UNIVERSITY OF CAPE COAST

LANDSCAPE INFLUENCE ON BEE ABUNDANCE AND DIVERSITY IN THE FOREST SAVANNAH TRANSITION ZONE OF GHANA AND COMMUNITY KNOWLEDGE OF POLLINATORS AND POLLINATION

EDDIEBRIGHT JOSEPH BUADU

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BY

EDDIEBRIGHT JOSEPH BUADU

Thesis submitted to the Department of Entomology and Wildlife of the School of Biological Sciences, University of Cape Coast in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Entomology

JULY 2016

DECLARATION

Candidate's Declaration

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

Candidate's Signature:...Date:......................

Name: Eddiebright Joseph Buadu

Supervisors' Declaration

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

Principal Supervisor's Signature:...Date:........................

Name: Professor Peter Kofi Kwapong

Co-supervisor's Signature:..Date:…………………

Name: Professor (Mrs) Mary Botchey

ABSTRACT

Global declines in pollinator diversity and abundance have been recognized, raising concerns about a pollination crisis of crops and wild plants. In many African countries including Ghana however research and publications on the subject are rare. To this end, a study was carried out from June 2013 to April 2014 to determine the influence of landscape type on bee species abundance and diversity in the Forest Savannah Transition Zone (FSTZ) of Ghana. The research also evaluated farmers' knowledge and perceptions of the importance of pollinators and pollination. Two sites each of the landscape types; Agricultural land, Natural vegetation and Settlement fringes were sampled from three subzones selected on the basis of the proportion of trees relative to grasses. Overall, 706 bees made up of 3 families, 18 genera and 34 species were collected and identified. Apidae was the most speciose bee family and Megachilidae the least. *Xylocopa*, *Amegilla* and *Lipotriches* were the most common genera whilst *Chalicodoma*, *Thyreus*, *Celioxys* and *Lithurgus* were represented by single individuals. The results of bee species abundance and diversity were mixed for the various comparisons. Overall, the study indicated that bee species diversity is significantly influenced by landscape type and percentage tree to grass proportions ($P \leq 0.05$). No such variation was observed for bee abundance probably due to the dominance of *Apis mellifera* Linnaeus. There were significantly more bee species in agricultural land and natural vegetation than in settlement fringes. Similarly, there were more bee species in the lower transition zone (area with the highest percent tree cover) than in either the middle or upper transition zone. Though most of the crop farmers interviewed had been farming for more than 10 years, they knew very little about pollinators and pollination, indicating the need to intensify education on the subject.

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I solemnly declare that I share the credit that goes with the production of this work with my wife, Catherine and the children, Friedrich, Joana, Eugenia and Prince for their prayers and moral support.

DEDICATION

To my wife and children

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ALARM	Assessing Large Scale Risks for Biodiversity with Tested Methods
API	African Pollinator Initiative
CBD	Convention on Biological Diversity
CCD	Colony Collapse Disorder
COP	Conference of the Parties
FAO	Food and Agricultural Organization
FSTZ	Forest Savannah Transition Zone
GPP	Global Pollination Project
GPS	Ground Positioning System
IPCC	International Panel on Climate Change
IPI	International Pollinator Initiative
IUCN	International Union for Conservation of Nature
MTDP	Medium Term Development Plan
NRC	National Research Council
SSSA	Systematics Society of South Africa
UNEP	United Nations Environment Project
USDA	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

To ensure successful pollination and maximum crop production, diverse populations of wild bee species, the most important group of pollinators, are essential (Kremen, Williams, Bugg, Fay & Thorp, 2004). Recent reports have pointed out that most pollinator populations have declined to levels that cannot sustain pollination services in agro-ecosystems due to increased disruption of habitats (Kearns, Inouye & Waser, 1998). This destruction is noticed in the forest savannah transition zone of Ghana where the bulk of the nation’s food is produced. There is however no solid documentation on the status and trends of bees in Ghana. A study of the abundance and diversity of wild bees in the FSTZ of Ghana is therefore required to reveal areas with declining bee populations or possible mismatches in in bee-plant interactions so that the necessary interventions can be applied to increase food production.

Background to the Study

Concern for the conservation of biological diversity for the survival of mankind, has been a central point of action by many countries and institutions. During the mid 1990’s global concerns emerged regarding the survival of pollinator diversity (Watanabe, 1994). From this increased awareness “The Forgotten Pollinators Campaign” was launched in 1995 in the United States to bring attention to the critical role pollination plays in food production and in maintaining viable ecosystems. The supporters of the campaign called for policy changes to protect habitats for pollinators and suggested subsidising farmers to do so (Ingram, Nabhan & Buchmann, 1996). The Convention on Biological Diversity (CBD) legitimised the global concerns through prioritising pollinators in their Conservation and Sustainable use of Agricultural Biological Diversity programme. This led to an international pollinator workshop, with the emphasis on bees, hosted by the Brazilian Government at the University of São Paulo in October 1998 (Dias, Raw & Imperatriz-Fonseca, 1999). At this workshop, a document called "The São Paulo Declaration on Pollinators" was produced, and in it, an International Pollinator Initiative (IPI) was proposed (Freitas *et al.*, 2009; Imperatriz-Fonseca & Dias, 2004). The International Pollinator Initiative-IPI (also known as the International Initiative for the Conservation and Sustainable Use of Pollinators) was officially formed in May 2000 at the 5th Conference of the Parties (COP5) to the CBD in Nairobi, Kenya with the endorsement of the São Paulo Declaration. The FAO was requested to facilitate and co-ordinate the Initiative in close co-operation with other relevant organisations. FAO, through the FAO/Netherlands Partnership Programme, supported the initial establishment of a regional African Pollinator Initiative, and the development and publication of its Plan of Action in 2003. The *African Pollinator Initiative (API)* was founded in January 1999, at the First Congress of the Systematics Society of South Africa (SSSA), in Stellenbosch, South Africa. Its Plan of action is based on four components, namely public awareness and education, placing pollination in the mainstream, conservation and restoration, and capacity building. It is in line with these objectives that this project was undertaken.

Conservation of plant diversity depends on the protection of forests, woodlands, grasslands and wetlands, and on a number of environmental services, such as pollination (Schoonhoven *et al*., 1998). Pollination contributes to food security, biological diversity and the economy. Worldwide, the number of flower-visiting species is estimated to be around 150,000 (Nabhan & Buchmann, 1997). Insects are the most important animal pollinator groups, with approximately 70% of angiosperm plants being insect pollinated (Schoonhoven *et al*., 1998). Insect groups such as moths, flies, wasps, bees, beetles, butterflies and other invertebrates are critically important for ensuring effective pollination of both cultivated and wild plants (Free, 1993; Wilcock & Neiland, 2002). Insects represent more than half of all living species (Strong, Law & Southwood, 1984) and their diversity in numbers, life forms, and functional roles such as herbivory, pollination, and predation contribute singnificantly to ecosystem stability (Lassalle & Gauld, 1993). Insects facilitate key ecosystem services such as pollination, nutrient recycling and seed dispersal without which ecosystems would collapse. Plant-insect interactions such as pollination and seed dispersal benefit plant populations (Ritchie & Olff, 1999), and may greatly influence the plant community structure especially in herbivory (Steffan-Dewenter, Munzenberg, Burger, Thies & Tscharntke, 2002). Furthermore, the vast majority of angiosperms, including agricultural crops are insect pollinated (Kevan, 1999). Crops that are highly dependent on pollinators to achieve economical yields include mango, pepper, cashew, pear, watermelon, egg plant, blackberry, citrus, oil palm and cucumber. Without insects to move pollen, some crops would be far less productive, and many fruits and vegetables would not ripen as evenly or as quickly. An estimated 60 to 80% of the world's quarter of a million species of flowering plants depends on animals, mostly insects, for pollination (Kremen *et al.*, 2004). Insect pollination is a necessary step in the production of most fruits and vegetables we eat and in regeneration of many forage crops used by livestock (Watanabe, 1994). Many plant species that are directly dependent on insect pollination for fruit and seed production (Velthuis & van Doorn, 2006) might experience pollination limitation when pollinator species are scarce (Ashman *et al.*, 2004). Pollinators are therefore crucial in realizing the national and UN millennium development goals of poverty reduction and natural resource management. Loss of pollinators has the potential to disrupt ecosystem function by effecting changes in the plant community (Lundberg & Moberg, 2003). There are, however, other crops that have self-fertile flowers, which are capable of setting seeds without the help of pollen vectors (e.g. cotton, soya, and tomato) but floral visits by pollinators improve both the quality and quantity of their seeds or fruits (Richards, 2001).

Bees

Among the pollinator groups, bees have been considered a priority group (Dias *et al.*, 1999). Globally, bees are the most important and effective pollinators and are often considered to play a keystone role within ecosystems (Kearns *et al.*, 1998). Bees are the main pollinators of angiosperms (Bawa, Ashton & Salleh, 1990; Roubik, 1989) and solitary bees constitute 85% of the 25,000 known species of bees. Nearly 60-70% of flowering plants are bee pollinated (Axelrod, 1960). About 15% of the world´s crops are pollinated by domesticated bees (honey bees and bumble bees) while solitary bees and other wildlife pollinate about 80 percent (Ingram *et al.*, 1996). With an estimated

20,000-30,000 species worldwide (Michener, 2007) bees are the world's dominant pollinator taxon of wild plant species (Brosi, Armsworth & Daily, 2008) and most cultivated crop species (Timmermann & Kuhlmann, 2008). Crop pollination by bees and other animals is an essential ecosystem service that increases the yield, quality and stability of 75% of globally important crops (Klein *et al*., 2007). Bees rely solely on pollen and nectar for their energy requirements and provisioning of their nests making them frequent flower visitors and the most valuable of the insect pollinators. In agricultural settings, bees are essential to production as they pollinate most crops responsible for our fruits, vegetables, seed crops, and crops that provide fiber, drugs, and fuels (National Research Council, 2007). Many cash crops, vegetables and non-timber forest products including medicinal plants and nuts that support small-scale farmers' economies depend mainly on pollination services delivered by different bees (Munyuli, 2012b). In tropical forests, savannah woodlands, mangrove, and in temperate deciduous forests, many species of plants and animals would not survive if bees were missing (Ingram *et al*., 1996). 'About one mouthful in three in the diet directly or indirectly benefits from honey bee pollination,' explains the United States Department of Agriculture (USDA). Without bees to pollinate flowers and crops, over half of the world's population would starve to death (Ingram *et al*., 1996).

Potentially, the most significant problem and one that affects everyone who eats is the disruption of vital plant-pollinator relationships. Insect pollination is threatened by several environmental and anthropogenic factors, and concern has been raised over a looming potential pollination crisis. Bees, the main animal pollinators of wild and agricultural plants in most ecosystems

(Buchmann & Nabhan, 1996; Ollerton, Winfree & Tarrant, 2011), are currently suffering considerable declines in abundance and richness (Biesmeijer *et al*., 2006; National Research Council, 2007; Steffan-Dewenter, Potts & Packer, 2005). Declines in pollinators have been reported in several regions of the world including the USA, Mexico and Canada where both feral and managed honeybee numbers declined by 25 percent between 1997 and 1998 (Allen-Wardell *et al*., 1998). Cameron *et al*. (2011) reported a 96 percent reduction in the abundance of four North American bumble bee species, *Bombus occidentalis, B. pensylvanicus, B. affinis,* and *B. terricola* coinciding with a 23-87 percent reduction in their geographic ranges. Bees are important plant pollinators and any decline in their numbers or species constitutes a significant threat to both biological diversity and the ecosystem services they provide, and to whole agricultural economies (Kosior *et al*., 2007).

Drivers of pollinator decline

Drivers of pollinator declines are numerous and thought to be synergistic; however they have yet to be clearly characterized owing to geographically sporadic and temporally limited studies (Potts *et al*., 2010). Some authors attribute pollinator loss to changing land use practices (habitat loss through mechanical destruction, fragmentation, fire, overgrazing and recreation), agro-chemicals and other pollutants (e.g herbicides), parasites and diseases; competition between species and individuals induced by man and climate change (Abrol, 1990; Rasmont & Mersch, 1988). According to Luig *et al*. (2005) the five most important pressures on pollinators and pollinator services are land use practices, agrochemicals, parasites and diseases, genetically modified plants and invasive species.

Human activity, based on the assumption that pollination is a free and abundantly available ecosystem service, has put a large pressure on pollinators by both increasing their demand and removing their habitat (FAO, 2011). It is believed that humans have modified greater than 50% of the Earth’s land surface and this is but one change; others include changes in composition of air and water, and loss of overall biodiversity (Hooke & Martín-Duque, 2012). Biodiversity, therefore, is being exploited at much faster rates than ever before with negative implications for sustainable human livelihood (Turner *et al.*, 1990). A report by Wuver and Attuquayefio (2006) indicated that major human activities that impact on the biodiversity are bushfires, hunting, fuelwood harvesting and farming.

The global decline in pollinator populations has prompted an upsurge in pollinator monitoring programmes and initiatives designed to assess the current status and future trajectory of these environmentally and agriculturally vital populations. The Convention on Biological Diversity (International Pollinator Initiative, http://www.cbd.int/decision/cop/?id=7147) calls for the conservation and sustainable use of pollinators by monitoring pollinator decline, addressing lack of taxonomic information, and restoring pollinator diversity in agricultural and natural ecosystems among other goals. The ALARM Project (Assessing Large Scale Risks for Biodiversity with Tested Methods) was designed and funded by the United Nations Food and Agriculture Organization. The project assessed bee and flower fly populations in the Netherlands and England before and after 1980 analyzing more than 500,000 records. The results of the comprehensive survey, (reported in Beismeijer *et al.*, 2006), revealed a decline in these populations. In the United

States the North American Pollinator Protection Campaign (NAPPC) is instrumental in promoting the conservation and restoration of pollinator habitat and in constructing task forces that promote pollinator conservation. These programmes are linked by the common goal of pollinator conservation; however, effective conservation must be based on sound knowledge of the community dynamics driving pollinator populations. Currently, there are no accurate data available to reach firm conclusions on the status of global pollinators in terms of their abundance and diversity (Aizen & Harder, 2009; LeBuhn *et al*., 2013). The better we understand the drivers of bee biodiversity the more prepared we will be to preserve, manage, or supplement the habitats upon which they depend.

Statement of the Problem

Several scientific studies show that a diversity of wild bee species is important for sustainable crop production (Buschini, 2006; Munyuli, Potts & Nyeko, 2008). A diversity of wild bee species is also essential to ensure food is delivered to our tables every day. While commercially managed honey bees are known to be important in crop pollination and hence in crop production, there is a growing body of evidence that indicates that wild bees contribute to a substantially high proportion of crop pollination services than previously thought (Winfree, Aguilar, Vázquez, LeBuhn & Aizen, 2009).

Agriculture has been and continues to be the largest contributor to Gross Domestic Product (GDP) in Ghana. The bulk of food crops in Ghana are produced in the Forest Savannah Transition Zone (FSTZ). This is because large quantities of vegetables, cereals, tubers and fruits are harvested in the area and transported down south almost on a daily basis. Several food and cash crops are grown, mainly yam (*Discorea alata*), plantain (*Musa sapien*), maize (*Zea mays*), watermelon (*Citrullus lanatus*), tomato (*Lycopersicon esculentum*), egg plant (*Solanum melongena*), pepper (*Capsicum annum*), cucumber (*Cucumis sativus*), mango (*Mangifera indica*), cashew (*Anarcadium occidentale*); and several other fruits, vegetables and horticultural crops (Figure 1). Many of the crops cultivated in the FSTZ are pollinated by bees. These include mango, cola, cashew, cucumber, egg plant, tomato, pepper, shea, oil palm and water melon. The majority of these crops are grown either in a polyculture or monoculture system by small-scale farmers.

Many studies have confirmed that diverse communities of pollinators (mainly wild bees) provide more effective pollination services to crops and wild plants than less diverse communities (Breeze, Bailey, Balcombe & Potts, 2011). In addition, research has revealed that yields of insect-pollinated crops are more unstable when the pollinator community (in a region) consists of fewer species (Garibaldi, Aizen, Klein, Cunningham & Harder, 2011).

Recent reports have pointed out that most pollinator populations have declined to levels that cannot sustain pollination services in both agro-ecosystems and natural habitats due to the increased disruption of habitats in both temperate (Kearns *et al*., 1998) and tropical landscapes (Vinson, Frankie & Barthell, 1993). This situation is alarming given our reliance on these insect pollinators for biodiversity and food security. Experts have therefore expressed fears on local extinctions of native pollinators, the most vulnerable being bees, and especially solitary bees (Westerkamp & Gottsberger, 2000).

Bees, the most important group of pollinators, are affected by human disturbances such as habitat loss, grazing, logging, and agriculture (Kremen *et* *al*., 2007). Managed honey bees sharply declined by 25% in Europe between 1985 and 2005 (Potts *et al*., 2010). The decline of bees has led to the concept of a global pollination crisis, a situation where pollination services by bees are limited thus causing the yield and quality of crops to deteriorate. Landscape change is one cause of fragmentation, which may decrease bee abundance and richness (Jennersten, 1988; Steffan-Dewenter *et al.,* 2002; Steffan-Dewenter, Klein, Gaebele, Alfert, & Tscharntke, 2006). There are many human activities taking place in the FSTZ of Ghana which have the tendency to alter the landscape and affect bee populations. Among them are logging, bushfires, mining, urbanization and agriculture. For example, large trees which provide nesting sites for bees have been the target of loggers over the years. Where logging is common, cavity nesting bees, honey bees, stingless bees and carpenter bees are heavily impacted (Steffan-Dewenter *et al*., 2002). By ploughing, digging, cutting, paving and spraying unwanted vegetation (particularly wild flowers) we devastate the sites where wild bees make their homes.

Evidence in Ghana has shown that the rate of environmental degradation has increased in recent times (Gyasi *et al*., 1995), in such a way that previously rich forests are being converted to savannah woodland whilst existing savannah woodlands are being converted into near desert (Hawthorne & Abu-Juam, 1995). It has been estimated that Ghana’s high forest area of 8.2 million hectares at the turn of the last century had dwindled to about 1.7 million hectares by the mid-1980s (Hall, 1987), and about one million hectares by the mid-1990s (Forest Services Division, 1996). This obviously, leads to the decline of pollinators.

Ecosystem services such as pollination, pest control and seed dispersal, are delivered at a local scale by mobile organisms foraging within or between habitats (Lundberg & Moberg, 2003). Although these mobile organisms deliver services locally, their individual behaviour, population biology and community dynamics are often affected by the spatial distribution of resources at a larger landscape scale. While landscape effects are known to affect communities of herbivorous and predatory/parasitic insects in agro-ecosystems (Bianchi, Booij &Tscharntke, 2006; Cronin & Reeve 2005; Tscharntke, Klein, Kruess, Steffan-Dewenter & Thies, 2005), a similar evaluation of landscape impact on crop pollination is lacking. The configuration of the landscape, and how bees are able to disperse through the landscape will determine whether spatially fragmented resources are available (Steffan-Dewenter & Tscharntke, 2002; Tscharntke & Brandl, 2004). For instance, habitat loss and fragmentation can result in resource depletion but minimum patch sizes are important for the persistence of bee communities (Kremen *et al*., 2004). The protection of key habitats and connectivity within the landscape therefore represents an important tool for bee conservation (Byrne &Fitzpatrick, 2009). Other pressures such as grazing (Vulliamy, Potts & Willmer, 2006) and fire (Potts *et al*., 2003) modulate the availability of resources in the landscape and can funsdamentally alter habitat quality for bees. More frequent fires (Potts *et al*., 2003) and excessive grazing (Kreuss &

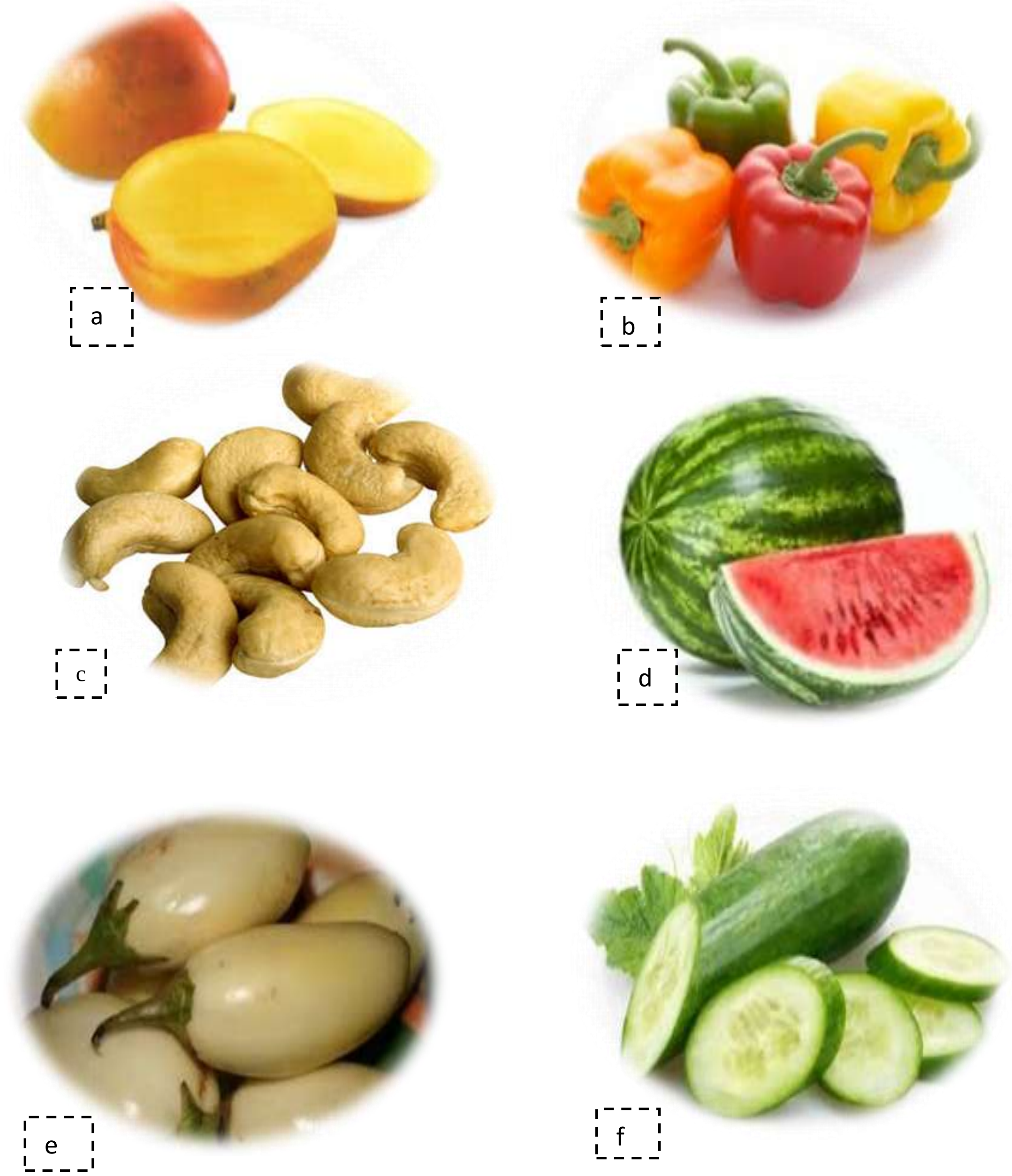


Figure 1: Some bee-pollinated crops cultivated in the FSTZ of Ghana.

a-Mango-(www.newtelegraphonline.com)

b-Pepper (www.sheknowns.com)

c-Cashew(www.dattaglobaltraders.com)

d-Watermelon (www.organicfact.net)

e-Garden egg(bellfat burnoff.com)

f-Cucumber (www.cushoemetics.com)

Tscharntke, 2002) can lead to habitats supporting fewer pollinators including bees.

