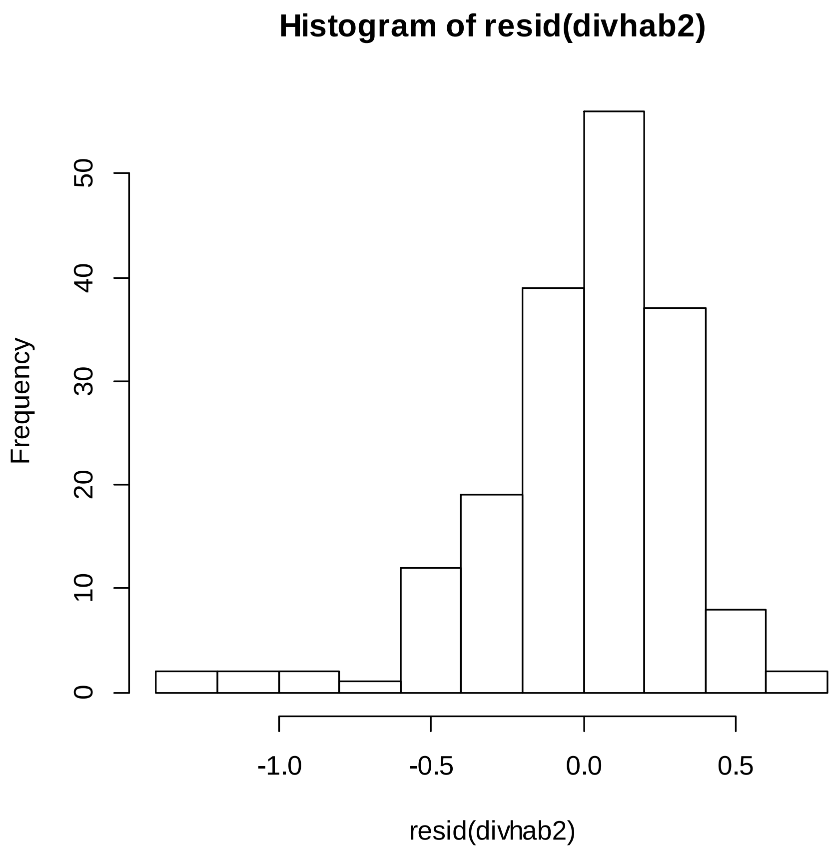
Model residual for abundance by habitat types



Histogram for raw (L) and model residual (R) for abundance within habitats



Model residual for diversity within habitat types



Model residual histogram for diversity within habitats

(B) The percentages of arthropods by families

FAMILY	PERCENTAGE	FAMILY	PERCENTAGE
Acrididae	0.221752	Lampyridae	0.181433
Aleyrodidae	1.753855	Lepidopsocidae	0.01008
Amaurobiidae	0.060478	Lepismatidae	0.216712
Anisopodidae	0.030239	Lestidae	0.070557
Aphididae	0.01008	Linyphiidae	0.917246
Apidae	2.046165	Lithobiidae	0.095756
Araneidae	1.149078	Lucanidae	0.065518
Armadillidiidae	0.080637	Lycosidae	0.020159
Asilidae	0.488862	Mantidae	0.075597
Blattidae	0.322548	Membracidae	0.125995
Braconidae	0.01008	Muscidae	2.328394
Calliphoridae	0.372946	Nymphalidae	0.700534
Carabidae	1.486745	Pentatomidae	0.065518
Cerambycidae	0.055438	Philodromidae	0.28223
Chrysomelidae	4.283842	Phylliidae	0.186473
Chrysopidae	0.025199	Pieridae	0.080637
Cicadellidae	12.72049	Pseudococcidae	0.025199
Clubionidae	0.236871	Psychodidae	12.18627
Coccinellidae	0.372946	Pyrochroidae	0.025199
Coreidae	0.035279	Rhagionidae	0.020159
Corsuliidae	0.211672	Sarcophagidae	0.01008
Crambidae	0.352787	Scolopendridae	0.01008
Culicidae	0.246951	Simuliidae	0.125995

Curculionidae	0.292309	Stratiomyidae	0.745893
Daesiidae	0.00504	Syrphidae	0.302389
Dolichopodidae	2.015926	Tenthredinidae	0.161274
Elateridae	0.287269	Tephritidae	5.579075
Empididae	0.146155	Termitidae	1.048281
Eribidae	0.146155	Thripidae	1.799214
Eupterotidae	0.060478	Tipulidae	0.650136
Forficulidae	0.251991	Trombiculidae	0.095756
Formicidae	39.12912	Tromibidiidae	0.403185
Gryllidae	0.478782	Helicidae	0.020159
Halictidae	0.312469		
Hydropsychidae	0.408225		
Hydroptilidae	0.856768		
Ichneomonidae	0.312469		
Ixodidae	0.015119		
Julidae	0.075597		