Worldwide, there is a great concern to protect plants and their pollinators in both natural and agricultural landscape structures (Buchmann & Nabhan, 1996; Lassale & Gauld, 1993). Predictions by IUCN suggest that 20,000 flowering plants and their co-dependent pollinators will be lost within the next few decades (Heywood, 1995). The international community has acknowledged the importance of a diversity of insect pollinators to support the increased demand for food brought about by predicted population increases.

Key challenges related to the conservation of bee faunas and pollination services in Sub-Sahara Africa (Eardley, Gikungu & Schwarz, 2009; Gikungu, 2006; Munyuli, 2011b) are the absence of basic knowledge of the natural history, abundance, diversity, spatio-temporal distribution, foraging activities and pollination efficiency of different species in both natural and agricultural landscapes. According to Michener (2000), African tropics could be richer in bees than oriental tropics but lack appropriate data to prove it. Studies conducted in Central Europe and the US show that bee diversity and abundance is influenced by the structure and composition of the surrounding landscape (Tscheulin, Neokosmids, Petanidou & Settele, 2011). Again, in sub-Saharan Africa and in Ghana, farmers' perception and awareness about the role of pollinators in crop production is very minimal. Despite the importance of bees in crop production and the contribution of agriculture to the Ghanaian economy, there are very few reliable data on bees particularly their species composition in Ghana to guide decisions on monitoring and conservation.

Interviews with crop farmers, extension agents, and agricultural lecturers on pollinators and pollination conducted in Ghana by the Afrcan Pollinator Initiative (2007) indicated that extension agents had more knowledge on pollination than crop farmers. For example, 75 percent of agricultural agents thought that pollinators needed to be protected as against 31percent of crop farmers. This study was however limited to only three vegetable growing areas in the Central region.

Purpose of the Study

The principal objective of this study was to determine the influence of landscape type on bee species abundance and diversity in the FSTZ of Ghana and to obtain information from local crop farmers on their knowledge level of pollinators and pollination.

Objectives of the Study

1. To identify and document the bee faunas in the FSTZ of Ghana.
2. To compare bee abundance and diversity across landscape types in the FSTZ of Ghana.
3. To compare bee abundance and diversity across the the three subzones in the FSTZ of Ghana.
4. To assess the knowledge level of local crop farmers on pollinators and pollination within the FSTZ of Ghana.

Hypotheses

1. Landscape type does not affect bee species abundance within the FSTZ of Ghana.

2. Landscape type does not affect bee species diversity within the FSTZ of Ghana.

Significance of the Study

To ensure successful pollination and maximum crop production, diverse populations of wild bee species, the most important group of pollinators (Kremen *et al*. 2007) are essential. Most studies on bees have taken place in the advanced countries whilst data on bee abundance and diversity in many countries of Africa including Ghana are rare. While there is no solid documentation on the status and trends of pollinators in the African continent, the overall global trends of demands for pollination against anticipated supply is relevant in an African context (Gemmill-Herren *et al*., 2014). Data on relative abundance and diversity of a population gives an indication of the population size or pollinator force (Kevan, 1999) within an ecosystem. No study to my knowledge has been conducted in Ghana to examine how different geographical landscapes might relate to the abundance and diversity of bee species. Such a study is necessary to reveal areas with declining bee populations or possible mismatches in bee-plant interactions which are prerequisites for conserving them for increased food production. Understanding those factors that determine the number and type of pollinators found in particular landscapes is essential to knowing how to conserve, manage and restore pollinator communities. If it is known which landscape types or habitats are ideal for maintaining diverse populations of bees, then ways of manipulating these habitats to support greater biodiversity can be encouraged. The need to document information on bee fauna in the FSTZ of Ghana is therefore urgent because of its major contribution to food security and livelihood sustenance. Knowledge of the abundance and diversity of wild bees in an area is the first step towards providing better habitat and resources for them (James & Pitts-Singer, 2008). This is crucial because bees are irreplaceable; their loss will be catastrophic (Abrol, 1990).

Delimitation

This research considered bee species abundance and diversity in the FSTZ of Ghana and also assessed the knowledge level of local crop farmers on pollinators and pollination. Only selected communities in the Ashanti and Brong Ahafo regions of Ghana which fall within the FSTZ were studied.

Limitations

Access to agricultural land was difficult owing to the bad nature of the road network in the study communities. Three set ups were destroyed by wildfire during the harmattan season between Decemebr 2013 and February 2014. Again, pan traps were sometimes found to have been either removed or content poured. These had to be replaced to ensure the reliability of the data collected. Lastly, some bee specimens were lost while being pinned for identification.

Definition of Terms

Abundance: It is the relative representation of species in in a given community.

Agricultural land: This refers to land cultivated with crops.

Diversity: It is the effective number of different species represented in a collection of individuals or a dataset.

Evenness: This is the measure of the relative abundance of the different species making up the richness of an area.

Landscape: This refers generally to an area of land containing a mosaic of patches.

Natural vegetation: This refers to a forest.

Settlement fringes: They refer to the immediate surroundings of the study communities.

Subzone: It is any of the upper, middle and lower portions of the Forest Savannah Transition Zone (FSTZ) of Ghana.

Organization of Study

This study is organized into six chapters. The first chapter provides an introductory overview of the entire study comprising background to the study, statement of the problem, purpose of the study, study objectives, significance of the study, delimitation, limitations, definition of terms and organization of the study. The second chapter deals with relevant literature on bee species abundance and diversity. Chapter three describes the materials and methods used for data collection. It encompasses the study area, sampling sites, sampling methods, lab work, survey of crop farmers and data analyses. The fourth chapter presents findings from the study and these are discussed with relevant literature in chapter five. Chapter six, the concluding chapter, provides a summary of the major findings, draws conclusions based on the study objectives and puts out recommendations for policy implementation and further research.

CHAPTER TWO

LITERATURE REVIEW

Forest Savannah Transition Zones

A transition zone is an area or place with more than one type of properties; the properties can be related to weather conditions, topography or physical features. In ecology, a transition zone is an area distinguished from adjacent parts by distinctive physical conditions and supporting a particular type of flora and fauna. A FSTZ thus refers to the region between a forest and a savannah.

Forests in most West African countries show a strong floristic and structural gradient correlated with climate (Swaine & Hall, 1986). In Ghana, the FSTZ is formed from two vegetation types namely the semi-arid Guinea savannah vegetation to the north and the moist Semi-deciduous forest to the south. The change from forest to savannah is complex and fragmentary, with a mosaic of the two vegetation types apparently determined by a variety of factors. Subtle differences in water regimes caused by changes in evapotranspiration due to relatively small variation in altitude, or by variation in soil drainage and water retentionp properties, assume greater importance and correlate with the local pattern of forest and savannah (Swaine, Hall & Lock, 1976). Following decades of rapid land cover conversions of the original forest savannah mosaics, the present vegetation is much fragmented with considerable loss of tree cover (Amanor & Pabi, 2007; Pabi & Attua, 2005). The vegetation which reflects both savannah and forest characteristics is a savannah woodland interspersed with high forest mosaics and gallery forests along banks of streams and rivers (Amanor & Pabi, 2007). The ecotone is prone to erratic conditions of both climatic and environmental nature. The Upper, Middle and Lower FSTZs differ in their floristic composition and structure. Spatial variations in plant density and diversity occur from complex interactions based on local ecological conditions (Barnett & Kohn, 1991). The vegetation in the Upper FSTZ is predominantly grassland, interspersed with clusters of low-density drought resistant trees such as baobabs or acacias whilst the lower zone is dominated by trees with a relatively small percentage grass cover. The lower zone contains most of the country's valuable timber species some of which are as high as 45m. They include *Milisia excelsa*, *Entandrophragma cylindricum*, *Triplochiton scleroxylon*, *Khaya ivorensis* and *Ceiba pentandra*. The middle section of the transition zone has an almost equal blend of trees and grasses. Many of the trees found in this region shed their leaves during the dry season from December to March. Major food crops grown in the ecotone are maize, yam, plantain, pepper, tomato and egg plants.

The Concept of Landscape

The term landscape refers generally to an area of land containing a mosaic of patches. Turner, Gardener & O'Neill (2001) defined landscape as an area that is spatially heterogeneous in at least one factor of interest. The size of a landscape varies depending on what constitutes a mosaic of habitat or resource patches meaningful to the particular organism. It could vary from an area smaller than a single forest stand (e.g, an individual log) to an entire ecoregion. A landscape is not necessarily defined by its size; rather, it is defined by an interacting mosaic of patches relevant to the phenomenon under consideration. The structure of a landscape is defined by the particular spatial pattern being represented, and it consists of two components: the amounts of different possible entities (e.g., different habitat types) and their spatial arrangements.

Landscape ecology is the study of how landscape structure affects the abundance and distribution of organisms. Based on landscape, species within habitat patches are predicted to be dependent not only on local conditions, but also on the surrounding landscape and interactions with other habitat patches ecology (Turner *et al*., 2001). Different species will perceive and react to landscape changes at different spatial scales (Steffan-Dewenter *et al*., 2002). Therefore, to understand patterns in species diversity and community composition within local habitats a landscape perspective is needed. This also has implications for management. Habitats cannot be successfully managed as independent entities; instead managers, ranging from farmers to governments, need to consider whole landscapes (Lindenmayer *et al*., 2008). In order to be able to maintain or enhance bee populations and the services they provide, it is, therefore, essential to better understand how the surrounding landscape affects bee abundance and diversity, especially in agro-ecosystems. At a landscape scale, the structure and composition of habitats, defined as the landscape context, and especially semi-natural and natural habitats, are the main drivers of bee diversity (Kremen, Williams & Thorp, 2002; Steffan-Dewenter *et al*., 2002). The surrounding landscape matrix may increase the amount of available resources or provide additional resources that do not occur within a local habitat fragment. Some bee species, for example, need different habitat types within their flight range to fulfil their specific requirements with respect to food resources, nesting sites and building material (Steffan-Dewenter *et al*., 2002; Westrich, 1996). Therefore, the surrounding matrix can significantly influence the ‘structural connectivity’ of habitat patches, thereby possibly increasing or decreasing local population density and even extinction risk (Ricketts, 2008).

Importance of Pollinators

One of the most important ecosystem services for sustainable crop production is the mutualistic interaction between plants and animals: pollination. A pollinator is the biotic agent (vector) that moves pollen from the anthers (male part) of a flower to the stigma (female part) of a flower to accomplish fertilization of the female gametes. Flower visitors range from generalists to specialists, and some of these gather nutrients from plants without aiding the pollination process (Roubik, 1995). Pollination is the basis for the maintenance of biodiversity in agricultural and natural landscapes. In agriculture, especially amongst pollen-limited crops, promoting pollination services is a means of increasing productivity without resorting to expensive agricultural inputs of pesticides or herbicides. For many plants, a well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit. Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruit to pests, disease, bad weather and agro-chemicals, and saving on water use (UNEP, 2010). Pollination is a crucial stage in the reproduction of most flowering plants, and pollinating animals are essential for transferring genes within and among populations of wild plant species (Kearns *et al*., 1998). It is estimated that pollen transferred by animal vectors accounts for

90% of the pollination occurring in flowering plants worldwide (Buchmann & Nabhan, 1996).

The ecological, agricultural and economic importance of pollinators is immense and yet inestimable. Pollinators strongly influence ecological relationships, ecosystem conservation and stability, genetic variation in the plant community, floral diversity and evolution. The importance of pollination as an ecosystem service is perhaps mostly associated with the agricultural landscape. Crop production can profit in several ways from pollination, including an increase in seed number, seed quality, fruit production, fruit quality and uniformity in ripening (Kearns *et al.*, 1998). Recent studies have tried to capture the value of pollination service in numbers and conclude that the importance of pollination services in agriculturally dominated landscapes has long been underestimated. In a review of the importance of pollinators for world crops, it was found that 87 of the leading global food crops are entirely or partly dependent on animal pollination and that these crops make up 35% of the global food production (Klein, Steffan-Dewenter & Tscharntke, 2006). About 75% of the 115 leading global food crops profit from pollination and pollination is essential or highly important for 40% of the pollinated crops (Klein *et al*., 2007). Globally, it is estimated that insect pollination contributes 67% of the biotic pollination requirements of plants (Potts *et al.*, 2010). A global study of how much the production of crops that nourish humanity is dependent on animal pollination, based on FAO crop production data, reveals that pollinators such as bees, flies, butterflies and moths, and beetles affect 35 percent of the world’s crop production (Kremen & Ricketts, 2000; Klein *et al*, 2007). Although 60% of the global food production comes from crops that do not depend on animal pollination; mainly staple crops like cereals such as wheat, maize and rice, ensuring nutritional diversity, either comes from crops that depend on pollinators or from a small percentage of crops (5%) for which the dependence upon animal pollination is still unknown (Klein *et al*., 2007).

Economic estimates on a national basis for the role of pollination in the United States, Canada, Europe, New Zealand and Australia have been used as an estimate of more than US$50 billion in values to global agriculture alone (Borneck & Merle, 1989; Gordon & Davis, 2003; Matheson & Schrader, 1987; Morse & Calderone, 2000; Winston & Scott, 1984). The worldwide value of pollination was estimated at 153 billion pounds per year or approximately 39% of the world crop production value (625 billion pounds) from the total value of 46 insect pollinated direct crop species (Gallai, Salles, Settele & Vaissiere, 2009); and more recently at almost 300 billion Euros, with its value still rising (Lautenbach, Seppelt, Liebscher & Dormann, 2012). Estimates vary in large measure for different researchers because different underlying approaches are used for computing values. For example, Muth and Thurman (1995) stated that the value of commercial pollination services is the amount farmers pay to beekeepers to rent bees, and critisized other studies for inflated estimates of pollination service values. Beyond these estimates of pollinator contributions to crop production, other aspects of agriculture also depend upon pollinators. Seed production and grazing resources for livestock and wildlife and soil fertility all benefit from pollination services, as do many functions of natural ecosystems (Food and Agricultural Organization {FAO}, 2008).

The area covered by pollinator-dependent crops has increased by more than 300 percent during the past 50 years (Aizen, Garibaldi, Cunningham & Klein, 2008; Aizen & Harder, 2009). Many cash crops, vegetables and non timber forest products including medicinal plants and nuts that support African economies depend mainly on pollination services delivered by different types of pollinators (Munyuli, 2010). Pollinators provide extremely valuable service and benefits to society. By increasing food security, pollinators contribute to the improvement of livelihoods and to the significant increase of income of some of the world's poorest people in Sub-Saharan Africa including Ghana.

Pollinators, most importantly bees, are necessary for plant reproduction, and they are a fundamental part of a food web (Kearns *et al*., 1998). At least 450 crop species globally depend on pollination by bees (Munyuli, Kasina, Lossini, Mauremootoo & Eardley, 2011). The honeybee (*Apis mellifera* Linnaeus) is the single-most important pollinator in the world (Aizen & Harder, 2009). It is considered one of the most valuable pollinators in agriculture. It is estimated that honey bees alone pollinate plants that make up 30% of the human diet (McGregor, 1976). It is reported that non-managed wild bees are responsible for an estimated 3.07 billion dollars in pollination each year to crops (Losey & Vaughan, 2006). Therefore, the production and diversity of agriculture seem to depend to a large extent on biotic pollination, particularly on the service provided by the honey-bee (*Apis mellifera*), the single most important pollinator species, and a plethora of wild bee species.

In the developed countries, insect pollination has increased considerably during the past few decades and arrangements for insect pollination are now part of standard management practices when growing many crops. For example, in the USA alone, over one million honeybee colonies are rented annually for pollination services (Thapa, 2006; Roubik, 2002).

Ecosystems' Dependence on Pollinators

Ecosystem services are functions provided by nature that improve and sustain human well being (Daily, 1997). These services include climate regulation, soil production, water purification, seed dispersal, pest control and crop pollination. Crop pollination, pest control and seed dispersal, are produced on a local scale by mobile animals foraging within or between habitats (Gilbert, Gonzales & Evans-Freke, 1998; Lundberg & Moberg, 2003). Animal pollination is important to the sexual reproduction of many crops (Free 1993, Westerkamp & Gottsberger, 2000; Williams, 2003) and the majority of wild plants (Ashman *et al*., 2004; Kearns *et al*., 1998) which can also be important for providing calories and micronutrients for humans (Sundriyal & Sundriyal, 2004). Pollination is critical for food production and human livelihoods, and directly links wild ecosystems with agricultural production systems. Animal-mediated pollination contributes to the sexual reproduction of over 90 percent of the approximately 250 000 species of modern angiosperms (Kearns *et al.*, 1998). The vast majority of flowering plant species only produce seeds if animal pollinators move pollen from the anthers to the stigmas of their flowers. Roubik (1995) provided a detailed list for 1330 tropical plant species, showing that for approximately 70% of tropical crops at least one variety is improved by animal pollination. For European crops, Williams (1994) assessed the pollinator needs for 264 crop species and concluded that the production of 84% of these depends at least to some extent upon animal pollination. This interaction diffusely affects human survival through its roles in sustaining much biodiversity on Earth and contributing to the integrity of most terrestrial ecosystems. With this huge dependence, pollinators are thus considered to be keystone species in the world's ecosystems. Without this service, many interconnected species and processes functioning within an ecosystem would collapse.

Pollinators and Socio-economic Conditions in Ghana

Most of the economically active population in the FSTZ of Ghana engage in agriculture consistent with the national figure of over 60 percent (Al-Hassan & Diao, 2007). Other major income generating activities undertaken by rural communities in the FSTZ of Ghana besides crop farming are animal rearing, charcoal burning, hunting, firewood collection and small scale mining. These activities are carried out almost on daily basis without measures taken to restore the original environment. This heavy dependence on natural capital has resulted in the highly degraded nature of the FSTZ; a major challenge to the sustainability of pollinators including bees. Obviously, farmers can play significant role in the conservation of bees if they are made aware of the importance of bees to the improvement of their livelihood and sustainability of their agricultural systems.

Bee Pollinators

Bees are flying insects closely related to wasps and ants and are noted for their role in pollination and honey production. They range in colour from dull brown and black to bright blue and greens, and they vary in length from about sixteen of an inch to more than an inch (Shepherd, Buchmann, Vaughan

& Black, 2003). Bees are found in every continent (except Antarctica) and in every habitat where insect pollinated flowers grow (Shepherd *et al*., 2003).

In scientific terms, bees are in the insect superfamily *Apodea.* This superfamily includes lots of families, subfamilies, tribes (Michener, 2000) and approximately 25,000 species worldwide (O' Toole & Raw, 1991) of which 3000 species are found in sub-Saharan Africa (Eardley, Kuhlmann & Pauly, 2010). Different species usually have different physical traits, like wing shape or tongue length. Bees can be either social or solitary, depending on the level of cooperation between closely related females (O' Toole & Raw, 1991). Many people are most familiar with social bees because they can be more visible than solitary bees. Many social species produce substances that people use, like honey and beeswax, and people can see large groups of social bees feeding in orchards and gardens. Most bees, however, aren't social -less than 15 percent of bees live in colonies (O' Toole & Raw, 1991). The rest are solitary. They may exhibit some social tendencies, but they don't build large hives or store lots of extra honey. Instead, they build small nests that are big enough to hold a few eggs or a single egg.

Social bees

Social bees, according to O' Toole & Raw (1991), have colonies of hundreds (bumblebees) or tens of thousands (honeybees), of individuals and seek to nest in well sheltered underground or aboveground cavities. Two familiar social bees are honeybees and bumblebees both of which live in large groups. Social bees use waxy secretions from their bodies to build large nests and containers in which to store food and raise young. A third type of social bee is the stingless bee. Stingless bees are native to tropical areas (e.g. *Meliponula bocandei)*, where some societies use them for honey production.

Although honeybees and bumblebees are both social, their societies differ considerably. Honeybee colonies, or hives, are perennial. A queen and her daughters use wax from the wax glands on their abdomens to build a nest that lasts them for generations. If the hive becomes overcrowded, the workers, who are all female, will raise a new queen by feeding her royal jelly from a gland on their heads throughout her development. The old queen will leave the hive with about half of the workers in order to build a new nest, and the new queen will stay behind. The bees know that they need to raise a new queen when they stop receiving enough queen substance-a pheromone that the queen produces in her mandibular glands.

Bumblebees, on the other hand, have annual nests. Each year, the queen mates in the fall and then spends the winter underground. In the spring, she emerges and builds a nest in which she lays eggs. When her daughters hatch, they become workers, and they help the queen enlarge the nest. At the end of the summer, the queen lays eggs that hatch into new queens and male drones. The drones gather at a mating site in order to mate with the queens from various colonies, and the cycle continues.

Solitary bees

Solitary bees are so named because, unlike honeybees and bumblebees, they do not live in colonies (Muller *et al*., 2006; O’Toole & Raw, 1991) Sometimes, lots of solitary bees build their nests close together, but with the exception of mating and the occasional group defence of the nest site, these bees do not usually interact with each other (Shepherd *et al*., 2003). About two thirds of all solitary bee species nest in the ground. Lots of solitary bees are known for how they make their nests. They can burrow *tunnels* in the ground (mining bees), in wood (carpenter bees), and in dead, hollow branches (small carpenter bees, sweat bees), or they can take over existing structures such as tunnels made in dead wood by beetle larvae (mason and leafcutter bees). Some use empty termite hills or wasp nests. A few species lay their eggs in empty snail shells, either dividing the cell into chambers using glandular secretions or laying one egg in each shell. A few bees, known as cuckoo bees, are parasitic - they lay their eggs in the nests of other bees. Some cuckoo bees don't have any structures for collecting pollen, since they rely on other bees' pollen to feed their young.

Female solitary bees build their nests and provide food for their offspring alone (James & Pitt-Singer, 2008). They may use cerumen, a type of wax secreted from their bodies, or propolis, a glue bees make from tree resins. Nests are generally lined and partitioned with materials such as mud, leaves, plant resin, and glandular secretions. These linings protect the brood from desiccation, disease, and excess moisture (Shepherd *et al*., 2003). Other solitary bees are known for the types of flowers they frequent or other distinguishing traits. Tiny sweat bees, for example, are attracted to people's sweat. Orchid bees are brightly coloured and often have a metallic appearance. Scientists believe that orchids and orchid bees have co-evolved so that the two are now dependent on one another. While social and solitary bees have considerable differences in how they live and build nests, they have a lot in common when it comes to reproduction.

Bee Families

Bees are insects of the superfamily Apoidea among which are seven major families (Michener, 2000). The families are Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Melittidae and Stenotritidae. Like all insects, the body of a bee consists of three regions, the head, thorax and the abdomen. They differ from the other hymenopteran insects by possessing small, distinct pronotal lobe that is well separated from and is below the tegula, and an extension of the pronotum ventro-laterally as a pair of processes, one on each side that encircle or nearly encircle the mesosoma behind the forecoxa (Michener & Griswold, 1994; Michener, 2000). The most important traits used in identifying bees to family are tongue length, wing venation, and how they transport pollen (Michener, 2000). Globally, over 30,000 species of bees have been named, and there are more yet to be identified (Michener, 2000).

Some families of bees, Halictidae in particular, are noteworthy among insects due to their substantial inter-specific (Brady, Sipes, Pearson & Danforth, 2006) and intra-specific (Soucy, 2002) variability in social behaviour. The behavioural plasticity observed within halictid social behaviour is of particular relevance as an example of how some species can exhibit more than one type of sociality across geographic and climatic gradients e.g both *Lasioglossum calceatum* and *Halicyus rubicundus* are social in lower altitude and solitary at higher altitudes (Eickwort, Eickwort, Gordon & Eickwort, 1996). An adjunct to the levels of social organization found within bees is their varying forms of parasitism, namely usurpation and robbing, social parasitism and cleptoparasitism (Michener, 2007). In all cases, the parasite benefits from resources gathered and or constructed by the host, with the host presumably incurring a fitness cost in the process. It is estimated that 15-20% of all bee species are parasites with the percentage of parasitic species tending to increase with latitude (Petanidou, Ellis & Ellisadam, 1995; Wcislo, 1987).

Factors Influencing Bee Abundance and Diversity

Bees thrive in an environment which has adequate, varied and nutritious forage (Munyuli, 2012b). The adult bee uses nectar as an energy source whilst most pollen provides protein and other nutrients for larvae. They have a long proboscis for which is a sort of complex tongue that enables them to obtain nectar from flowers. Practically, bees require three main basic types of resources to persist in a landscape (Munyuli, 2012b): (i) floral resources (both pollen and nectar) for provisioning nest cells and for sustenance, (ii) appropriate nesting substrates or other nest-building materials and, (iii) the provision of suitable abiotic conditions (microclimate and local topography). For instance, the survival of pollinators in the farmland depends on how much foraging habitat (area and quality) and breeding/nesting habitat (area and quality) are conserved and maintained healthy in the agricultural matrices. Other factors influencing bee diversity and abundance include presence of natural or semi natural habitats, life history traits and land-use factors. Many of the factors influencing bee abundance and diversity were discussed in chapter one.

Floral resources

Bees are herbivores that feed their larvae with a mixture of pollen and nectar or rarely plant oils (Michener, 2007). Flowers provide food for bees in the form of nectar and pollen. Ideally, you should have many different kinds of flowers that bloom at different times of the year, so there is always something available to the bees on any given day. A greater diversity of flowers will naturally attract a greater diversity of bees, and also provide a greater diversity of nectar and pollen. Not all nectar and pollen is equally nutritious, so a variety is important for a healthy bee diet. Robertson (1925) was one of the first to observe that bees do not collect pollen on flowers randomly but that there are specialists and generalists. Even generalist bees show a restricted range of pollen sources (Muller & Kuhlmann, 2008). The quantitative pollen requirements of bees are little known. In a study of forty one bee species, Muller *et al.*, (2006) revealed that 85% of them require the whole pollen content of more than 30 flowers to provision a brood cell and some species even needed the pollen of more than a thousand flowers to rear a single larva. This implies that tens of thousands of flowers of a certain plant must be available within range to sustain a viable population of an oligolectic bee species. Hence, the loss of plant diversity and flower quantity due to habitat destruction and fragmentation of the landscape is assumed to be responsible for the decline of many bee species (Muller *et al.*, 2006). Oligolectic bees are bees which forage on a small number of flowering species. Social bee species are typically polylectic (Michener, 2007) and are generally believed to be less prone to extinction. Polylectic bees are those that forage on a wide range of floral resources. Specialized bees generally do not switch to other host plants, even if their preferred plants are not in flower (Williams, 2003). Hence selection for synchrony of bee emergence with host plant flowering that is positively affecting individual fitness can be expected, especially in arid and semi-arid environments with highly variable precipitation (Powell & Mackie, 1966). Generally, it is hypothesized that host plant synchrony might be a mechanism for an elevated rate of speciation in desert bees (Danforth, Ballard & Ji, 2003) explaining the higher bee species diversity in semi-arid and arid environments. Thus, oligolectic bees that are strictly dependent on their host plants are more species rich in desert and Mediterranean environments and less diverse in temperate biota (Moldenke, 1979).

Nesting resources

Nesting resources for bees include the substrates within, or on which, bees nest and also the materials required for nest construction. Bees are extremely diverse in their nesting ecology and comprise a number of distinct guilds (O’Toole & Raw, 1991): miners, carpenters, masons, social nesters and cuckoos. Miners excavate tunnels in the ground or soft rocky substrates and line their tunnels with grandular secretions. Carpenter bees also excavate nests, but use wood as a substrate, and include species in the genera *Xylocopa*, *Ceratina* (Apidae) and *Lithurgus* (Megachilidae). In contrast, mason bees (most Megachilidae) utilize pre-existing holes which can be in the form of hollow plant stems, abandoned insect nest burrows in the ground or woody substrates, small cavities or cracks in rocks and even snail shells (O’Toole & Raw, 1991). Mason bees then line the inside of the pre-existing hole with materials such as leaves or soil. Within the mason guild, the leaf-cutter bees use only freshly gathered leaf or petal material to line their nests. Social nesters tend to use relatively large pre-existing cavities to establish social colonies and include three taxa within the Apidae: honeybees (*Apis*), bumblebees (*Bombus*) and stingless bees (*Meliponini*). Nesting preference of solitary bees can be basically classified into two groups (O'Toole and Raw 1991). About three-fourths (Westrich, 1996) of them are soil-nesting bees (also called mining, digging, ground-nesting, subterranean-nesting or fossorial-nesting bees). They prefer open, bare ground for excavation of deep holes. Soil nesting species favour dry, fine grained soils with low humus content (Klemm, 1996). The other solitary bees, mainly mason bees and carpenter bees, stay above ground and nest in cavities (Willmer & Stone, 2004). They nest in existing cavities (such as beetle burrows in wood, deserted snail shells, hollow plant stems and dead twigs and branches, or man-made cavities like nail holes and key holes) or in self-made cavities in trees, galls, cones and fruits (Cane, 1991). In agriculturally dominated landscapes, the nesting substrates for cavity nesters are found at structures with scrubs and trees that provide dead wood. One guild of bees, the cuckoobees or cleptoparasites, are found in several families and do not construct their own nests but instead parasitize the nests of others and use the food provisioned by the host to rear her offspring (Shepherd *et al*., 2003). These bees are parasites on other solitary bees and bees with lower levels of sociality.

Most non-parasitic bees dig burrows in the ground and hence prefer dry, sandy soil bare of vegetation, often on hillsides. The rest use hollow plant stems or holes in wood left by wood-boring beetles, instead of digging a tunnel in the ground. You can attract ground-nesting bees simply by making sure to leave some spots of exposed, undisturbed soil in your yard. Bumble bees nest underground, but use abandoned rodent burrows instead of digging their own. A nesting bee will use mud, leaves, or another material to build walls and divide the tunnel into a linear series of small, sealed cells.

In parallel with floral resources, the temporal and spatial distribution of nesting resources may determine the bee community composition in a given location (Cane, 1991; Potts *et al*., 2005). Eltz, Bruhl, van der Kaars & Linsenmair (2002) found that the abundance, size and species of trees in tropical forests of Southeast Asia influenced the density of stingless bee nests. Nesting resources shown to affect bee nesting success include; the abundance, size and species of trees in tropical forests for stingless bees (Samejima, Marzuki, Nagamitsu, & Nakasizuka, 2004) cavity shape and size for honeybees (Oldroyd & Nanork, 2009), and the diameter of pre-existing holes for colletid bees (Scott, 1994); soil hardness, slope and aspect of the ground for halictid bees (Potts & Willmer, 1997); and soil texture for solitary bees (Cane, 1991). The diversity of nesting strategies and the specialization of guilds means that the availability of the correct quantity and quality of resources, both in space and time, are key determinants for which species a landscape can support (Tscharntke *et al*, 2005). Any environmental disturbance (e.g. habitat loss, fragmentation, agricultural intensification, or fire) will alter the distribution of nesting resources. As bees are central place foragers and have species-specific flight distances, the location of the nest determines what floral resources are potentially available. The nesting traits of bee species will therefore determine their sensitivity to environmental change

(Moretti, de Bello, Roberts & Potts, 2009). In order to manage the landscape for bee conservation it is essential to understand how land use change affects nesting resources and how this interacts with the availability of other resources such as nectar and pollen.

Climatic factors

Bees are affected by climatic conditions. Gikungu (2006) determined that floral resources and weather are the key determinants of bee foraging behaviour. Even where floral resources are available bees are found to fly for short distances in poor weather conditions (Roubik, 1989). Temperature, in particular, is very important for internal as well as external activities of honey bee colonies. Veddeler, Klein and Tscharntke (2000) determined that overall, foraging behaviour of bees is temperature dependent. Bees are ectothermic, requiring elevated body temperatures for flying. The thermal properties of their environments determine the extent of their activity (Willmer & Stone, 2004). The high surface-to-volume ratio of small bees leads to rapid absorption of heat at high ambient temperatures and rapid cooling at low ambient temperatures. All bees above a body mass of between 35 and 50 mg are capable of endothermic heating, i.e. internal heat generation (Bishop & Armbruster, 1999; Stone & Willmer, 1989; Stone, 1993). Examples of bee pollinators with a body weight above 35 mg are found in the genera *Apis, Bombus, Xylocopa and Megachile*. Examples of small bee pollinators are found in the family *Halictidae,* including the genus *Lasioglossum.* All of these groups are important in crop pollination. In addition to endothermy, many bees are also able to control the temperatures in their flight muscles before, during and after flight by physiological and behavioural means (Willmer &

Stone, 1997). Examples of behavioural strategies for thermal regulation include long periods of basking in the sun to warm up and shade seeking or nest returning to cool down (Willmer & Stone, 1997).

In a recent review, Hegland, Nielsen, Lázaro, Bjerknes and Totland (2009) discussed the consequences of temperature induced changes in plant-pollinator interactions. They found that timing of both plant flowering and pollinator activity seems to be strongly affected by temperature. Insects and plants may react differently to changed temperatures, creating temporal (phenological) and spatial (distributional) mismatches with severe demographic consequences for the species involved. Mismatches may affect plants by reduced insect visitation and pollen deposition, while pollinators experience reduced food availability. Key biological events such as insect emergence and date of onset of flowering need to occur in synchrony for successful pollination interactions. In temperate climates bees become inactive during cold winter and remain within their nest feeding on stored honey. In tropical climates periods of inactivity due to cold weather are usually shorter.

All activities of honey bees were recently found to be controlled by temperature and relative humidity (Abou-Shaara & Al-Ghamdi, 2012, Hossam, Ahmad, & Abdelsalam 2012). Maintaining a suitable range of temperature from 33 to 36 °C inside colonies has been found to be very ideal for honey bees (Tautz, Maier, Groh, Rossler & Brockmann, 2003). Deviation from this range can affect the developmental period of honey bee immature stages, emergence rate (Tautz *et al*., 2003), colour of emerged bees (DeGrandi-Hoffman, Spivak & Martin, 1993), learning ability (Tautz *et al*., 2003), adult brain (Groh, Tautz, & Rossler, 2004) and disease prevalence. A relative humidity of 75% within colonies is considered suitable for immature stages (Ellis, Nicolson, Crewe, & Dietemann, 2008) of honey bees. In the case of external activities, no clear direct impact of relative humidity on honey bees has been reported, including foraging activity (Joshi & Joshi, 2010). The integration between temperature and relative humidity is thus very important for bee activity.

A study by Munyuli (2012b) in Uganda showed that light intensity is positively related to bee diversity (species richness) and to the proportion of bee contribution to fruit set. In Indonesia, it was found that diversity of solitary bees increased positively with light intensity (Klein Steffan-Dewenter, & Tscharntke, 2003b). Though most bees are diurnal and actively forage during the day, some bees begin foraging at dusk and are nocturnal to various degrees (Wcislo *et al*., 2004). Nocturnal or crepuscular activity has evolved independently several times in at least four bee families, presumably to exploit flowers that offer pollen and nectar rewards at night or as a response to greater competition, parasitism and predation risk during the day (Wcislo *et al*., 2004). Among dim-light foraging bees, some such as *Xylocopa tabaniformis*, *Xenoglossa fulva*, *Ptiloglossa guinnae* and *Megalopta genalis* are active only during crepuscular periods (Janzen, 1974). In others, such as *X. tranquebarica* in Thailand, *Apis dorsata, Apis mellifera* and *Lasioglossum* (Sphecodogastra) *texana*, nocturnal activity on moonlitnights has been reported (Kerfoot, 1967a, b; Dyer, 1985).

Climate change may be a further threat to pollination services (Hegland *et al*., 2009; Memmott, Craze, Waser & Price, 2007). Thomas *et al*. (2004) predicted that by 2050 climate change, even in the absence of other drivers of extinction, would doom 15–37% of all species to eventual extinction. According to UNEP (2010) many of the predicted consequences of climate change, such as increasing temperatures, changes in rainfall patterns, and more erratic or extreme weather events will impact negatively on pollinator populations. Less mobile pollinators (small bees and beetles, for example) may be most severely impacted.

With pollinator interactions, the most important effect of climate change is an increase in temperatures (Intergovernmental Panel on Climate Change {IPCC}, 2007). Changing climates may cause changes in the time of growth, flowering and maturation of crops, with consequent impacts on crop-associated biodiversity, particularly pollinators. Estimates from IPCC (2007) indicate that average global surface temperatures will further increase by between 1.1 degrees Celsius and 6.4 degrees Celsius during the 21st century, and that the increase in temperature will be greatest at higher latitudes (IPCC, 2007). Deutsch *et al*. (2008) found that an expected future temperature increase in the tropics, although relatively small in magnitude, is likely to have more deleterious consequences than changes at higher latitude. This, according to them, is because tropical insects are more sensitive to temperature changes and that they are currently living in an environment very close to their optimum temperature. It is therefore likely that tropical agroecosystems will suffer from greater population decrease and extinction of native pollinators than agroecosystems at higher altitudes. Climate change will very likely affect the interaction between pollinators and their sources of food, i.e. flowering plants, by inter alia changing the dates and patterns of flowering. Recent analysis has suggested that, under realistic scenarios of climate change up to 2100, between 17 precent and 50 precent of pollinator species will suffer from food shortages due to the temporal mismatch of their flight activity times with flowering of food plants (Memmott *et al.,* 2007). These authors concluded that the anticipated result of these effects is the potential extinction of some insect pollinators and some plants, and hence the disruption of their crucial interactions.

Natural and semi-natural habitats

Natural and semi-natural habitats provide foraging areas for bees (Carreck & Williams, 1997). For example, availability of large, old and hollow trees which are common in forest areas has been found to benefit pollinators such as bees and seed dispersers as they offer nesting or resting sites (Gordon, Manson, Sundberg, & Cruz-Angón, 2007). Many wild bees that contribute to pollination require forage sources outside of the crop bloom period which is provided for by surrounding natural vegetation (Tuell, Fiedler, Landis & Isaacs, 2008). Natural landscapes adjacent to crop fields provide floral resources all season and are important to the sustainability of wild bee populations. Several scientific studies have reported that increased areas of semi-natural habitat on farms and within the agricultural landscape favours diversity and abundance of native bees. A research conducted by Kremen *et al*. (2004) in California revealed that both native bee diversity and abundance are significantly related to the proportional area of wild habitat surrounding the farm. A large body of research shows that cultivated fields surrounded by simple habitats (i.e., other monocultures) have significantly fewer bees than crops surrounded by uncultivated land, and the number of bumblebees on crops increases with proximity to natural habitats (Darvill, Knight & Goulson, 2004; Ockinger & Smith, 2007; Osborne *et al*., 2008). Greenleaf and Kremen (2006), monitored native bee populations responsible for pollination of tomato and discovered that *Bombus vosnesenskii* was present more often in farms proximate to natural habitats. Such habitats experience less disturbance compared to cultivated fields and thus help maintain overall biodiversity by buffering temporal variation in resources (Corbet, 1995; Dover, Sparks, Clarke, Gobbett & Glossop, 2000; Fussell & Corbet, 1991; Holland & Fahrig, 2000; Ricketts *et al*., 2008). Other studies have reported a positive relationship between coffee fruit set and the amount of semi-natural habitats in the landscape (Gemmill-Herren & Ochieng, 2008) or the proximity of coffee fields to forest habitats (Klein *et al*., 2003b; Klein, Steffan-Dewenter & Tscharntke, 2003a; Ricketts, 2004; Veddeler, Olschewski, Tscharntke & Klein, 2008). The positive effect of semi-natural habitats on fruit or seed set is always attributed to more visitations from these semi-natural features (Breeze, Bailey, Balcombe & Potts 2011; Winfree, Bartomeus & Cariveau, 2011). The sensitivity of pollinators to agricultural management and other types of anthropogenic disturbance depends upon specific pollinator life history traits such as nesting guild, dietary specialization and social organization (Winfree *et al*., 2009; Williams *et al*., 2010b). Hence, differences in ecological and life history traits among pollinator species may also explain their differential response to land-use gradients.

Natural history traits

Foraging habits

Bees may be put into three categories based on their foraging habits (Leong & Thorp, 1999). Bees that seek out and forage on only a few plants do so because their pollen and nectar are highly nutritious and provide a complete diet. The advantage to the plant kingdom from this behaviour is enormous, since it assures cross-pollination within a single species. A few species of bee are known to pollinate one and only one species of flower. Bee-flower mutualisms of this type, known as *monolectic*, are rare but extremely important from an evolutionary perspective. Neither species will survive without the other, so a loss of one means the loss of both. Most bees, however, are opportunistic foragers that gather pollen from a vast number of species. These bees, known as *polylectic*, are valuable to farmers who often grow more than one crop at a time or more than one crop in sequence. Polylectic bees are generalist feeders and forage on many different plant species (Shepherd *et al*., 2003). Bees that are generalist adapt to a change in plant diversity more readily than specialists. Both honey bees and bumble bees are polylectic. Even bees that are polylectic tend to visit only one type of flower per foraging trip, a trait known as "floral consistency." Nature's way of ensuring good pollination, floral consistency prevents a bee from going from a clover to a vinca to a cucumber to a bean, for example. Such random flower visits would not yield the pollination necessary to set seed and maintain plant populations from year to year. Although polylectic bees are able to forage on many different plants, they still have preferences. Bees thrive in an environment which has adequate, varied and nutritious forage (Munyuli, 2012b). The adult bee uses nectar as an energy source whilst most pollen provides protein and other nutrients for larvae. They have a long proboscis for which is a sort of complex tongue that enables them to obtain nectar from flowers. Practically, bees require three main basic types of resources to persist in a landscape

(Munyuli, 2012b): (i) floral resources (both pollen and nectar) for provisioning nest cells and for sustenance, (ii) appropriate nesting substrates or other nest-building materials and, (iii) the provision of suitable abiotic conditions (microclimate and local topography). For instance, the survival of pollinators in the farmland depends on how much foraging habitat (area and quality) and breeding/nesting habitat (area and quality) are conserved and maintained healthy in the agricultural matrices. Other factors influencing bee diversity and abundance include presence of natural or semi natural habitats, life history traits and land-use factors.

Sociality

Bees can be either social or solitary, depending on the level of cooperation between closely related females (O’ Toole & Raw, 1991). Social bees include bumblebees and honeybees though the two differ considerably in their social behaviour. They usually nest in well sheltered underground or aboveground cavities. A third type of social bee is the stingless bee. Many people are most familiar with social bees because they can be more visible than solitary bees. Solitary bees, more than 95% of the more than 3,500 native bee species, do not cooperate with each other (Michener, 2000). They are so named because, unlike honeybees and bumblebees, they do not live in colonies. They may exhibit some social tendencies, but they don't build large hives or store lots of extra honey. Instead, they build small nests that are big enough to hold a few eggs or a single egg. Sometimes, lots of solitary bees build their nests close together, but with the exception of mating and the occasional group defence of the nest site, these bees do not usually interact with each other. Solitary bees can burrow tunnels in the ground (mining bees), in wood (carpenter bees), and in dead, hollow branches (small carpenter bees, sweat bees), or they can take over existing tunnels made in dead wood by beetle larvae (mason and leafcutter bees). While social and solitary bees have considerable differences in how they live and build nests, they have a lot in common when it comes to reproduction. A lot has already been said about sociality in a previous section.

Body size

Body size has been shown to be a powerful trait to predict bee flight ranges, with small bees having smaller flight ranges than large bees (Gathmann & Tscharntke, 2002; Greenleaf, Williams, Winfree, & Kremen, 2007; Van Nieuwstadt & Iraheta, 1996). Depending on bee size, resource utilisation, therefore, occurs over different spatial scales (Kremen *et al*., 2007; Öckinger & Smith, 2007; Winfree *et al*., 2009) An increased ability of a species to move over large distances, therefore, may increase its capacity to persist within fragmented landscapes (Bommarco *et al*., 2010). Within a bee's flight range, all ecological requirements must be fulfilled (Steffan-Dewenter *et al*., 2002; Westrich, 1996). In case more than one type of land cover is needed for the fulfilment of their requirements (e.g. nesting and foraging), all types of land cover must be within the bees' flight range. Due to their bigger flight range, larger bees are, therefore, less dependent on small-scale landscape context (Greenleaf *et al*., 2007), whereas small bees are limited to patches of one single type of land cover.

Land-use factors

Agriculture

Increased land use for agriculture leads to loss of bee habitats and habitat fragmentation and probably constitutes the most important driver of wild pollinator losses (Potts *et al*., 2010). High spatial and temporal instability of agricultural sites, associated with intensive agricultural practices (e.g. soil ploughing, pesticide use, crop rotation, landscape simplification) are the main causes of bee diversity loss in farmland areas (Goulson, Lye, & Darvill, 2008; Tscharntke *et al*., 2005). Loss of safe habitats (Richards, 2001) and corridors (Gilbert, Gonzales & Evans-Freke, 1998; Joshua, Julier & Roulston, 2009) for pollinators have been found to be the main threats to pollinators in fragmented landscapes. Wild bees have been declining along with increasing agricultural intensification (Biesmeijer *et al*., 2006). Intensified farming methods are driving the loss of valuable natural and semi-natural habitats including hedgerows, shrub-lands, old fields, natural grasslands, field margins and woodlands (Tilman *et al*., 2001). The demise of these natural and semi-natural habitats has led to a decrease in wild plant diversity. Habitat destruction is detrimental to bee populations through the loss of floral resources, nesting resources, and mating and resting sites, especially since some oligolectic bees require specific flowers (Kearns & Inouye, 1997; Kevan, 1999). Habitat loss is thought to be one of the major factors that contribute to bee declines. Intensively managed farm landscapes often lack the untilled ground, rotting logs, dead stumps, litter, tree snags, plants, and small cavities that native bees require for nest construction. Industrial farming monocultures, and more generally the lack of wild flower diversity within and around croplands, limit the amount of food that bees have access to both in space and in time. Bees can go hungry as farming becomes more intensified (Tirado, Simon & Johnston, 2013). This has a potentially damaging effect on bees because bees need an optimum nutrient balance to support their growth and reproduction (Vanbergen, 2013).