(C)

1. Results of standardized coefficients showing the effects of independent variables (method and habitat) on the diversity of arthropods in the AFR

Formula = diversity ~ method + habitat + method*habitat	
Intercept	0.000
MethodSN	0.472
methodST	0.497
HabitatR	-0.323
HabitatS	-0.237
methodSN:HabitatR	0.029
methodST:HabitatR	0.171
methodSN:HabitatS	0.317
methodST:HabitatS	-0.139

2. Results of standardized coefficients showing the effects of independent variables (method and habitat) on the abundance of arthropods in the AFR

Formula= Logabundance ~ method + habitat + method*habitat	
Intercept	0.000
MethodSN	0.093
methodST	0.841
HabitatR	0.115
HabitatS	0.565
methodSN:HabitatR	-0.172
methodST:HabitatR	-0.331
methodSN:HabitatS	-0.386
methodST:HabitatS	-0.646

3. Results of standardised coefficient values of the effect of sampling methods on the diversity of arthropods both wet and dry seasons in the AFR.

Formula= diversity ~ method + season + method*season	
Intercept	0.000
SeasonWET	0.636
MethodSN	-0.240
MethodST	0.333
SeasonWET:methodSN	-0.029
SeasonWET:methodST	0.027

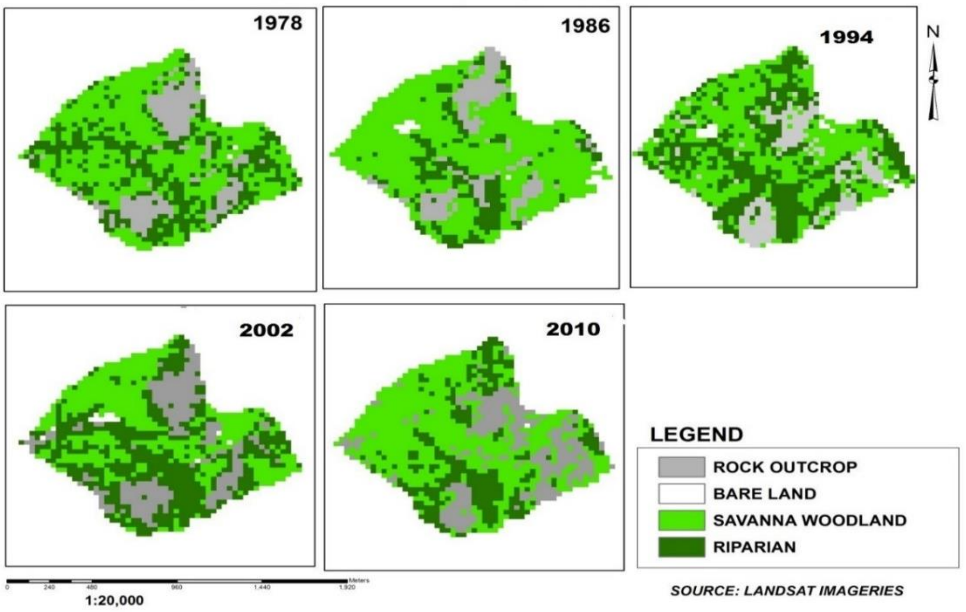
4. Results of standardised coefficient values of the effect of sampling methods on the abundance of arthropods both wet and dry seasons in the AFR.

Formula= Logabundance ~ method + season + method*season	
Intercept	0.000
SeasonWET	0.461
MethodSN	-0.079
MethodST	0.179
SeasonWET:methodSN	-0.166
SeasonWET:methodST	0.261

(D)

A slug trapped in a pitfall trap. It was unable to escape due to the smooth lining of the pitfall trap.

(E)



Landsat satellite images showing the change in land cover for 5 time series in the AFR

Set ups for beating sheet (Left) and pitfall trap (Right)

Sweep net sampling in the savanna (Left) and gallery forest (Right) during the dry season

Display of insects trapped by sticky traps. A huge moth stuck on the sticky board (left) and hundreds of trapped flying ants (right)

Sticky trap laid on the floor of rocky habitat (G) with its surface dried and back chewed by termites