Chemical application

Widespread use of pesticides is a common practice in the current chemically intensive agriculture systems. Many flowers, nest sites, and the general environment around bees are often contaminated with chemicals, mostly pesticides. These insecticides, herbicides and fungicides are applied to crops, but reach the bees through pollen and nectar, and through the air, water or soil (Decourtye & Devillers, 2010; Desneux, Decourtye & Delpuech, 2007). These pesticides, by themselves, or in combination, can be toxic to bees acutely in the short-term or, in low-doses, with chronic effects that weaken and can ultimately kill bees. Most investigation of pesticide impact on pollinators comes from studies using honey bees, *Apis mellifera*. There is thus considerable information on the foraging behaviour of social bees and their risk to pesticides exposure (Desneux *et al*., 2007; Fisher, & Moriarty, 2011; Rortais, Arnold, Halm & Touffet-Briens, 2005). In contrast, studies on solitary bee exposure to pesticides are few, despite a growing awareness of pesticide impact that affects them (Brittain, Vighi & Bommarco, 2010; Williams *et al*., 2010a).

Excessive use or inappropriate application of pesticides is known to impact negatively on a wide range of pollinators (Batra, 1981; Kevan, 1975;

O’Toole, 1993). The application of pesticides in agriculture reduces species richness and abundances of bees (Kearns *et al*., 1998). The effect of insecticides and herbicides reaches far beyond the crops to which they are applied. Landscape-scale surveys of wild bees and butterflies show that species richness tends to be lower where pesticide loads and cumulative exposure risks are high (Brittain *et al*., 2010). Some pesticides weaken honey bees so that they become more susceptible to infection and parasitic infestation (Tirado *et al*., 2013). According to UNEP (2010), the chemical destruction of habitats through the massive application of herbicides can have long-term consequences, particularly on the distribution of pollinating insects in agro-environments. Herbicides destroy nectar and pollen resources for bees and may have an even larger impact than insecticides (Kearns *et al*., 1998). Large-scale herbicide application in and around cultivated farm fields drastically reduces the diversity and abundance of weeds and wild flowers. Wild bees are also negatively affected by the use of fungicides. Furthermore, fertilizer use reduces plant diversity and therefore nutritional diversity for bees (Kovacs-Hostyanszki, Batary & Baldi, 2011)). There is thus an important trade-off between crop protection by agrochemicals and protection of pollination services.

Fragmentation

A small patch where bees nest does often not provide enough foraging resources, which forces bees to forage farther away. Hence, the total area requirement of bees depends on the distance between the required resources (Westrich, 1996). Although bees are good flyers, they will try to keep their activity area low and nest in the vicinity of their foraging resource. This gets more complicated by the fragmentation of habitat patches (Westrich, 1996). Fragmentation leads to isolation of habitat and reduced patch colonization and is believed to negatively affect bee populations (Tscharntke & Brandl, 2004). Connectivity among habitats has been suggested as important for the ability of urban green areas to support biodiversity (Elmqvist *et al*., 2004). A study by Steffan-Dewenter *et al*. (2002) showed that the abundance of bees increased with habitat connectivity in an agricultural landscape. Apart from reducing connectivity, fragmentation affects the structure of the matrix between the habitat patches that must be crossed. A higher proportion of matrix between patches often means increased disturbance (Tscharntke & Brandl, 2004) and the type of matrix affects the movement of pollinators (Tscharntke and Brandl, 2004). Although the matrix can act as a barrier for bees (Powell & Powell, 1987), bees may easily survive in a network of patches that are available within their foraging range (Cane & Tepedino, 2001). It remains to be investigated how much the fragmentation of resource patches affects movement and performance of wild bees at the landscape scale.

Urbanization

There are two schools of thought concerning the effect of urbanization on pollinator diversity and community structure. One school of thought considers urbanization as one of the major causes of insect decline, in particular through the alteration of ecological features important to pollinators, such as food and nesting sites. Generally, bee species diversity within cities is lower than in nearby wilder habitats (Eremeeva & Sushchev, 2005; Matteson, Ascher & Langellotto, 2008; McIntyre & Hostetler, 2001). Analysis of data from several urban studies indicates that more than 90% of the individual bees collected belong to only 12 common genera (Cane, 2005). It appears that some elements of the natural bee fauna disappear from urban habitats. This happens because urbanization leads to native plant loss and also alters the availability of nesting resources. In Sweden, Ahrne´, Bengtsson & Elmqvist, (2009) measured percent impervious surface in the landscape surrounding survey sites and reported lower species richness of bumble bees and cavity nesting bees in areas containing a higher percentage of impervious surfaces. Indeed, urban disturbances eliminate potential ground nesting habitats because of impervious surface (Porter, Forschner & Blair, 2001). Many urban soils are probably too compacted to nest in (Matteson *et al*., 2008).

The second school of thought believes that urban habitats are remarkably good for pollinators. Though urbanization leads to native plant loss, cities may also have sites with diverse vegetation and little disturbed seed bank**s** (Tommasi, Miro, Higo & Winston, 2004). Half of all German Apidae species have been found in urban Berlin (Saure, 1996) while 35 percent of British hoverfly species can be found in a garden in Leicester (Owen, 1991). Cavity-nesting bees may fail to find enough nesting resources in urban green spaces and backyards due to frequent mowing and removal of dead stems (Matteson *et al*., 2008), but cities also provide a high diversity of compensating anthropogenic substrates suitable for cavity-nesting bees, such as wooden fences, barns and mortar brick walls (Saure, 1996, Cane & Tepedino, 2001). Generalists bee species with broad tolerances are favoured in urban areas (Cane, 2005), while specialists suffer from the absence of their host plants. In a study by Ahrne´ *et al*. (2009), urbanized sites were found to be more favourable to a diverse wild bee fauna than agricultural areas. While some garden flowers are cultivated for showiness at the expense of nectar and pollen, others may be very attractive to pollinators. Plantings of native flowers oftenconcentrate bee resources in a small area and can be a magnet for native pollinators (Frankie, Thorp, Schindler, Ertter & Przybylski, 2002). There is evidence that rural open space, hedgerows, and undeveloped fields surrounding urban centres will help to maintain floral diversity and thereby augment bee diversity in urban habitats (Osborne & Corbet, 1994; Osborne, Williams & Corbet, 1991; Steffan-Dewenter *et al*., 2002).

Fire regime

The loss or degradation of the landscape by fire can eliminate or reduce the availability of nesting sites as well as the quality and accessibility of food plants, resources that must generally be located within close proximity to nest sites. Wildfire causes a reduction in both wild bee diversity and abundance (Potts *et al*., 2010) by removing the vegetation cover and other resources on which bees depend. Research shows that farmers that leave residues on soil or practice mulching may be inadvertently encouraging wild bees (Shuler, Roulston & Farris, 2005).

Pollinator Decline

Recent studies show that the populations of many pollinating insects are on decline. Evidence suggests that pollinators are declining worldwide (Bartomeus *et al*., 2013; Biesmeijer *et al*., 2006; Buchmann & Nabhan, 1996; Burkle, Martin & Knight, 2013; Cameron *et al*., 2011; Kearns *et al*., 1998; National Research Council, 2007; Potts *et al*., 2010) as a result of changes in land use, fragmentation, agricultural intensification, pesticide use, invasive species, diseases, urbanization, and climate change (Burkle *et al*., 2013; Kremen *et al*., 2002; Steffen-Dewenter *et al*., 2002). There is an increasing evidence that the abundance and diversity of both wild and managed pollinators have declined across the world (Biesmeijer *et al*. 2006; Kremen *et al*., 2002; Osborne *et al*., 1991, Potts *et.al*., 2010; Richards, 2001). Complete colonies die, invoked by multiple stressors; a phenomenon called Colony Collapse Disorder (CCD). In many countries up to dozens of wild bee species have gone extinct already and many are rare or endangered (Banaszak, 1995; Steffan-Dewenter, Potts & Packer, 2005) especially long-tongued bees and species with a specialized diet (Biesmeijer *et al*. 2006). A dramatic decrease of honey bee colonies, especially wild honey bee colonies was noticed in 1994 (Watanabe, 1994). Recognition of widespread loss of pollinators and pollinator services by the Convention on Biological Diversity (through the Agricultural Biodiversity programme and International Pollinator Initiative) resulted in FAO (2008) coordinating the 'Rapid Assessment of Pollinators' status' which sought to compile global evidence of the extent of pollinator shifts and loss of pollination services.

Causes of Pollinator Decline

There seems to be general agreement that declines in bee populations and in their overall health are the product of multiple factors, both known and unknown and which can act singly or in combination (Williams *et al*., 2010a). The causes of pollinator decline are multiple and are closely linked to human activities. They include habitat loss and fragmentation (Kearns *et al*., 1998), intensive agriculture (Klein *et al*., 2007), introduced species (Goulson *et al*., 2008), and pesticide use (Kearns *et al*., 1998). Potts *et al*., 2010) observed insect pollinators are under threat due to a combination of factors including habitat fragmentation, agrochemicals, climate change and non-native species.

The loss of plant diversity and flower quantity due to habitat destruction and fragmentation of the landscape is assumed to be responsible for the decline of many bee species (Muller *et al*., 2006). Urbanization and increasing agricultural intensification have destroyed and fragmented many natural habitats (Vanbergen, 2013). Intensified farming methods have destroyed the formerly non-cropped areas to create more space for cultivation and larger field sizes. Not surprisingly, loss of these habitats and the loss of wild flowers mean loss of nesting habitat and foraging resources for bees. Indeed habitat loss is thought to be a major factor causing bee declines. Research shows that habitat loss likely causes both a reduction on wild bee diversity and abundance (Potts *et al*. 2010). Industrial farming has also driven a shift from traditional hay meadows-very important flower rich habitats for wild bees-to silage production from fields virtually devoid of wild flowers which are cut before any flowers emerge (Pfiffner & Müller, 2014). In addition to habitat loss, agricultural practices such as tillage, irrigation and the removal of woody vegetation destroy nesting sites of wild bees (Kremen *et al*., 2007) resulting in bee population declines.

Industrial farming monocultures, and more generally the lack of wild flower diversity within and around croplands, limit the amount of food that bees have access to both in space and in time. Bees can go hungry as farming becomes more intensified (Tirado *et al*., 2013). In turn, this has potentially damaging effects upon bees because they need an optimum nutrient balance for support of their growth and reproduction (Vanbergen, 2013). Flowering crops, such as oilseed rape (canola), can provide alternative food for some wild bee species that are able to exploit crop flowers effectively, but not for the more specialist species. Moreover, such crops only provide short pulses of food in the summer season for a few weeks. This is only of limited use for bees-native and managed bees need pollen and nectar resources for food throughout the whole foraging season. Different wild bee species are active at different times so floral resources are needed from early spring to late summer to provide all the bee species with adequate food (Pfiffner & Müller, 2014; Veromann *et al*., 2012). Wild bees require native wild flowers present in semi-natural habitats to provide them with the necessary floral resources (Rollin *et al*., 2013). Widespread use of pesticides is a common practice in the current chemically intensive agriculture systems. Recent scientific studies have shown that chemical intensive agriculture is implicated in the decline of bees and the pollination services they provide to our crops and wild flowers. A study conducted in eastern Canada indicated that, blueberry production, which depends largely on pollination by as many as 70 species of native insects, failed in 1970, and subsequent years, because of aerial spraying of fenithrothin (Kevan, 1991). Ever increasing applications of fertilisers, herbicides and insecticides and their synergistic negative impacts on bee health (Johnston, Huxdorff, Simon & Santillo, 2014, Tirado *et al*., 2013) and loss of natural and semi-natural habitat on field, farm and landscape levels are major drivers of bee declines.

Many beekeepers agree that the external invasive parasitic mite, *Varroa destructor*, is a serious threat to managed honey bee colonies globally (de Jong, 1997; Wilson, Pettis, Henderson & Morse, 1997). The *Varroa* mite is a parasite of adult honey bees and honey bee brood. It weakens and kills honey bee colonies and can also transmit honey bee viruses. The *Varroa* mite may be a contributing factor to the colony collapse disorder, as research shows it is the main factor for collapsed colonies in Ontario, Canada (Ernesto, Eccle, Mcgowan & Correa-Benitez, 2009) and Hawaii, USA (Welsh, 2012). Other new viruses and pathogens are likely to put further pressure on bee colonies. The ability of bees to resist diseases and parasites seems to be influenced by a number of factors, particularly their nutritional status and their exposure to toxic chemicals.

Many of the predicted consequences of climate change, such as increasing temperatures, changes in rainfall patterns, and more erratic or extreme weather events, will have impacts on pollinator populations including wild bees (UNEP, 2010). Climate change will very likely affect the interaction between pollinators and their sources of food, i.e. flowering plants, by inter alia changing the dates and patterns of flowering. Recent analysis has suggested that, under realistic scenarios of climate change up to 2100, between 17% and 50% of pollinator species will suffer from food shortages due to the temporal mismatch of their flight activity times with flowering of food plants (Memmott *et al*., 2007). The authors concluded that the anticipated result of these effects is the potential extinction of some insect pollinators and some plants, and hence the disruption of their crucial interactions.

Pollinator declines can result in loss of pollination services which have important negative ecological and economic impacts that can significantly affect the maintenance of wild plant diversity, wider ecosystem diversity, crop production, food security and human welfare (Holzschuh, Steffan-Dewenter, Kleijn & Tscharntke, 2007).

Bee Conservation Measures

Pollination happens before fertilisation, which is required for fruit and seed development. If no pollinators are present to facilitate pollination, the result is little or no fruit and seeds. For many researchers on pollination, adopting relatively simple practices or rules as those listed here will help to increase bee abundance and diversity in agricultural landscapes to levels that will contribute to good crop yields in pollination-dependent crops year after year.

Hedgerows

Apart from possible aesthetic values, hedgerows are food and nesting resources for a large variety of animals, including pollinators such as birds, bats and insects (Marshall *et al*., 2003). Planting hedgerows (a good farm landscape management practice) is generally promoted for its positive environmental outcomes. In fact, hedgerows have been found to support higher bee species richness and population density than other agricultural or natural habitats in USA (Afrcan Pollinator Initiative, 2007; Hannon & Sisk, 2009).

Field margins

Field margins act as miniature reserves within the mosaic of agricultural land, and can act as a valuable resource, offering both differing degrees of refuge for wild species and resources for them to use, as well as acting as a potential green corridor (Munyuli, 2010). They sometime support significantly higher number of wild bee species as natural habitats compared to fields, depending on the quality of the surrounding landscape (Munyuli, 2010). More recently, Potts *et al*. (2009) found that pollinator biodiversity (particularly bees and butterflies) could be restored in agricultural landscapes in UK by developing and implementing novel management strategies to improve grasslands and field margins.

Management of roadside habitats

Roadsides are important habitats for pollinators, particularly bees and butterflies. Roadsides support a variety of pollen and nectar sources and unlike agricultural fields, are un-ploughed, and therefore can provide potential nesting sites for ground nesting bees (Munyuli, 2011b). According to him, suitable road habitats for bees must include a diversity of flowering species and nesting substrates because of the range of specialized floral and nesting requirements of bees.

Management of fallows

In many rural communities in Ghana, the cropping period is usually followed by a fallow period for a few years. Fallow periods conventionally serve to restore soil fertility (Montagnini & Mendelsonh, 1996), suppress weeds and protect soils. Fallows are the most important features in the conservation of pollinators in agricultural landscapes in Uganda (Munyuli, 2010). Fallows represent a source and stable foraging and nesting habitat for bees. Fallow pieces of land can also be planted with wildflower mixes for supporting bees. Seed mixes can be custom designed to contain plants that bloom outside the crop’s bloom period.

Management of woodlands and forest plantations

One strategy that potentially facilitates the maintenance or recovery of biodiversity within agricultural landscape is the establishment of native forest plantations on degraded agricultural lands (Mosquera-Losada *et al*., 2009). Planting trees or leaving tree plantations in agricultural landscapes may contribute to conserving and restoring biodiversity by offering habitats for birds and other animals and by enhancing seed dispersal into agricultural landscapes (Harvey & Haber, 1999; Paritsis & Aizen, 2008).

Management of natural forests

Forest reserves are the most suitable habitats for most bee and butterfly species in farmlands of central Uganda (Munyuli, 2010). Preventing these forest patches from degradation may enable the conservation of both specialist and generalist bee species. Research shows that meliponine bees are strongly associated not only with flowering plant community but also with forests in tropical countries mainly because of cavity tree nesting opportunities (Munyuli, 2010). The destruction of termite mounds and forest logging can lead to disappearance of these important bees. Mitigating charcoal burning, grazing intensity, systematic and intensive timber harvests in forest reserves can help to save wood-nest sites for various pollinator species (Munyuli, 2011b).

Management of grasslands and pasture lands

Living and dead materials used for fencing cattle paddocks have been frequently observed being used as nesting habitats by some bee species of the genera *Megachile*, *Lipotriches*, *Lasioglossum* and *Moerenhouti* in several sites (Masaka, Mukono and Kamuli districts) of central Uganda (Munyuli, 2010). In farmlands of central Uganda, grasslands were found to be ideal nesting habitats for several species belonging to Certinini, Halictini and to some Megachilini bee groups (Munyuli, 2010) that are among good and effective solitary bee species of crops of beans, cowpea, egg plants, cucurbits and avocado. In fact, it is generally admitted that grazing intensity (stocking density of animals) can affect the pollinator species richness, abundance and visitation frequency to flowering plants through changing the structure, composition and phenology of preferred bee food plants (Xie, Williams & Tang, 2008).

Managing floral resources within agricultural fields

Bees are entirely dependent on pollen and nectar for food, suggesting that floral abundance profoundly influence the bee fauna of given habitat (Cane, Minckley, Kervin, Rouslton & Williams, 2006) or landscape. Combined floral planting can be tested for its use in conserving beneficial insects within agricultural settings, with the ultimate aim of improving sustainable pollination of crops that depend on bees for reaching their potential yield (Julier & Roulston, 2009; Tuell *et al.*, 2008). If wild bee populations are supported throughout the season by the addition of flowering plants into farmland, farmers may receive greater pollination services from wild bees when the crop is in bloom.

Native bees endemic to agricultural landscapes, which are active beyond the bloom period of pollinator-dependent crops, necessitate farm management practices that will provide flowering plants throughout the growing season. Growing polycultures rather than monocultures in a field can result in a more diverse set of floral resources (Ball, 1992). Many bees are active through the growing season. Including flowers that bloom at different times of the year provides for and attracts a greater number of pollinator species, including those with long flight seasons. When a crop that needs pollination is not in bloom, these bees still need to feed themselves and their offspring. Most native bees search for nectar and pollen within close range of their nest, so availability of flowers will reduce the amount of time bees need to search for food, thus increasing the number of offspring they can raise. Cropping systems (Malézieux *et al*., 2009) diversification can also help in attracting high number of pollinators on-farms. For example, polyculture systems that consist of mixing beans, maize and cassava are likely to attract a different bee community than maize sole grown; and such situation can be beneficial especially if crops are planted such as they can flower at different periods of the year (Munyuli, 2011a). Again, the conservation of plant genetic resources is important in the attraction and maintenance of pollinators in fields and in the study of plant-pollinator dynamics. The decline in plant genotypic diversity can lead to decline in pollinators due to reduced plant diversity in both agricultural and natural ecosystems (Genung *et al*., 2010). Crop breeding and crop selection are important to obtain varieties that have desired characters to attract pollinators. Crops with floral attractiveness and rewards for insects can be used to enhance pollinator conservation as well as crop yield and yield stability (Hughes, Daily & Ehrlich, 2000).

Management to provide bee nesting sites within agricultural fields

Methods are available for providing or protecting nest sites and substrates for bee species in the agricultural fields; and many of them do not interfere with crop farming. They range from simple, low-cost measures to more complex and expensive methods. The protection of bees in farmlands of Sub-Sahara Africa consists of managing agricultural fields to create nesting sites opportunities for ground-nesting bee species and wood-nesting bee species within fields. Human and livestock buildings were also observed frequently being used by several solitary bee species in central Uganda (Munyuli *et al*., 2011). Houses were sometimes seen being inhabited by certain bee species in central Uganda, particularly bees from the Xylocopini and Ceratinini bee groups. Therefore, farmers are advised to avoid destruction of critical habitats for bees such as termite mounds. Native bees such as mason and leafcutter bees nest in hollow plant stems and beetle holes in trees. Providing these resources naturally can be as easy as letting plants grow in a ditch or leaving old trees in place in woods next to crop fields. For a more advanced approach, holes drilled into wooden blocks or bundles of cut plant stems can provide the necessary nesting sites that cavity-nesting bees require. Bumble bees prefer to nest in the ground in abandoned rodent burrows or other dry, well-insulated cavities. Undisturbed grassy areas around fields may provide suitable underground nesting sites. Bumble bees have also been known to nest in the stuffing of abandoned mattresses and car seats. Nesting boxes can be constructed and buried to encourage them to colonize a specific area. The majority of native bees dig nests in the ground. Adults of ground-nesting bees fly in and out of these nests many times, collecting pollen to feed to their developing larvae in the nest. Providing non-tilled areas of open ground or well-drained mounds of soil near fields can provide nesting places for these bees.

Mason bees and leafcutter bees build their nests in cavities using soil or leaf material to separate the individual cells. Providing appropriate materials nearby can help make it easier for bees to build their nests. Leafcutter bees prefer foliage of waxy-leaved plants such as rose, green ash, lilac and Virginia creeper for constructing their nests but will use other plants if necessary. Mason bees need access to mud to build their nests. The mud source can be a trench with wetted bare soil during the nesting period, or a bucket of mud placed near the nest.

Compensation to farmers

Providing investments and incentives are necessary steps in (reversing current trends) ending environmental degradation in rural areas as well contributing to the improvement of the environmental quality and provision of ecosystem services. Incentives for the provision of environmental services are therefore crucial in providing benefits to people and in improving livelihoods. Incentive mechanisms can be efficient tools for the conservation of biodiversity in agricultural landscapes (Pascual & Perrings, 2007). Payment for environmental service programmes are expected to compensate land users who adopt practices that generate environmental services (Aviron *et al*., 2009) for themselves and the community or his neighbours.

Information dissemination

Although, much remains to be learnt about how to convey scientific knowledge in user-friendly language to rural and urban audiences (Frankie *et al*., 2009, Frankie, Rizzardi, Vinson & Griswold, 2009) several dissemination strategies of information on pollinators can be used to promote the development of an informal pollinator-friendly policy in addition to the formal policy for the conservation of pollinators in agricultural landscapes. Sustainable conservation of pollinators needs development of policies at individual farmer, community, national, regional, and global levels (Byrne & Fitzpatrick, 2009). Hence, the need for influencing modification of current public policies and institutions and stimulating the formulation of new public policies that largely address the issue of pollinator diversity protection in rural landscapes.

Access to water

Water is often overlooked as a bee resource, but bees need access to water for survival. Water is particularly important in the dry season, when there may be little rainfall. Bees use water as an alternative food source for the larvae and are also used to dilute honey to make it more plentiful. In addition, water is used to create air conditioning in the hive during hot temperatures. Cold drops of water are brought into the hive and these drops evaporate creating cool air. Any water source for these insects must be clean and free from pesticides.

Minimizing direct exposure to risk

Bees visit crop fields to feed primarily when the crop is in bloom. Special care must be taken to protect these bees from risks such as exposure to insecticides and fire during the crop’s bloom period. Avoid insecticide applications immediately before, during and directly after bloom, and if sprays are required select only the most bee-safe products. These steps are critical for native bees to emerge, lay eggs and provision their nests with food for their young. Although pest control will be the primary factor driving pesticide selection, options that are less toxic to bees will help create a more suitable environment for bees.

Knowledge of Pollinator Services

The importance of pollination in agriculture has been recognised for millennia (Kevan & Phillips, 2001). The irony, however, is that although the importance, and fragility, of pollination for agriculture and nature conservation has been known for a long time, there appears to have also been a popular belief that flowering plants always somehow seem to get pollinated and bear fruits and seeds and carry on into the next generation. Even the identities of major and minor pollinators for many major crops plants worldwide remain unknown. Thus the science of pollination ecology has not advanced adequately, and this makes ample room for new and established researchers to contribute to knowledge about pollinators and the plants they pollinate, whether in natural or agroecosystems. An assessment of the state of indigenous knowledge of pollination carried out through visits to selected areas of Bolivia, New Zealand and South Africa in 1998 had a common thread: indigenous knowledge of pollination varies markedly even within a single community (Mayfield, 1998). In the Yungas region of the Andes in Bolivia, the rangeof beliefs and understanding amongst the Ayamara people who inhabit this area were very wide. Some farmers believed that bees were detrimental to flowers because they sucked energy from them, whereas some others had a complex, and very accurate knowledge of what the bees do when they visit flowers and how important bees are for production in certain crops. Despite this, the farmers as a whole did not take measures explicitly to protect pollinator populations in the region. The status of the pollinator community was in any case diverse and healthy, due to the absence of both insecticides and industrial agricultural practices. Amongst Brazil nut collectors on the Amazonian frontier of Bolivia, in the state of Pando, knowledge of pollination services also varied widely. Some believed that the bees visiting Brazil nut flowers were responsible for making the flowers fall and thus were detrimental to the production. Others said that they knew that the trees needed bees to visit the flowers for fruit to be produced and that the most common bee visitors relied on orchids in the forest when the Brazil nut trees were not blooming. New Zealand has a particularly restricted bee fauna of only 35-50 native bee species all of which are solitary bees (Mayfield, 1998). Despite the diverse taxa of wild pollinators- including flies, beetles, bumblebees, and solitary bees visiting kiwifruit flowers - few farmers consider wild pollinators to be an important source of pollination. Most crop pollination was perceived to be performed by commercial (imported) honeybees and other exotic bees including bumblebees (Ricketts, Williams & Mayfield, 2006). Local knowledge of pollinator behaviour and nesting needs are often strongest when pollinators live in close proximity to people. In Egypt, as economic development grows, the human/pollinator relationship slowly erodes, as can be seen in the case of Egyptian clover (Kamal, 2004). The difficulty of seeing the work of pollinators has surely contributed to the low level of appreciation in much local knowledge. The scientific world was quite late in understanding the service that insects render in visiting flowers (Sprengel, 1793) and a full appreciation of pollinators, especially bees only came about with the invention of the microscope, around 1595 (Freedberg, 2002).

Unlike other African countries such as South Africa, Kenya and Uganda, most studies on pollinators and pollination in Ghana are quite recent. In 2008, the abundance and diversity of cowpea insect flower visitors were assessed at the Teaching and Research farm of the University of Cape Coast. Out of the 561 individual insects collected, 58.5% were bees whereas 41.5% were non-bee species including wasps, ants, moths, butterflies, flies, bugs and beetles (Kwapong, Danquah &Asare, 2013). The study showed that bees were the most diverse and dominant insects that frequented the cowpea flowers alongside other floral visitors. *Apis mellifera* was the most dominant insect flower visitor of cowpea followed by *Xylocopa olivacea*. The visitation of all the bee species coincided with that of the opening and closing of the cowpea flowers.

A study of the impact of confidor 200SL (Imidacloprid) and aqueous neem seed extract (ANSE) insecticides on the abundance of pollinators and fruit-set of cocoa conducted by Kwapong and Frimpong-Anin (2013) revealed a significantly more abundant midges on ANSE treated farms compared to confidor treated farms. The results showed that confidor 200SL was more deleterious to midges and hence reduced cocoa fruit-set to a greater extent compared to ANSE. Kwapong and Frimpong-Anin therefore advocated for a more comprehensive approach to the study of the insect fauna complex within cocoa agroecosystem with regards to the management of both pests and beneficial insects. A related research was later conducted by Kwapong, Frimpong-Anin and Ahedor (2014) to assess the fruit-set, survival of set fruits to maturity, pod size, and number of seeds in pods at the canopy, mid- and basal-trunk sections of cocoa tree. Contrasting pattern in fruit-set, number of pods and number of seeds per pod along the vertical sections were recorded. While the least fruit-set occurred at the canopy level, mid trunk recorded the least and highest pod survival and beans per pod respectively. In sum, the study showed that pollination is highest at the basal section of cocoa tree. This observation was attributed to the abundance of pollinating midges at the lower level and the high number of flowers resulting from branches at the canopy level.

A research by Kudom and Kwapong (2010) showed that pollination was not required for fruit set in *Ananas comosus* L. A similar study carried out on the type of pollinators for certain crops and the level of awareness of pollinators and pollination by Mensah and Kudom (2011) revealed that

Xylocopa olivacea was more efficient in the pollination of *Luffa aegyptiaca* than *Apis mellifera* in terms of number of fruit set per single visit.

An initial stock taking on pollinator awareness in Ghana by the African Pollinator Initiative in 2007 revealed distinct differences among crop farmers, extension agents, and agricultural lecturers (API, 2007). The report indicated that extension agents had more knowledge on pollination than crop farmers. For example, 75 percent of extension agents thought that pollinators needed to be protected as against 31percent of crop farmers. Most crop farmers said they left insects that settled on their plants during flowering not because they really understood their role but for the fact that they provided honey for medicinal purposes and also formed part of God’s creation. According to the report, most farmers felt that the Ministry of Agriculture in Ghana had done very little to promote the awareness of pollinators and pollination (API, 2007). A later study on pollinator awareness conducted in three districts in Ghana at the end of the Global Pollination Project (GPP) in 2014, revealed 92.3 percent awareness among crop farmers (Aidoo & Kwapong unpubl. data). The report indicated that the crop farmers could identify structures on plants that were necessary for pollination to occur as well as listing some of the measures that could be adopted to increase pollinator presence on their farms. The farmers were also aware that their crops would not yield fruits without pollination. Among policy makers and extension officers, the study observed 100 percent pollinator awareness. All the policy makers noted that pollination was very important for food security in Ghana and that pollinators must be protected and conserved to promote biodiversity. Extension officers were of the view that negative agriculture practices such as inappropriate use of agro-chemicals, bush fires and destruction of natural vegetation must be avoided to promote the presence of pollinators on farms (Aidoo & Kwapong unpubl. data).

CHAPTER THREE

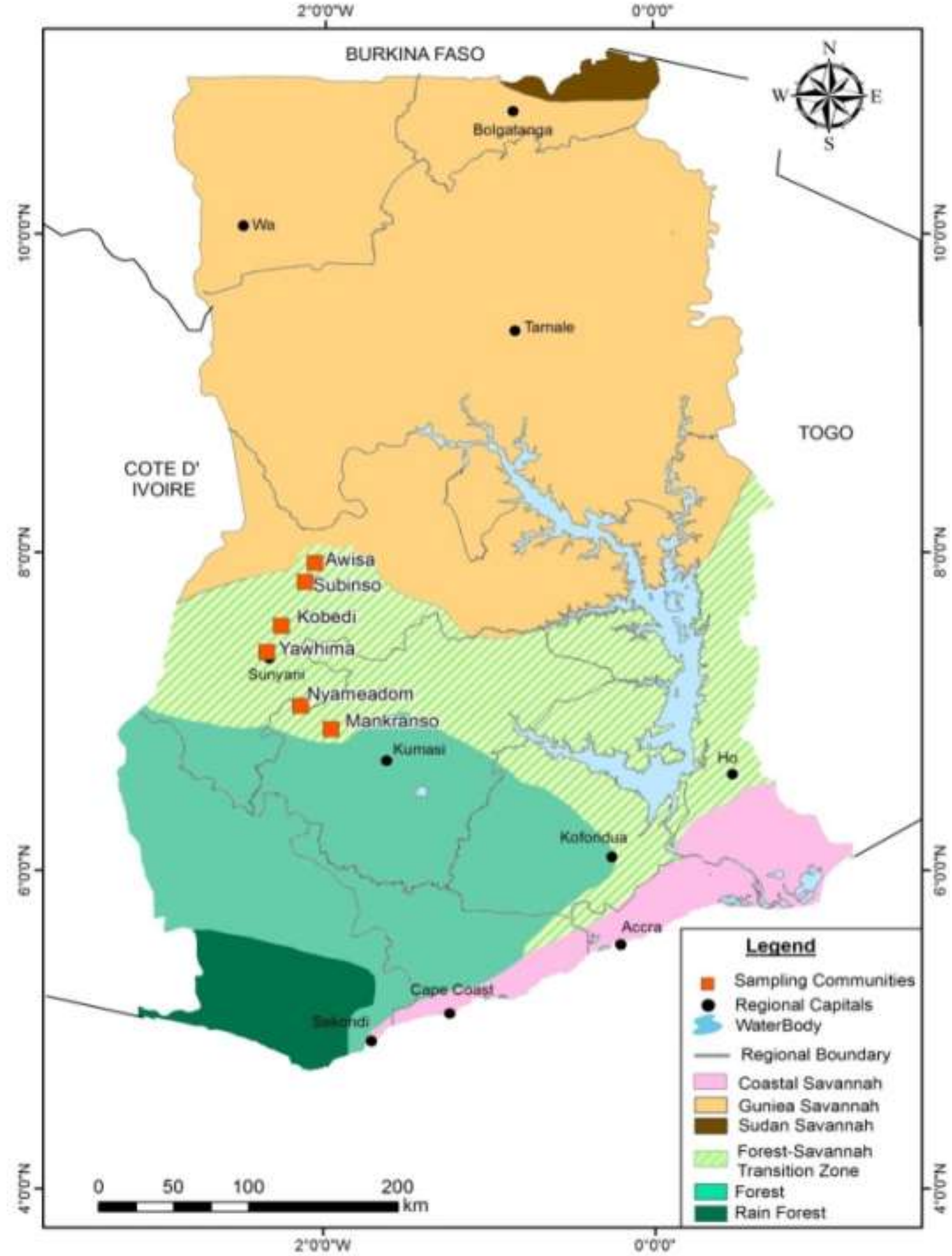
MATERIALS AND METHODS

Study Area

Ghana is situated on the Gulf of Guinea, neighbouring Ivory Coast, Togo and Burkina Faso. It has a total area of 239,500 km² and a population of 25 million (Ghana Statistical Service, 2012). This research was conducted within the Forest Savannah Transition Zone (FSTZ) of Ghana from June 2013 to April 2014 (Figure 2). This zone lies between the Northern Savannah Region and the northern part of the forest zone (middle belt). It stretches from the western section including Wenchi and Jaman districts, to the northern part of the Volta Region from the Krachi and Nkwanta Districts. It covers an area of 6,630,000 hectares (Ministry of Food and Agriculture {MoFA}, 1990). The zone, originally a forest, has lost most of its cover and is now a derived savannah. Factors responsible for this change include springing up of settlements, creation of small farms, gold mining as well as lumbering. To date, human factors continue to exert pressure on the remaining forest thereby pushing the savannah vegetation southwards. The topography of the area is generally rolling and undulatfing. Both temperature and relative humidity are quite high throughout the year averaging about 27^{o}C and 75% respectively (MoFA, 1990). Climatic, soil and vegetation characteristics are a blend of the northern savannah and the forest zone thus favouring crops from both savannah and forest regions. Hence most of the people in this intermediate region are basically farmers. Rainfall is in one peak in some years and two peaks in other years although the double maxima is more common (Boakye, 2010). Areas with bimodal rainfall receive the highest amount of rainy between April-May, the second rains season occurs in October-November (Boakye, 2010). This variation in the distribution of rainfall shows the transition nature of the zone. Soils are predominantly lateritic and the texture is mainly silt or sandy loam. Mean annual rainfall is about 1300mm. The area is dominated by tall grasses such as the elephant grass and varieties of Andropogon species mixed with tress such as *Daniella oliverti* and *Terminalia avicannoides*. As expected, whereas the Upper FSTZ has a larger percentage grass cover in relation to trees, the Lower FSTZ is dominated by trees. That is, the vegetation opens up gradually and the trees reduce in height and number as one travels up north.

Sampling Sites and Field Work

The FSTZ of Ghana was divided into three subzones or blocks based on the proportion of trees relative to grasses (Figures 3 & 4). The region with approximately 70% or more grass cover relative to trees was named the Upper FSTZ while that with 30% or less grass cover in relation to trees was named the Lower FSTZ. The middle portion with an almost equal proportion of grasses and trees was named the Middle FSTZ. This categorization was based on visual appraisal of the FSTZ carried out before bee sampling commernced.



Source: Modified from http://www.apipnm.org

Figure 2: Map of Ghana showing the communities sampled within the FSTZ

Figure 3: The subzones of the FSTZ. a = Upper FSTZ, b = Middle FSTZ & c = Lower FSTZ

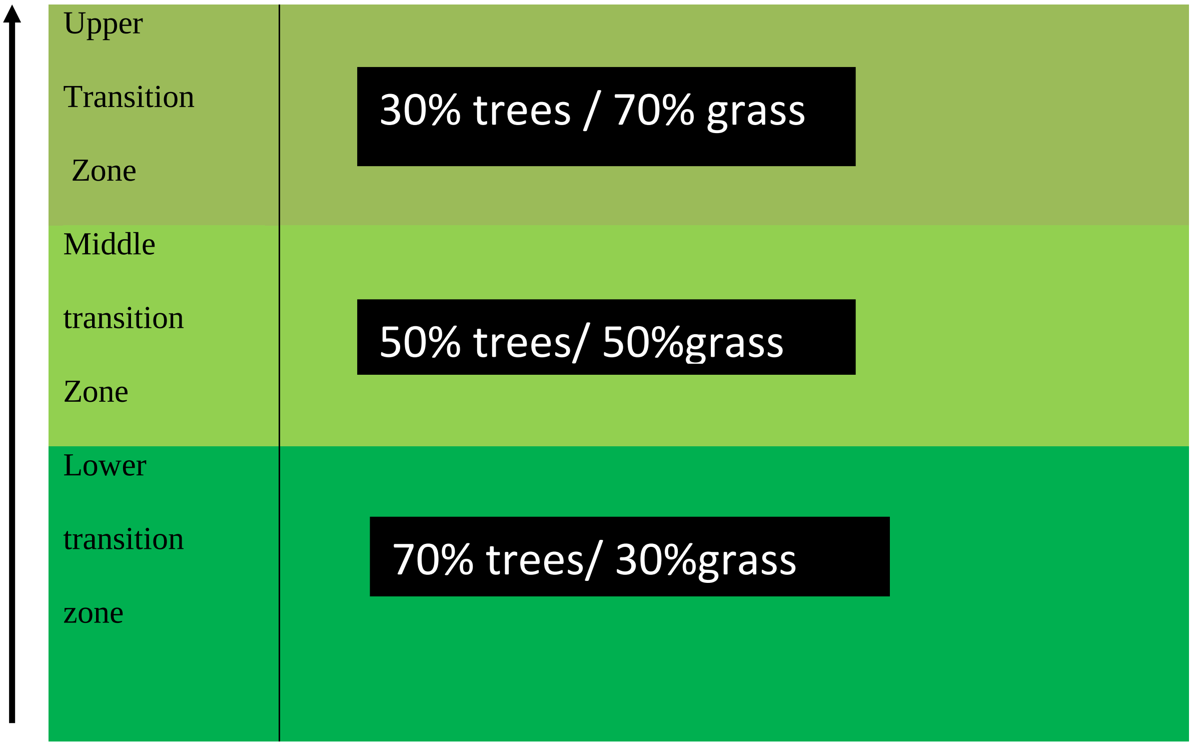


Figure 4: Schematic representation of tree-grass proportions within the FSTZ

Three landscape types namely agricultural land, settlement fringes and natural vegetation area were identified from each subzone and replicated (Table 1). Thus a total of eighteen (18) sampling sites were covered across the study area made up of two agricultural sites, two settlement fringes and two natural vegetation sites within each of the three subzones (ie Upper FSTZ, Middle FSTZ and Lower FSTZ).

Table 1

Subzones, Locations and Landscape Types Studied Within the FSTZ of Ghana

Subzone	Location 1	 2	Landscape type
Upper FSTZ	Awisa	Subinso	Agricultural land Settlement fringes Natural vegetation
Middle FSTZ	Kobedi	Yawhimah	Agricultural landscape Settlement fringes Natural vegetation
Lower FSTZ	Mankranso	Nyameadom	Agricultural landscape Settlement fringes Natural vegetation

At each site, a 500m by 3m fixed transects were constructed (Figure 5). A set of three, 5.08cm PVC pipes were erected at intervals of 100m along each transect. The pipes were placed in a triangular form with each separated from the other by a distance of 1m and projecting 1m high above the surface of the ground (Figure 6). The study used both quantitative and qualitative (participatory) methods for data collection.

Bee Sampling Methods

Two complementary methods were adopted to sample bees from the wild and crop flowers. These were the use of pan traps and netting, following the approaches described by Potts *et al*. (2005) and Munyuli (2012a). The use of pan traps is a technique employed to sample diversity and relative abundance of insects because it is inexpensive and relatively easy to use (Leong & Thorp, 1999). It was established from an experiment conducted in agricultural and semi-natural habitats by Westphal, Bommarco, Carre´, Lamborn and Morison (2008) that the pan trap method of bee collection was the least biased and most successful technique for sampling. In addition, it has been established that pan traps are easy to use by researchers with varying levels of entomological experience. Pan traps of the colours yellow, white and blue (Droege *et al*., 2010) were filled with soapy water and placed on the PVC pipes for 48 hours during each sampling period (Figure 7). Preliminary data and previous monitoring studies showed that different coloured pan traps attract different species of bees (LeBuhn *et al*., 2003; Leong & Thorp, 1999).

The times for placing and retrieving the pan traps were recorded to control for minor differences in sampling efforts among transects. After 48 hours, the content of each pan trap was poured into a nylon mesh, washed with clean water and transferred into pre-labelled vials containing 70% ethanol for preservation (Figure 8).

According to Wilson, Griswold and Messinger (2008), pan traps show a strong generic bias, attracting 85% of the Halictinae genera (e.g. Agapostemon, Halictus, Lasioglossum) while neglecting to attract Bombus or many species in the family Colletidae. To accurately sample bee communities, they recommend that pan-trapping must be used in conjunction with aerial netting. Therefore, a sweep net was used to collect flower visiting bees for thirty minutes along the same transects the second day after setting up the traps. A walk was taken along each transect and any bee found on plants occurring within 2m on either side was collected. The target of the sampling was for all categories of bees-honeybees, stingless bees, carpeneter bees, masonry bees etc.

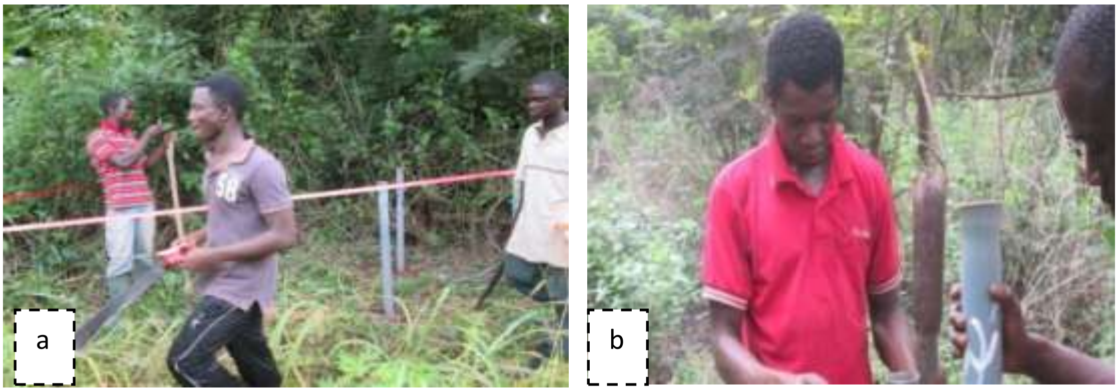


Figure 5: Transects being constructed by field assistants

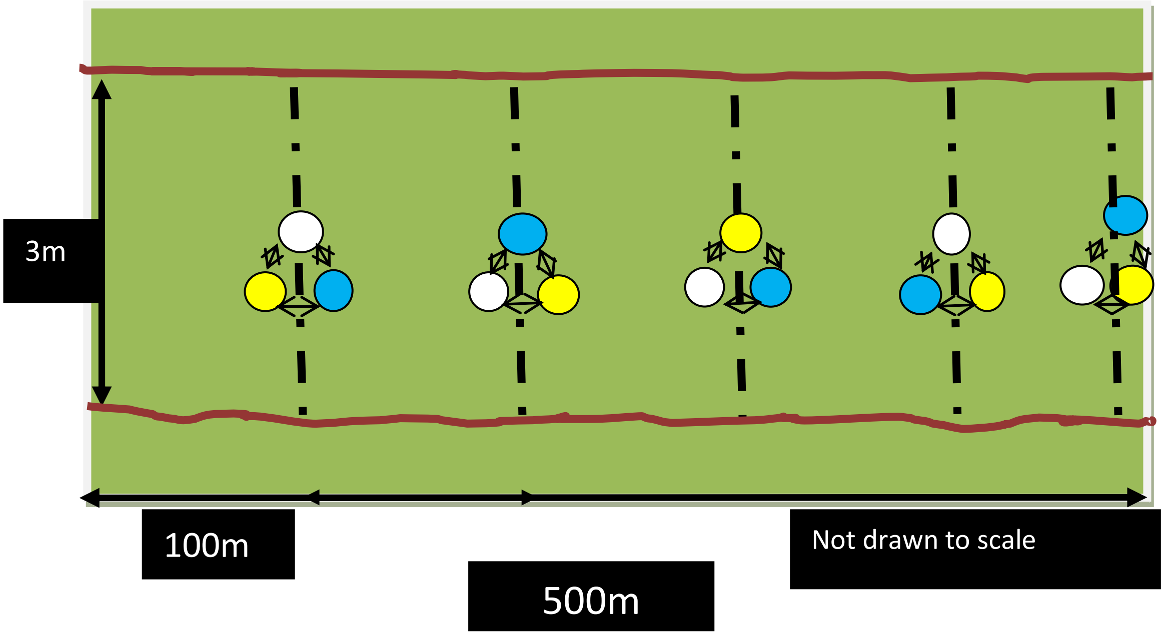


Figure 6: Set-up within each transect for collecting bees

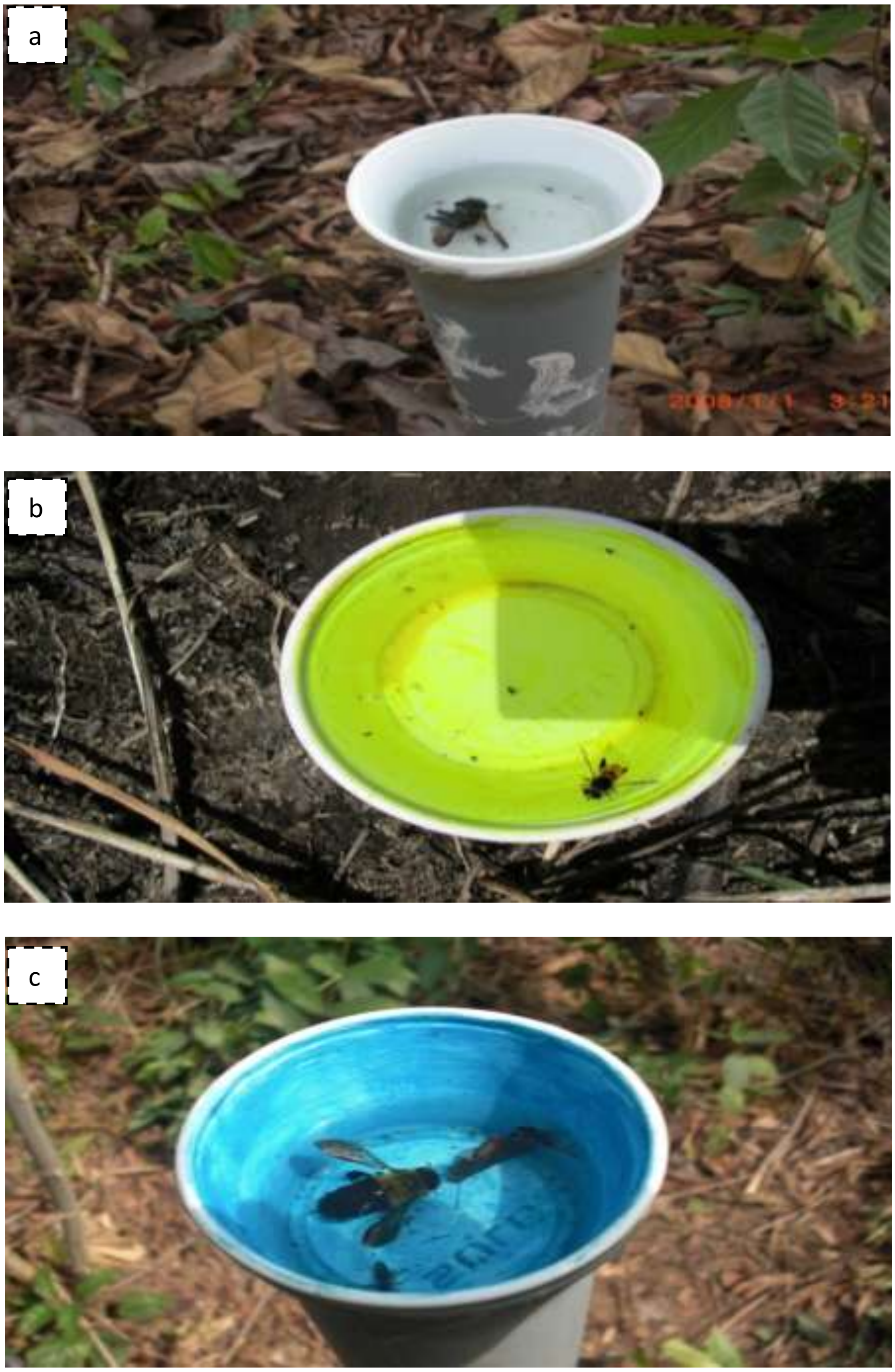


Figure 7: Pan traps (a=white, b=yellow & c=blue) containing bees collected from the field.

Temperature and relative humidity values were recorded on each sampling day using acurite portable digital weather station. The device was held 1m high from the ground with the panel facing upwards. Temperature and relative humidity readings were taken after the device had remained stable for at least two minutes. GPS readings of all sampling sites were documented. Sampling was done every other month, beginning in June 2013 and ending in April 2014. Sampling for three or more consecutive years would have been desirable (Williams, Minckley & Silveiria, 2001) but could not be done due to time and resource constraints. According to Magurran (2004), longer sampling periods are likely to produce additional species that are uncommon, more difficult to collect, or have migrated into the area since sampling began. After each sampling period, the samples collected were transported to the University of Cape Coast (UCC) Entomology Museum. A total of 108 samples were obtained from eighteen sites and six visits.

Laboratory Work

At the UCC Entomology Museum, the different species collected were sorted out and pinned for identification (Figure 9). The species identified were counted, recorded and stored in a wooden frame (Figure 10).

Figure 8: Specimens from field collections under temporal storage

Figure 9: Bee specimens being prepared for identification

Figure 10: Bee species sorted out and stored permanently in the museum

Survey of Crop Farmers in the Study Communities

An interview was conducted on crop farmers from the studycommunities to solicit information on their knowledge level of pollination and pollinators as well as their own contribution to landscape structural changes (Figures 11a & b). A semi-structured questionnaire was designed to capture as much information as possible on pollinators and pollination from crop farmers. Earlier, homage had been paid to the community heads/chiefs to announce the mission of the research team. A total of 190 available crop farmers of a previously 200 selected crop farmers representing 18% of total crop farmers in the study communities participated in the study (Munyuli, 2011b). The snowball sampling method was used to select the respondents. This was done by asking the assembly member of each community to identify one crop farmer. Each crop farmer in turn identified one other crop farmer. The process continued until all the 200 crop farmers needed for the research had been obtained. My interactions with officials of the District MoFA offices gave a total of 1100 crop farmers in the six study communities. The survey intrument comprised two main parts (Appendix 5). The first section sought general socio demographic information about respondents whilst the second part gathered information relating to farmers' knowledge on pollinators and pollination. To ensure a high content validity, the semi-structured questionnaire was pretested on ten crop farmers and fine-tuned before it was administered. All interviews and discussions were conducted face to face in the main local language (Twi) in the farmers' homes as previously agreed.

Data Analyses

Numbers of the different bee species sampled from the eighteen locations within the FSTZ of Ghana were first entered on Ms. Excel worksheet. EstimateS version 9.0 (Colwell, 2013) was used to compute

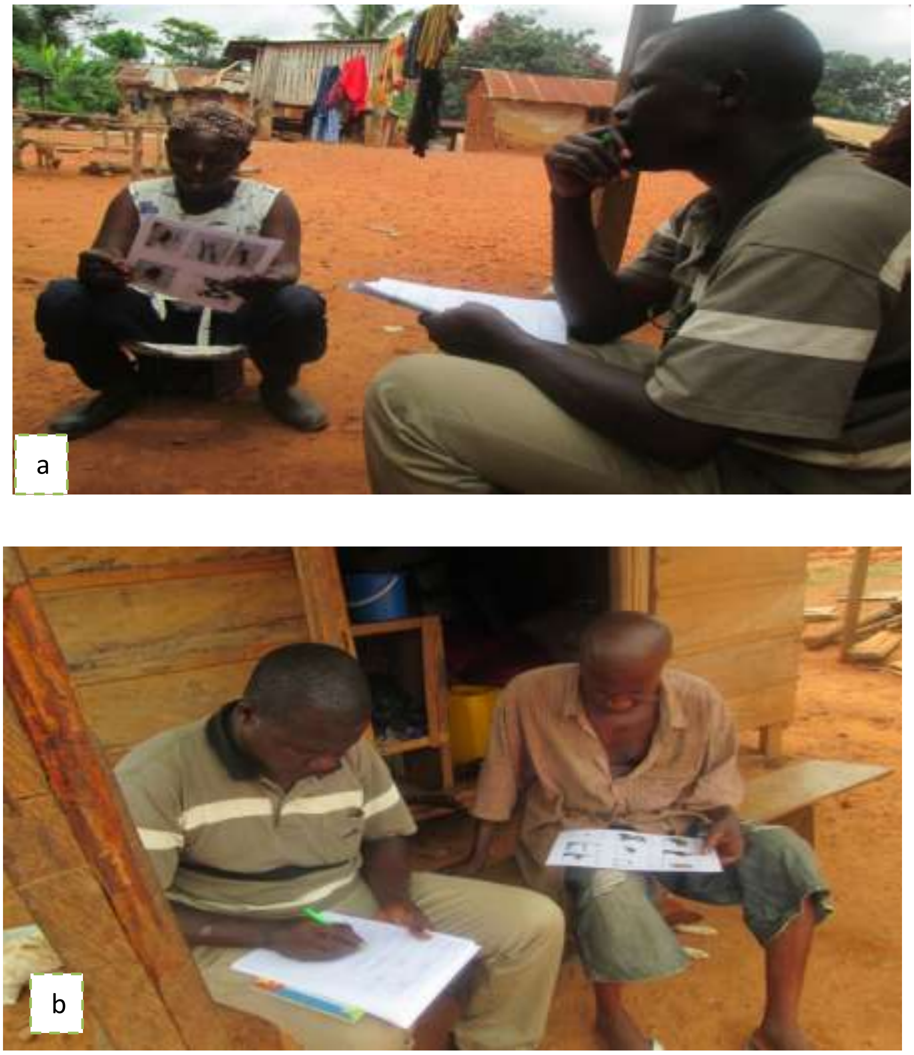


*Figure 11*a & b: Community members being interviewed on pollinators and pollination.

Shannon’s diversity index, species abundance, species richness and species evenness of bees collected from different landscape types and subzones. Species diversity is the effective number of different species that are represented in a dataset. Abundance refers to the relative representation of species in a community. Species richness is simply the number of different species present in a dataset. Evenness is the measure of how similar different species are in an assemblage in terms of their abundances. It is a measure of the relative abundance of the different species making up the richness of an area. High evenness is equated with high diversity and vice versa (Magurran, 2004). EstimateS computes multiple measures of biodiversity factors based on the pattern of species accumulation over multiple samples.

To compare the abundance and diversity of bees among the pre-selected landscape types and subzones, the results from EstimateS was subjected to analysis of variance (ANOVA) using SPSS version 21. Species richness is often used as a diversity measure because of its simplicity; however the number of species encountered while sampling will increase as sample size increases. It is therefore difficult to compare species richness values among sites if abundance values differ. Species richness can only truly be compared among sites when the community has been sampled sufficiently to represent all species present. Invertebrate communities are almost never sampled completely. Therefore for purposes of comparison, it is useful to measure diversity using indices that incorporate both species richness and abundance. For this reason, the Shannon diversity index (H) was used. The Shannon’s diversity index is calculated using the formula:

$$H = \sum_{i=1}^{n} \text{Pi} \ln(\text{Pi}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..$$

where Pi is the proportion of the total number of bees belonging to species i and ln (Pi) is the natural logarithm of that proportion and ∑ is summation over all species (n). Data from the interview guide was analysed using frequencies and simple percentages.

CHAPTER FOUR

RESULTS

The Bee Fauna of the FSTZ of Ghana

A total of 706 bees made up of 3 families, 18 genera and 34 species were identified during the study (Table 2). The families were Apidae (18 species), Halictidae (11 species) and Megachilidae (5 species). Thus by far, Apidae is the most speciose bee family in the FSTZ, and the least is Megachilidae. The most common genera were *Xylocopa*, *Amegilla* and *Lipotriches*.

Bee Species Distribution in the FSTZ of Ghana

Among the 34 bee species identified, it appears *Apis mellifera* (Linnaeus) is the only bee that did not discriminate in occurrence. This is because it was found in all subzones and in each of the three landscape types (Table 3). However, some species were either found in a single landscape type or a single subzone. Those found in a single landscape type included *Amegilla nila*, *Xylocopa torrida*, *Lipotriches cirrita* and *Lithurgus sparganotes* which were all found in only agricultural land. The rest were *Meliponula bocandei, Coelioxys torrida*, *Chalocodoma cinta*, *Thyreus nitidulis* and *Lipotriches tetraloniformis*. The first three of these species were found in natural vegetation only whilst the last two occurred only in settlement fringes. Five bee species occurred in a single subzone but not a single landscape type. These were *Xylocopa nigrita*, *Lipotriches nigrociliata*, *Megachile semierma, Megachile bituberculata* and *Compsomelissa nigrinervis*. The first four species occurred in the Lower FSTZ whilst the last was limited to the Upper FSTZ.

Table 2

List of Bees Collected From the FSTZ of Ghana From June 2013 to April 2014 and their Respective Genera and Families

No.	Family	Genus	Species
1	Apidae	*Apis*	*Apis mellifera* (Linnaeus, 1758)
2	,,	*Amegilla*	*Amegilla cingulata* (Fabricius, 1775)
3	,,	,,	*A.calens* (Lepeletier,1841*)*
4	,,	,,	*A. acraensis* (Fabricius,1793)
5	,,	,,	*A.albocaudata* (Dours,1869)
6	,,	,,	*A. nila* (Eardley,1994)
7	,,	*Meliponula*	*Meliopnula bocandei* (Spinola, 1853)
8	,,	*Compsomelissa*	*Compsomelissa nigrinervis* (Cameron, 1905).
9	,,	*Ceratina*	*Ceratina moerenhouti* (Vachal, 1903)
10	,,	*Thyreus*	*Thyreus nitidulus* (Fabricius, 1804)
11	,,	*Allodape interrupta*	*Allodape interrupta* (Vachal, 1903).
12	,,	*Braunsapis leptozonia*	*Braunsapis leptozonia* (Vachal, 1909)
13	,,	*Xylocopa*	*Xylocopa imitator* (Smith, 1854)
14	,,	,,	*X. albiceps* (Fabricius, 1804)
15	,,	,,	*X. olivacea* (Fabricius, 1778)

Table 2 continued

No.	Family	Genus	Species
16	,,	,,	*X. nigrita* (Fabricius, 1775)
17	,,	,,	*X.hottentota hottentota* (Smith, 1854)
18	,,	,,	*X. torrida* (Westwood, 1838)
19	Halictidae	*Lipotriches*	*Lipotriches orientalis* (Friese, 1909)
20	,,	,,	*L. natelensis* (Cockerell, 1916)
21	,,	,,	*L. nigrociliata* (Cockerell, 1932)
22	,,	,,	*L. tetraloniformis* (Strand, 1912)
23	,,	,,	*L. cirrita* (Vachal, 1903)
24	,,	,,	*L. guinensis* (Strand, 1912)
25	,,	*Pseudapis*	*Pseudapis amoenula* (Gerstacker, 1870).
26	,,	*Halictus*	*Halictus* sp.
27	,,	*Nomia*	*Nomia ivorensis* (Pauly, 1990)
28	,,	,,	*N. viridicincta* (Meade-Waldo, 1916)
29	,,	*Lasioglossum*	*Lasioglossum quebecensis* (Crawford,
30	Megachilidae	*Megachile*	*Megachile semierma* (Vachal, 1903)
31	,,	,,	*M. bituberculata* (Ritsema, 1880)
32	,,	*Chalicodoma*	*Chalicodoma cincta* (Fabricius, 1781)
33	,,	*Coelioxys torrida*	*Coelioxys torrida* (Smith, 1854).
34	,,	*Lithurgus*	*Lithurgus sparganotes* (Schetterer, 1891)

In summary, 4 bee species were found in only agricultural land, 3 species in only natural vegetation and 2 species in only settlement fringes. With subzones, 1 species was limited to the Upper FSTZ and 4 to the Lower FSTZ. No species was limited to the Middle FSTZ only.

Total Numbers of Bees per Landscape Type and Subzone

With landscape types, 297 bees were sampled from agricultural land, 258 from settlement fringes and 151 from natural vegetation. These figures correspond respectively to 42.1%, 36.5% and 21.4% of the total of 706 bees (Table 4). Considering subzones, 286 bees were sampled from the Upper FSTZ, 146 from the Middle FSTZ and 274 from the Lower FSTZ which account for 40.5%, 20.7% and 38.8% respectively.

Table 3

Bee species distribution among Landscape Types and Subzones

NO.	SPECIES NAME	UPPER FSTZ			MIDDLE FSTZ			LOWER FSTZ		
		AGR.	SET.	NAT.	AGR.	SET.	NAT.	AGR.	SET.	NAT.
1	*Apis mellifera*	√	√	√	√	√	√	√	√	√
2	*Amegilla cingulata*	x	x	√	√	x	x	√	√	x
3	*Amegilla calens*	√	x	√	x	√	√	√	x	√
4	*Amegilla acraensis*	x	x	√	x	x	x	√	√	x
5	*Amegilla albocaudata*	x	√	x	x	x	x	√	x	x
6	*Amegilla nila*	x	x	x	√	x	x	√	x	x
7	*Meliponula bocandei*	x	x	√	x	x	x	x	x	x
8	*Compsomelissa nigrinervis*	√	x	√	x	x	x	x	x	x
9	*Ceratina moerenhouti*	√	x	x	√	x	x	x	√	x
10	*Thyreus nitidulis*	x	x	x	x	x	x	x	√	x
11	*Allodape interrupta*	√	√	x	√	x	√	x	√	x
12	*Braunsapis leptozonia*	x	√	√	x	√	x	x	√	x
13	*Xylocopa imitator*	√	x	√	x	x	√	√	x	√
14	*Xylocopa albiceps*	√	√	x	x	x	x	√	√	√
15	*Xylocopa olivacea*	√	x	√	√	x	√	√	√	x
16	*Xylocopa nigrita*	x	x	x	x	x	x	√	√	√
17	*Xylocopa hottentota*	x	x	x	x	√	x	√	x	√
18	*Xylocopa torrida*	√	x	x	x	x	x	√	x	x

Table 3, continued

NO.	SPECIES NAME	UPPER FSTZ			MIDDLE FSTZ			LOWER FSTZ		
		AGR.	SET.	NAT.	AGR.	SET.	NAT.	AGR.	SET.	NAT.
19	*Lipotriches orientalis*	x	x	x	x	x	√	√	x	√
20	*Lipotriches natelensis*	x	x	x	√	√	x	√	√	√
21	*Lipotriches nigrociliata*	x	x	x	x	x	x	√	√	x
22	*Liporiches tetraloniformis*	x	x	x	x	x	x	x	√	x
23	*Lipotriches cirrita*	√	x	x	x	x	x	x	x	x
24	*Lipotriches guinensis*	√	x	√	x	x	x	x	√	x
25	*Pseudapis amoenula*	x	√	x	√	x	x	√	x	x
26	*Halictus* sp.	√	x	x	x	√	x	√	x	x
27	*Nomia ivorensis*	x	√	√	x	x	x	√	x	x
28	*Nomia viridicincta*	x	x	x	√	x	x	√	√	x
29	*Lasioglossum quebcensis*	√	x	x	x	x	x	√	√	x
30	*Megachile semierma*	x	x	x	x	x	x	√	√	x
31	*Megachile bituberculata*	x	x	x	x	x	x	√	√	x
32	*Chalocodoma cinta*	x	x	x	x	x	√	x	x	x
33	*Celioxys torrida*	x	x	x	x	x	x	x	x	√
34	*Lithurgus sparganotes*	x	x	x	√	x	x	x	x	x

KEY: AGR, SET and NAT refer respectively to agricultural land, settlement fringes and natural vegetation. √= **Present x = Absent**

1	🟦	Species occurring in all areas
2	🟪	Species occurring in a single landscape
3	🟩	Species occurring in a single subzone

Table 4

Proportion of Wild Bees Sampled From Different Landscape Types and Subzones

Landscape type	No.of bees	Percentage	Subzone	No.of bees	Percentage
Agricultural landscape	297	42.1	Upper FSTZ	286	40.5
Settlement fringes	258	36.5	Middle FSTZ	146	20.7
Natural vegetation	151	21.4	Lower FSTZ	274	38.8
Total	706	100.0	Total	706	100.0

Species Rarity Within the FSTZ of Ghana

Five out of the 34 bee species collected occurred as singletons. Singletons are species represented by only one individual in a sample. The Lower FSTZ had three singletons which were *L. tetraloniformis, T. nitidulis* and *C. torrida.* The Middle FSTZ also recorded two singletons namely *L. spaghanotes* and *C. cinta*. No species was represented by a single individual in the Upper FSTZ (Table 3).

Variation in Bee Diversity Within Subzones

Though four biodiversity measures namely richness, evenness, abundance and diversity have been presented in the results for purposes of clarity, all interpretations and discussions have been limited to abundance and diversity in line with the main project objective.

Upper FSTZ

With the exception of species abundance (F=0.89, p=0.413), significant variations were observed in bee species diversity (F=316.95, p=0.000), richness (F=100.54, p=0.000) and evenness (F=48.17, p=0.000) across landscape types within the Upper FSTZ (Table 5; Probability details are provided in Appendix 2).

Whereas species abundance was the same for all landscape types within the Upper FSTZ, bees were most diverse in natural vegetation and least diverse in settlement fringes (Table 5).

Middle FSTZ

Species diversity (F=215.30, p=0.000), richness (F=27.65, p=0.000) and evenness (F=43.98, p=0.000) significantly varied across landscape types in the Middle FSTZ (Table 5). As with the Upper FSTZ, there was no significant difference in bee species abundance across landscape types (F=1.65, p=0.195).

Within the Middle FSTZ, bee diversity was highest in agricultural land and lowest in settlement fringes.

Lower FSTZ

In the Lower FSTZ, there were significant differences among landscape types for all measures of biodiversity: species richness (F= 106.96, p=0.000), abundance (F=3.46, p=0.03), diversity (F=35.87, p=0.000) and evenness (F=7.37, p=0.001) (Table 5).

Table 5

Species Richness, Abundance, Diversity and Evenness of Bee Assemblages From Three Landscape Types in the FSTZ Clustered by Subzones

Subzones	Landscape	Measure of Biodiversity			
		Species Richness	Abundance	Diversity (H')	Evenness (E)
Upper TZ					
	Agricultural Land	12.00 ± 0.35$^{\mathbf{a}}$	167.45 ± 89.22$^{\mathbf{a}}$	1.09 ± 0.02$^{\mathbf{a}}$	0.50 ± 0.02$^{\mathbf{a}}$
	Settlement Fringes	6.24 ± 0.18$^{\mathbf{b}}$	89.15 ± 61.21$^{\mathbf{a}}$	0.57 ± 0.01$^{\mathbf{b}}$	0.27 ±0.01$^{\mathbf{b}}$
	Natural Vegetation	10.36 ± 0.40$^{\mathbf{c}}$	279.15 ± 147.64$^{\mathbf{a}}$	1.19 ± 0.03$^{\mathbf{c}}$	0.55 ± 0.03$^{\mathbf{a}}$
Middle TZ					
	Agricultural Land	9.18 ± 0.39$^{\mathbf{a}}$	682.40 ± 298.40$^{\mathbf{a}}$	1.43 ± 0.05$^{\mathbf{a}}$	0.71 ± 0.04$^{\mathbf{a}}$
	Settlement Fringes	5.41 ± 0.29$^{\mathbf{b}}$	157.38 ± 115.28$^{\mathbf{a}}$	0.49 ± 0.02$^{\mathbf{b}}$	0.30 ± 0.02$^{\mathbf{b}}$
	Natural Vegetation	6.77 ± 0.43$^{\mathbf{c}}$	342.34 ± 191.75$^{\mathbf{a}}$	0.86 ± 0.03$^{\mathbf{c}}$	0.44 ± 0.03$^{\mathbf{c}}$
Lower TZ					
	Agricultural Land	21.70 ± 0.47$^{\mathbf{a}}$	322.24 ± 135.49$^{\mathbf{a}}$	1.93 ± 0.03$^{\mathbf{a}}$	0.98 ± 0.04$^{\mathbf{a}}$
	Settlement Fringes	16.63 ± 0.49$^{\mathbf{b}}$	351.93 ± 155.67$^{\mathbf{a}}$	1.66 ± 0.03$^{\mathbf{b}}$	0.87 ± 0.04$^{\mathbf{b}}$
	Natural Vegetation	8.28 ± 0.44$^{\mathbf{c}}$	1219.72 ± 539.37$^{\mathbf{b}}$	1.51 ± 0.06$^{\mathbf{c}}$	0.67 ± 0.05$^{\mathbf{c}}$

Within each column, means (x ± se) followed by the same letter are not significantly different at $p > 0.05$ *level as determined with Fisher's protected least significant difference (LSD) test for means comparison*

As with the Middle FSTZ, agricultural land topped bee species diversity in the Lower FSTZ. Settlement fringes however came second with natural vegetation recording the lowest. Bees were however more abundant in natural vegetation than in either agricultural land or settlement fringes.

Summary of Bee Species Abundance and Diversity Within Subzones

When the three landscape types in each subzone were compared statistically, bee species abundance varied only in the Lower FSTZ and was highest in natural vegetation and lowest in agricultural land. Bee species diversity however varied across landscape types within each subzone. Natural vegetation recorded the highest diversity in the Upper FSTZ whilst in both the Middle and Lower FSTZs agricultural land had the highest. Settlement fringes recorded the lowest diversity in the upper and Middle FSTZs whilst natural vegetation obtained the lowest in the Lower FSTZ.

Variation in Bee Diversity per Landscape Type Across Subzones

Agricultural land

Species diversity (F=293.94, p=0.000), richness (F=205.6, p=0.000) and evenness of bees (F=45.99, p=0.000) for agricultural land significantly varied across subzones (Table 6) whilst abundance did not differ significantly (F= 1.99, p = 0.138).

Bee species diversity was highest in the Lower FSTZ and lowest in the Upper FSTZ for agricultural land.

Settlement fringes

Species diversity, richness and evenness were significantly diffrent {(F=877.11, p=0.000), (F=307.32, p=0.000), (F=148.25, p=0.000) respectively} across subzones for settlement fringes (Table 6). Differences in bee species abundance were not significant (*F*=1.49, *p*=0.227) across subzones for settlement fringes.

Species diversity was highest in the Lower FSTZ and lowest in the Middle FSTZ for settlement fringes.

Natural vegetation

With natural vegetation, all the four biodiversity measures differed across subzones: species diversity (F=57.33, p=0.000), richness (F=19.09, p=0.000), abundance (F=3.19, p=0.044) and evenness (F=8.24, p=0.000) (Table 6).

Both species diversity and abundance were highest in the Lower FSTZ for natural vegetation. Whereas lowest species diversity was recorded in the Middle FSTZ lowest abundance was observed in the Upper FSTZ.

Summary of Bee Species Abundance and Diversity per Landscape Type Across Subzones

Comparing the performance of each landscape type in the three subzones, species abundance significantly varied for only natural vegetation. It was highest in the Lower FSTZ and lowest in the Upper FSTZ. On the other hand, species diversity significantly varied among subzones for all the three

Table 6

Species Richness, Abundance, Diversity and Evenness of bee Assemblages per Landscape Type across Subzones in the FSTZ

Landscape	Sub-zones	Measure of Biodiversity			
		Species Richness	Abundance	Diversity (H')	Evenness (E)
Agricultural Land					
	Upper TZ	12.00 ± 0.35^{a}	167.45 ± 89.22^{a}	1.09 ± 0.02^{a}	0.50 ± 0.02^{a}
	Middle TZ	9.18 ± 0.39^{b}	682.40 ± 298.40^{a}	1.43 ± 0.05^{b}	0.71 ± 0.04^{b}
	Lower TZ	21.70 ± 0.47^{c}	322.24 ± 135.49^{a}	1.93 ± 0.03^{c}	0.98 ± 0.04^{c}
Settlement Fringes					
	Upper TZ	6.24 ± 0.18^{a}	89.15 ± 61.21^{a}	0.57 ± 0.01^{a}	0.27 ± 0.01^{a}
	Middle TZ	5.41 ± 0.29^{a}	157.38 ± 115.28^{a}	0.49 ± 0.02^{b}	0.30 ± 0.02^{a}
	Lower TZ	16.63 ± 0.49^{b}	351.93 ± 155.67^{a}	1.66 ± 0.03^{c}	0.87 ± 0.04^{b}
Natural Vegetation					
	Upper TZ	10.36 ± 0.40^{a}	279.15 ± 147.64^{a}	1.19 ± 0.03^{a}	0.55 ± 0.03^{a}
	Middle TZ	6.77 ± 0.43^{b}	342.34 ± 191.75^{a}	0.86 ± 0.03^{b}	0.44 ± 0.03^{b}
	Lower TZ	8.28 ± 0.44^{c}	1219.72± 539.37 ^{b}	1.51 ± 0.06^{c}	0.67 ± 0.05^{c}

Within each column, means (x ± se) followed by the same letter are not significantly different at p > 0.05 level as determined with Fisher's protected least significant difference (LSD) test for means comparisons landscape types and was highest in the lower transition. However, whereas lowest species diversity for agricultural land was recorded in the Upper FSTZ that for settlement fringes and natural vegetation occurred in the Middle FSTZ. Thus regardless of landscape type, the Lower FSTZ was by far the most preferred subzone for bees whilst the Upper FSTZ was the least preferred.

General Variation in Bee Species Abundance and Diversity Across Landscape Types

There was no significant variation in bee species abundance across landscape types (F= 0.13, p=0.884) though natural vegetation appeared to have recorded the highest number of bees (Figure *12*). Bee species diversity however significantly varied (*F*=11.64, p=0.009) across landscape types with agricultural land obtaining the highest number of species whilst settlement fringes had the lowest (Figure *13*).

General Variation in Bee Species Abundance and Diversity Across Subzones

As observed for landscape types, species abundance did not differ across subzones (F=0.06, p=0.941) (Figure 14) though the Lower FSTZ appeared to have recorded more bees than both the middle and Upper FSTZs. Bee species diversity significantly varied across subzones (F=49.29, p=0.000) (Figure 15). The Lower FSTZ recorded the highest diversity whilst the Upper FSTZ had the lowest diversity. This means that bee species diversity shows a tendency to decline from south to north.

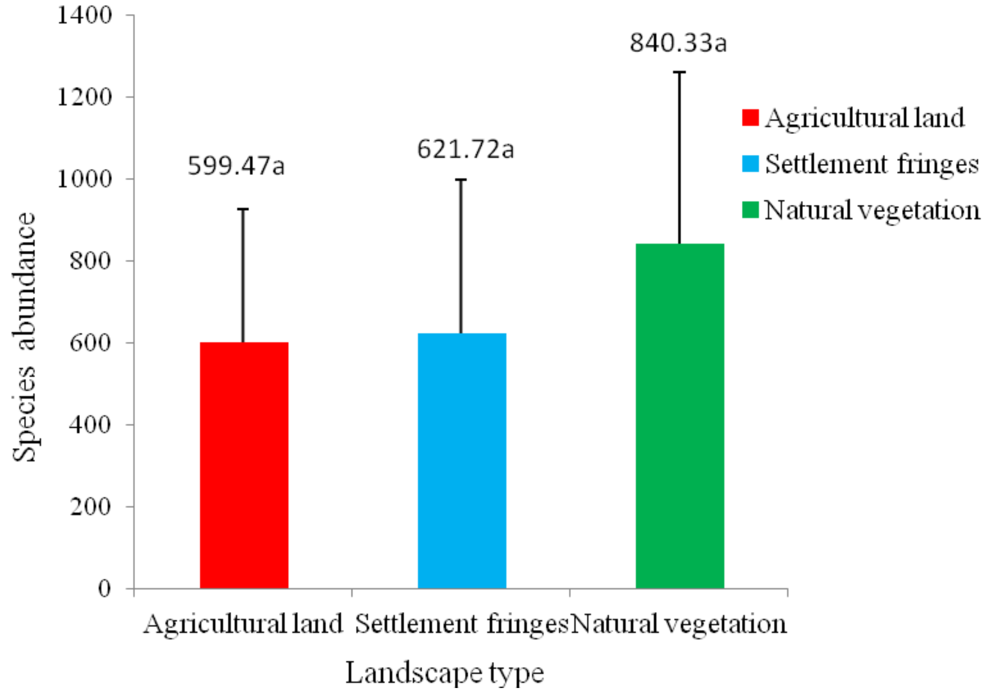


Figure 12: Variation in species abundance of bees across landscape types

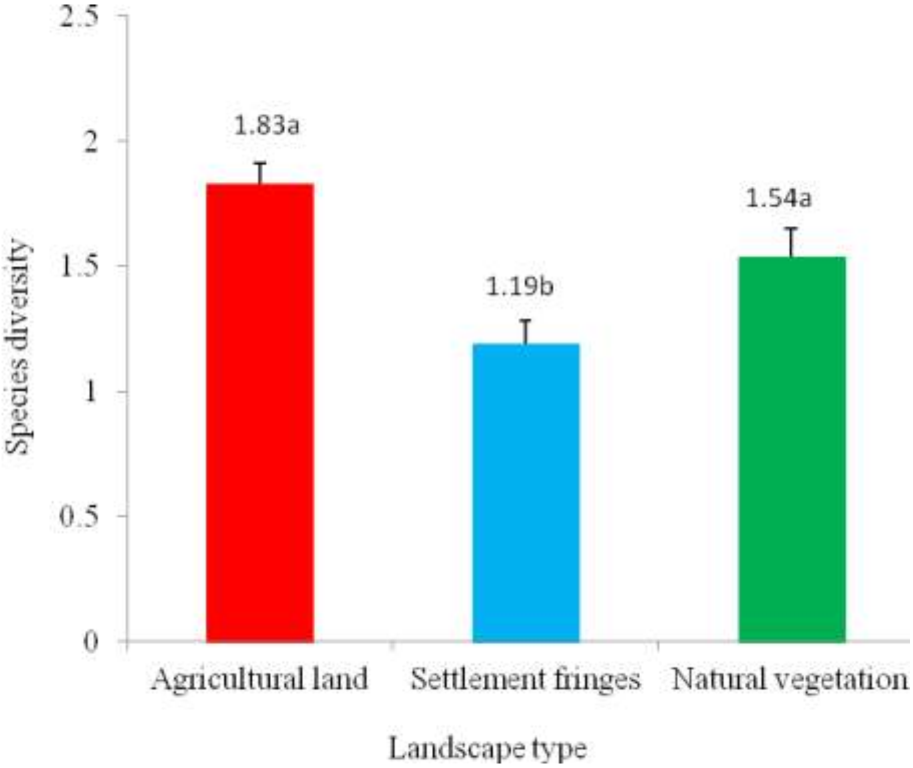


Figure 13: Variation in species diversity of bees across landscape types

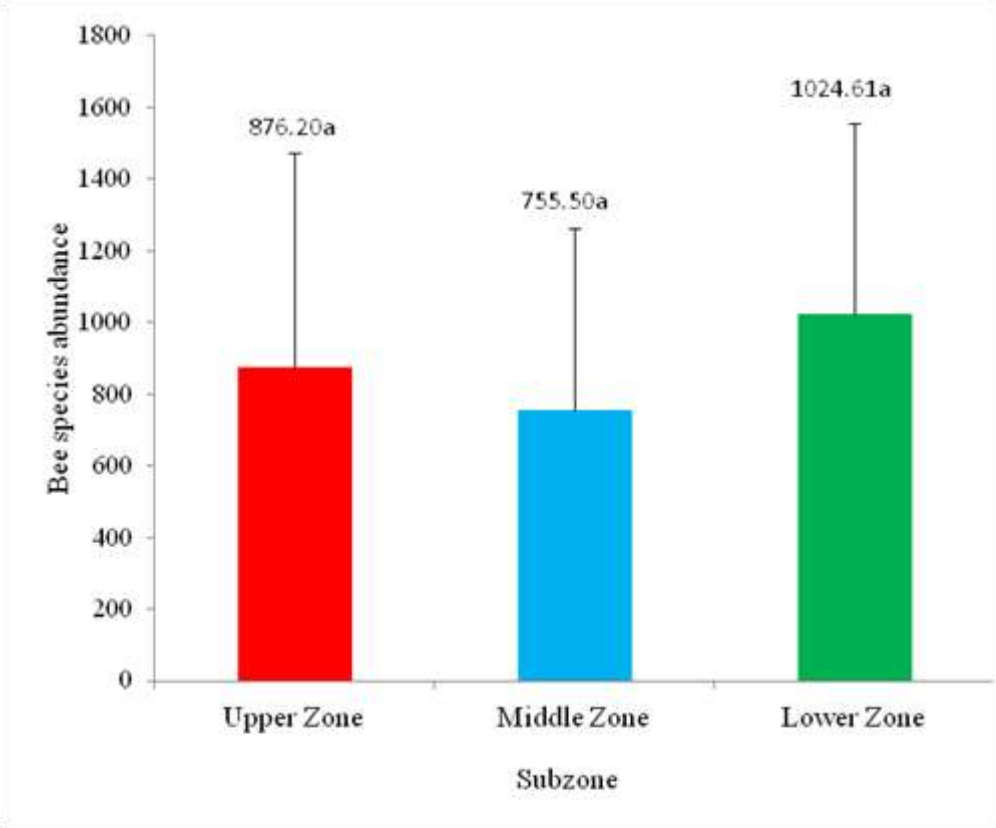


Figure 14: Variation in species abundance of bees across subzones

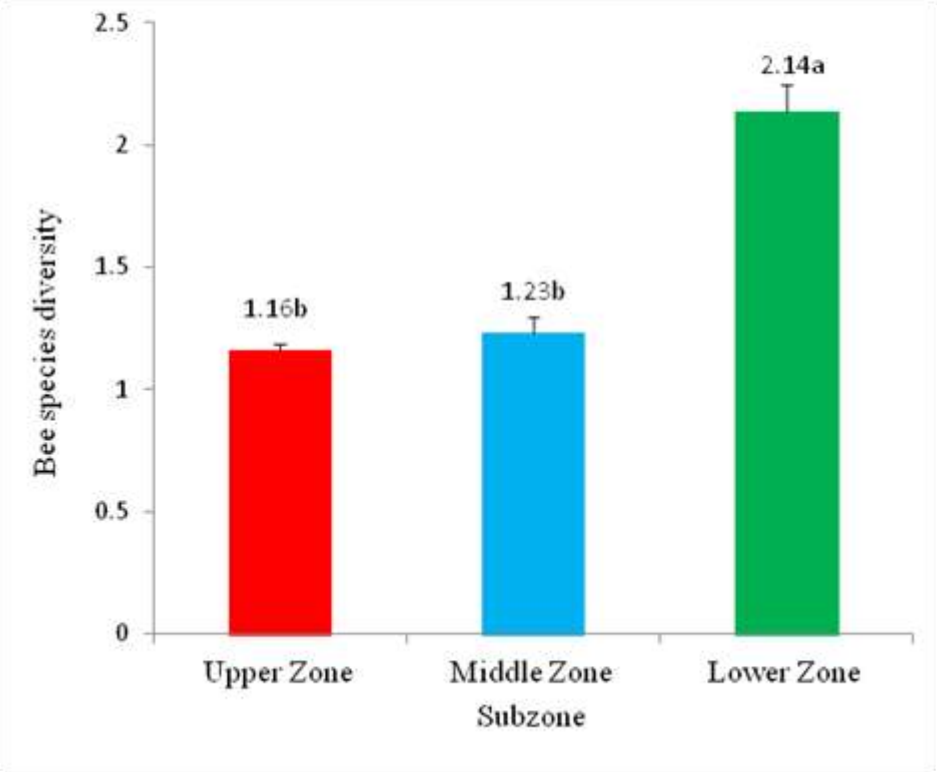


*Figure 15***:** Variation in species diversity of bees across subzones

Variation in Bee Abundance and Diversity With Relative Humidity and Temperature Across Subzones

Whereas no clear relationship was observed among bee abundance, relative humidity and temperature (Figure 16), bee species diversity appeared to increase with increasing relative humidity but temperature was generally stable across subzones (Figure 17). This requires further investigation.

Variation in Bee Species Abundance and Diversity Across Sampling Months

Though not statistically different among sampling months (F = 1.312, p = 0.322), bee species abundance was highest in February 2014 and lowest in December 2013 (Figure 18). Bee species diversity differed significantly among sampling months (F = 6.307, p = 0.004) and was highest in February 2014 but lowest in August 2013 (Figure 19). Beside this observation, no clear trend in both species abundance and diversity across sampling months was observed.

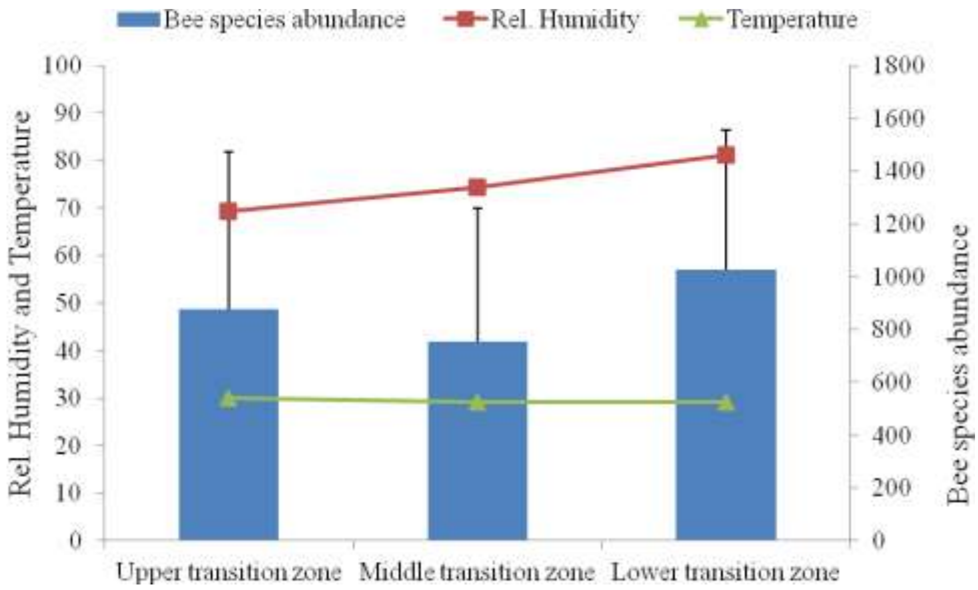


Figure 16: Variation in bee abundance with relative humidity and temperature across subzones.

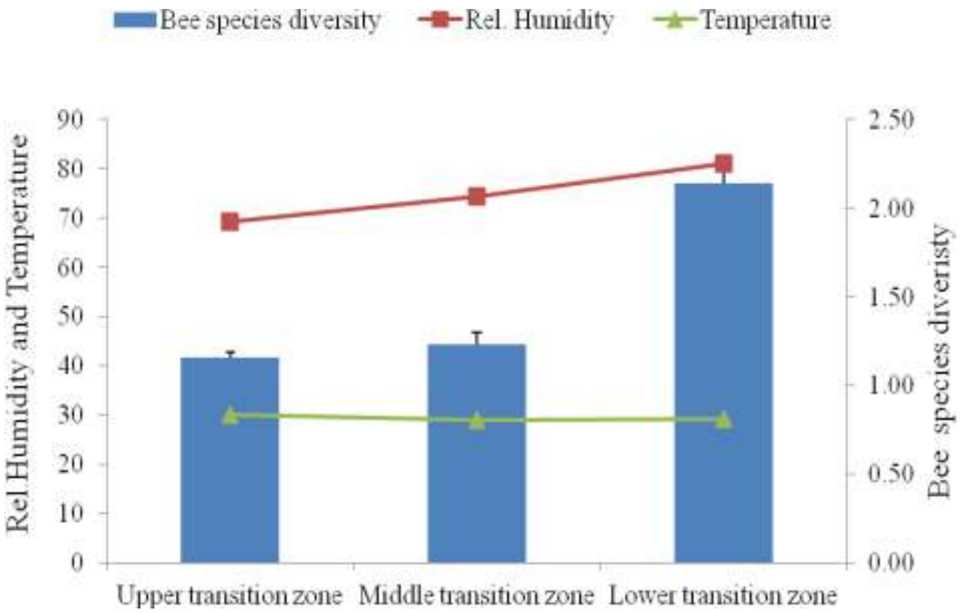


Figure 17: Variation in bee diversity with relative humidity and temperature across subzones

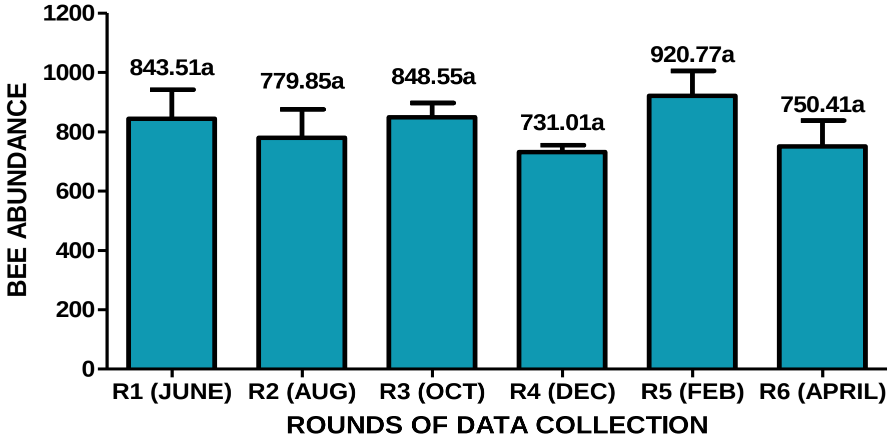


Figure 18: Variation in bee species abundance across sampling months

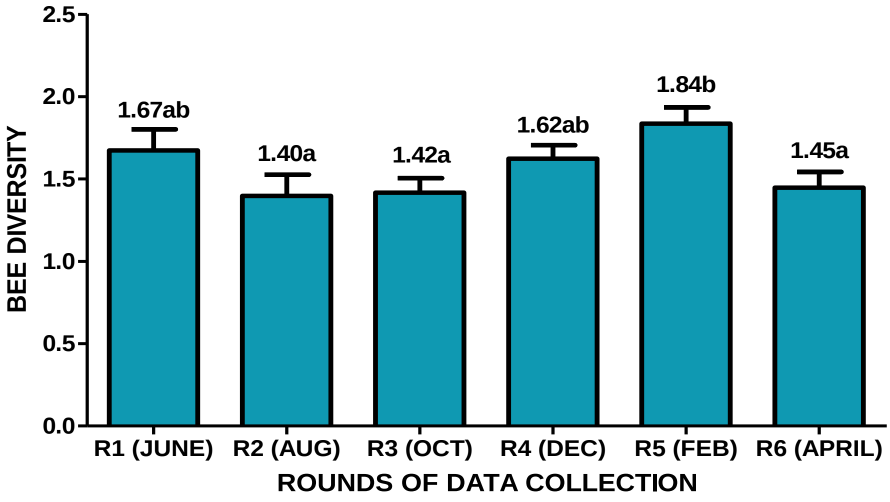


Figure 19: Variation in bee species diversity across sampling months

The Knowledge Level of Local Crop Farmers on Pollinators and Pollination

Age and gender distribution of crop farmers

Table 7 shows the distribution of age and gender of crop farmers who were interviewed. The results show an almost equal proportion of male and female crop farmers. Majority of the crop farmers interviewed were either 50 years old or younger (60% for males and 62% for females).

Table 7

Age and Gender Distribution of Crop Farmers (N=190)

Age bracket	% Males	% Females
30 and below	12.1 (23)	8.9 (17)
31-40	10.5 (20)	14.2 (27)
41-50	8.9 (17)	9.5 (18)
51-60	10.5 (20)	10.0 (19)
61-70	5.8 (11)	7.4 (14)
above 70	1.6 (3)	0.5 (1)
Total	49.4	50.5

Educational background of crop farmers

With the educational background of crop farmers, it was observed that as many as 89% of the respondents had either not received any formal education or had only obtained basic education (Table 8). Less than 10% had received secondary, technical or vocational education and only 1.6% of the farmers had received tertiary education. This is an indication that farming in the rural areas is largely in the hands of illiterates and semi literates.

Table 8

Educational Background of Crop Farmers

Educational background	Number of farmers	Percentage
No formal education	82	43.2
Basic Education	87	45.8
Secondary/Tech/Voc education	18	9.5
Tertiary education	3	1.6
Total	190	100

Years of crop farming

Table 9 shows that majority of the crop farmers in the study area had been farming for more than ten years.

Table 9

Years of Crop Farming by Farmers

Years of crop farming	Number of farmers	Percentage
0-5	12	6.4
6-10	28	14.7
More than 10	150	78.9
Total	190	100

Importance of flowers to crop farmers

Majority of the respondents (84.7%) were of the view that presence of flowers signal plant reproductive maturity (Table 10). Only six farmers (3.2%) knew that flowers help in pollination and therefore crop yield.

Table 10

Importance of Flowers to Crop Farmers

Importance of flowers	Number of farmers	Percentage
Attract insect for pollination	6	3.2
Signals onset of fruit	161	84.7
Signals abundant harvest	23	12.1
Total	190	100.0

Training on pollinators and pollination

As shown in Table 11, 177 crop farmers among a total of 190 indicated that they have never been provided with any training on pollinators and pollination since they started farming.

Table 11

Training of Crop Famers on Pollinators and Pollination

Trained on pollination	Total	Percentage
Yes	13	6.8
No	177	93.2
Total	190	100.0

Farmers' views on the need to protect flower visiting insects

Most of the crop farmers were of the view that insects found on flowers of food crops do not have to be protected because all insects destroy crops (Table 12).

Table 12

Protection of Insects Found on Crop

Insects should be protected	No.	Percentage
Yes	23	12.1
No	167	87.9
Total	190	100.0

Crop farmers' reasons for protecting insects found on crops

Among the 23 crop farmers who thought that insects found on flowers should be protected, 17 indicated the contribution of insects to crop production as their reason for making that decision (Table 13). Four of the remaining six said insect found on food crops must be protected because they are God's creation while the remaining two said they should be protected because some produce honey.

Table 13

Why Insects Found on Crop Must be Protected

Reasons	Number of farmers	Percentage
Some help in crop production	17	73.91
Are God's creation	4	17.39
Some produce honey	2	8.7
Total	23	100.0

Ways of protecting insects found on crops

On how to protect insects that visit food crops, majority of the farmers (78.26%) thought this could be achieved by avoiding chemical application or spraying. The rest either said they should be provided with food or left untouched.

Table 14

Ways to Protect Insects Found on Crops

How to protect insects found on crops	No. of farmers	Percentage
By avoiding chemical application	18	78.26
By leaving the insects untouched	3	13.04
By providing food for the insects	2	8.70
Total	23	100

Part of crop and period of day insects were found on crops

In all cases, majority of the crop farmers indicated that insects which visit their crops do so in the morning than any other period of the day (Tables 15 & 16).

1. *Apis mellifera*

Of a total of 73 farmers who saw honey bees on their crops, majority said they found them on the flowers (Table 15). This is followed closely by those who found them on leaves. This is not surprising as bees will sometimes settle on the leaves before they move to the flowers.

2. *Xylocopa* sp.

Majority of the farmers who knew about *Xylocopa* sp. said they found them on the flowers. Less than half of this total said they found them on the leaves. No farmer indicated seeing *Xylocopa* either on the branch or fruit.

3. *Amegilla* sp.

A total of 18 crop farmers said they knew about *Amegilla* sp. A large majority of this total said they found the bees on the flowers. None found them on branches or fruits.

4. *Meliponula bocandei*

Only five of a total of 190 respondents knew about this bee. Four of these farmers (80%) said they found *Meliponula* on the flowers.

5. Houseflies

Houseflies constituted the least seen on crops among the non bee species of insects. Of the 38 farmers who saw houseflies on their crops, most of them said they found them on the leaves followed by flowers. No housefly had been seen on a branch, stem or fruit.

6. Butterflies

Majority of farmers (61.5%) who had seen butterflies on their crops indicated that they found them on the leaves. Approximately half of this number (31.8%) said they found them on the flowers. With respect to period of day when butterflies were seen on crops 65.4% found them in the morning, 23.65% in both morning and evening, 4.73% in the afternoon and 2.03% in the evening. Six farmers (4.05%) found them all day.

7. Grasshoppers

Of the 190 crop farmers interviewed, 179 of them had at least seen grasshoppers once on their crops. A large majority of these farmers (81.6%) said they found grasshoppers on the leaves.

8. Praying mantis

As with grasshoppers, majority of the crop farmers who had seen praying mantis on their crops said they found them on the leaves.

9. Ants

Seventy nine crop farmers indicated they had ever seen ants on their crops. Most of these either said they found them on leaves or the stem.

Table 15

Part of Crop where Bees are Found

Percent Number of Insects

Name of insect	Leaves	flowers	branches	Stem	Fruit	Total
Apis mellifera	47.9 (35)	49.3 (36)	0 (0)	1.4 (1)	1.4(1)	100 (73)
Xylocopa sp	64.3 (18)	28.6 (8)	0 (0)	7.1 (2)	0 (0)	100 (28)
Amegilla sp	27.8 (5)	66.7 (12)	0 (0)	5.6 (1)	0 (0)	100 (18)
Meliponula bocandei	0 (0)	80 (4)	0 (0)	1 (0)	0 (0)	100 (5)
Housefly	86.8 (33)	13.2 (5)	0 (0)	0 (0)	0(0)	100 (38)
Butterfly	61.5 (91)	31.8 (47)	1.4 (2)	1.4 (2)	4.1(6)	100 (148)
Grasshopper	81.6 (146)	9.5 (17)	0.6 (1)	7.3 (13)	1.1 (2)	100 (179)
Praying mantis	77.3 (51)	16.7 (11)	0 (0)	1 (4)	0 (0)	100 (66)
Ant	41.8 (33)	13.9 (11)	0 (0)	43.0 (34)	1.2 (1)	100 (79)

Table 16

Period of Day Insects are Found

Percent Number of Insects

Name of insect	morning only	afternoon only	evening only	Morning& evening	all day	Total
Apis mellifera	68.5 (50)	1.4 (1)	0 (0)	23.3 (17)	6.8 (5)	100 (73)
Xylocopa sp.	50.0 (14)	7.1 (2)	3.6 (1)	39.3 (11)	0 (0)	100 (28)
Amegilla sp.	55.6 (10)	5.6 (1)	0 (0)	38.9 (7)	0 (0)	100 (18)
Meliponula bocandei	80.0 (4)	0 (0)	0 (0)	20.0 (1)	0 (0)	100 (5)
Housefly	71.1 (27)	2.6 (1)	2.6 (1)	23.7 (9)	0 (0)	100 (38)
Butterfly	65.5 (97)	4.7 (7)	2.0 (3)	23.7 (35)	4.1 (6)	100 (148)
Grasshopper	60.9 (109)	2.8 (5)	2.8 (5)	27.4 (49)	6.1 (11)	100 (179)
Praying mantis	63.6 (42	0 (0)	0 (0)	30.3 (20)	6.1 (4)	100 (66)
Ant	55.7 (44)	3.8 (3)	0 (0)	36.7 (29)	3.8 (3)	100 (79)

CHAPTER FIVE

DISCUSSION

Introduction

This research examined bee species abundance and diversity across landscape types within the Forest Savannah Transition Zone of Ghana. It was hypothesized that landscape type does not influence bee species abundance and diversity. The results of the analyses were mixed. However, landscape types and subzones generally influenced bee diversity whilst species abundance was the same.

Bees Found in the FSTZ of Ghana

The dominance of *Apis mellifera* over the other bee species could be attributed to their generalist foraging behaviour, physique and perennial large colonies (O' Toole & Raw, 1991). *A. mellifera* feeds on a wide range of floral resources (polylectic) and this enables it to live in diverse environments. Its social behaviour and occurrence in large numbers makes it a highly successful bee. Being a long distance forager, *A. mellifera* is able to visit distant and sparsely distributed floral-rich patches far removed from their hives. Even though honeybees have on the average, a foraging range of about 3km, a study carried out in the Congo forest indicated that they can sometimes forage up to a distance of 25 km away from their hives (Roubik, 2001).

The other bee species varied in their occurrence with some species being very rare. Flowering resources are usually identified as the most important resources for pollinators, and indeed, floral abundance and floral diversity are important (Potts *et al*., 2003; Potts *et al*., 2005). In addition, there is an increasing body of evidence suggesting that nest sites and nesting resources may also play important roles, particularly for bees. Bees exhibit a diverse array of nesting strategies with respect to the part of the habitat they nest in, the type of substrate they use, and the materials required for nest construction (O'Toole and Raw, 1991). According to O'Toole and Raw, bees are extremely diverse in their nesting ecology and comprise a number of distinct guilds: miners, carpenters, masons, social nesters and cuckoos. The diversity of nesting strategies and the specialization of guilds means that the availability of the correct quantity and quality of resources, both in space and time, are key in determining which species a landscape will support (Tscharntke *et. al*., 2005). The occurrence of certain bee species in specific landscape types and subzones may have been in response to the availability of the correct quantity and quality of nesting and floral resources. For several decades, bee researchers and beekeepers have tried to conserve pollinating insects like honeybees by providing nesting sites and good forage, and protecting them from pesticides (Thapa, 2006).

Species rarity is common in bee fauna. Studies conducted to document bee fauna in several parts of the world have reported high proportions of singletons and doubletons (Williams *et al*., 2001). According to Manuel, Roubik, Finegan and Zamora (1999), rarity of native bees is common in open or exposed sites particularly among the ground nesters. For example, most species of Lasioglossum were found mostly in farmlands where bare nesting sites were more readily available. Apart from Lithurgus spaghanotes which is a wood nester, the remaining four singletons namely *Lipotriches* *tetraloniformis, Thyreus nitidulis, Chalicodoma cinta* and *Coelioxys torrida* are ground nesters confirming the findings of Manuel *et al*. (1999). It is possible that these were sampled from bare open areas of the study area. Michener (1979) observed that even with intensive sampling bee species rarity can still reach high levels comprising between 16 and 42%. Again, pollinator populations rise and fall, as do all animals, in response to environmental variables such as weather conditions, levels of parasitism, or abundance of nesting sites.

A total of 34 bee species were identified in the FSTZ of Ghana over a period of 12 months. This number could probably have been higher but for the high levels of human-mediated activities prevailing within the study areas. According to Kremen *et al*. (2007), bees, the most important group of pollinators, are affected by human disturbances such as habitat loss, grazing, logging, and agricultural intensification. Pesticides usage, bushfires, logging, mining and grazing are quite common in the FSTZ of Ghana and may have negatively affected wild bee species diversity and abundance.

The use of pesticides in agriculture is well documented (Decourtye & Devillers, 2010) as causing pollinator declines, especially where spraying time coincides with flowering time. Insecticides pose a major threat to pollinators, and pesticide-induced declines in bee populations are yearly reported in many countries of the world (Williams *et al*., 2010a). Deliberate misuse of pesticides despite label warnings and recommendations has caused major pollinator kills (Johansen & Mayer, 1990; Kevan, 1977). In the US, a report of the use of diazinon to control aphids in alfalfa fields resulted in a massive decline of pollinating alkali bees, which took several years to show recovery (Johansen & Mayer, 1990).

The use of fire to clear the land of weeds is a common practice in the FSTZ of Ghana. Fire is applied for three major reasons: to clear the land for the new planting season, to regenerate fresh forbs for livestock or for hunting game. Many farmers in the study area engage in this activity probably because they find it easier and cheaper compared to hiring labour. This has both direct and indirect implications for biodiversity. Not only are bees killed by the raging fire but their forage and nesting resources are also destroyed. Some bees may however escape to other safer habitats.

Another activity common in the study area is logging. Timber is harvested by both authorized and illegal operators for various reasons; firewood, furniture, construction and exports. There are several wood processing companies doing brisk business within the FSTZ zone. Their activities are depleting the FSTZ of diverse tree populations at a very fast rate which is denying bees especially wood nesters of shelter, nesting materials and food resources the same way as bushfires.

One significant economic activity within the study area is surface mining. Small-scale surface mining presently appears to pose the greatest threat to the environment in the FSTZ of Ghana. The activities of small-scale surface miners have resulted in the destruction of the surface soil and several wetlands which could serve as forage and nesting sites for bees. This has the potential to cause declines in wild bee diversity and abundance leading to lower food production.

Another factor that may have affected bee diversity and abundance in the study area is grazing. The response of bees to grazing is dependent on the intensity of grazing (Winfree *et al*., 2009). Where grazing is associated with a decrease in floral abundance and diversity, it negatively affects bee populations (Vulliamy *et al*., 2006) through removal of food sources and destruction of underground nests (Kearns *et al*., 1998). Generally, it is admitted that grazing intensity (stocking density of animals) can affect the pollinator species richness, abundance and visitation frequency to flowering plants through changing the structure, composition and phenology of preferred bee-food plants (Xie *et al*., 2008). Almost every rural home in Ghana rears one type of animal or the other. Some of these animals are sometimes left to move freely in the communities rendering settlement areas unstable and depriving them of the relevant floral and nesting resources required by bees.

Variation in Bee Species Abundance and Diversity Within Subzones

Upper FSTZ

Two key factors influencing bee diversity and abundance are floral and nesting resources (Smith, Warren, Thompson & Gaston, 2006). The absence of variation in bee species abundance within the UFTZ may be due to the dominance of *A. mellifera* in every landscape type. According to Carreck and Williams (1997) natural and semi-natural habitats adjacent to crop fields provide floral resources all season and are important to the sustainability of wild bee populations. The natural vegetation in the Upper FSTZ may have been floristically richer than both agricultural land and settlement fringes hence the highest bee diversity recorded. This is because such areas are often spared from burning and even when they are affected there is less devastation.

Natural areas are therefore the most stable environments in the Upper FSTZ and thus offer adequate floral and nesting resources for bees.

On the other hand, burning is a tool used by farmers for clearing the land each year before planting starts. This perennial activity could make such areas less suitable for wild bees through denying them of their necessary nesting and floral resources. According to Willmer and Stone (2004) different kinds of flowers of varying phenologies attract different pollinators. While some wild bee species are generalists and can pollinate a wide range of flowers, others are specialists and depend on particular plant species for their survival. Again, monocultures dominate the Upper FSTZ with many farmers cultivating only one type of crop on their land. This practice results in the establishment of a less diverse weed community (Ball, 1992) which in turn sacrifices floral diversity. In addition, there is a massive application of weedicides in farms in the Upper FSTZ which was confirmed through the interview conducted. These activities may have resulted in lower bee species diversity in agricultural land compared with natural vegetation.

Unlike urban areas or cities where ornamental flowering plants are cultivated to beautify houses or for landscaping, this study was conducted in rural settlements deprived of horticultural plants with the exception of plantain. Animal rearing is the second most important occupation in the upper zone after crop production. Some of these animals are sometimes left to graze within the communities rendering settlement fringes highly unstable and depriving them of the needed bee resources. These may have contributed to the lowest bee species diversity observed in settlement fringes.

Middle FSTZ

Bee species abundance did not differ among the three landscape types in the Middle FSTZ probably for the same reason of *A. mellifera* dominance as explained for the Upper FSTZ. However, unlike the Upper FSTZ, many farmers in the Middle FSTZ engage in the mixed cropping system cultivating more than one crop on the same piece of land (Appendix 4). Examples of such crops are mangoes, pepper, cashew, cassava, oil palm, garden eggs and tomatoes. These crops are pollinated by bees. According to Ball (1992), weed communities are more diverse in the mixed cropping system than when crops are grown in a monoculture and this creates a more favourable habitat and food conditions for pollinators. Weeds provide alternative food resources (pollen, nectar, alternate host) thus aiding in the survival of viable populations of pollinators. Secondly the use of weedicides for farming is less widespread in the Middle FSTZ compared to the Upper FSTZ. Possibly the high presence of weeds as alternate food sources for pollinators and reduced usage of weedicides may have contributed to the highest bee species diversity in agricultural land.

Settlement fringes probably recorded the lowest bee species diversity for the same reason as explained for the Upper FSTZ.

Lower FSTZ

The mixed cropping system identified for the Middle FSTZ is even more common in the Lower FSTZ. Thus the same reasons assigned for the high bee species diversity in agricultural land in the Middle FSTZ hold for agricultural land in the Lower FSTZ. The lowest bee diversity observed in natural vegetation is quite unusual. Logging and small scale mining which are quite common in most natural areas in the Lower FSTZ probably contributed to this observation as already discussed.

Variation in Bee Abundance and Diversity per Landscape Type Across Subzones

The highest bee species diversity observed for all landscape types in the Lower FSTZ may have been in response to higher floral diversity and abundance as compared to the other subzones. According to Steffan-Dewenter and Tscharntke (2002), a high diversity of flowering plants results in high bee diversity. Again, it is likely that the three landscape types within the lower zone offered the best nesting sites for bees. Cane (1991) observed that the temporal and spatial distribution of nesting resources may determine the bee community composition in a given location. The Lower FSTZ has characteristics that make it more attractive to diverse bee populations compared to the Upper and Middle FSTZs (70% trees and 30% grasses). The high tree density and diversity in the Lower FSTZ may have provided adequate nesting sites for wood nesting bees (e.g *Meliponula bocandei*) and also offered higher floral resources. Meliponine bees are strongly associated with forests in tropical countries mainly because of cavity tree nesting opportunities (Munyuli, 2010). Besides, the Lower FSTZ is less prone to bushfire incidence and drought compared to the Middle and Upper FSTZs. These are favourable conditions for bees.

Bees were less diverse in the Middle and Upper FSTZs probably because of the prevalence of grass vegetation which may be ideal nesting sites for ground nesters but lack adequate floral resources. It may also be due to the greater impact of human interfence resulting from high levels of grazing, fire incidence, water scarcity and weedicide application. In fact, it is generally admitted that grazing intensity can affect the pollinator species richness, abundance and visitation frequency to flowering plants through changing the structure, composition and phenology of preferred bee food plants (Xie *et al*., 2008). According to Potts *et al*. (2010), wildfire causes a reduction in both wild bee diversity and abundance by removing the vegetation cover and other resources on which bees depend. Winfree *et al*. (2009) observed that increased application of pesticides can lead to disappearance of specialist pollinators while increasing the prevalence of common and generalist bee species in the landscape.

General Variation in Bee Species Abundance and Diversity Across Landscape Types

In parallel with floral resources, the temporal and spatial distribution of nesting resources may determine the bee community composition in a given location (Cane, 1991; Potts *et al*., 2005). It has been established that floral and bee diversity and abundance are positively associated (Potts *et al*., 2003; Biesmeijer *et al*. 2006). Petanidou and Ellis (1996) documented a correlation between diversity in the family Andrenidae and diversity of annual flower species. Potts *et al*. (2003) monitored bee populations in Israel and found a strong association between diversity in *Andrenidae* and *Megachilidae* and floral diversity. Again, Heithaus (1974) in a study of four different plant communities in Costa Rica determined that floral abundance and diversity positively correlated with pollinator diversity and abundance. In Uganda, Munyuli (2010) observed that higher bee diversity indicates the availability of resources for species with different requirements. Similarly, Banaszak (1995) observed that there is a relationship between diversity of Apoidea and floral diversity. The three landscape types in the study area may have recorded the same bee abundance owing to the dominance of *A. mellifera* in every landscape type. The dominance of *Apis mellifera* is attributed to its generalist foraging behaviour, physique and perennial large colonies (O' Toole & Raw (1991).

The highest bee species diversity recorded in agricultural land was probably in response to higher floral diversity. Mono-cropping may be common in the Upper FSTZ but crop farmers in the study area largely engage in the mixed cropping system, cultivating two or more of cassava, tomatoes, pepper, egg plant, yam, cashew, water melon, groundnut, oil palm or plantain on the same piece of land. These and the many weed species on the farm may have provided diverse floral resources for bees with different food requirements. Farmland heterogeneity (richness of habitats) increases pollinator diversity because plant species provide complementary resources over time and space, and insect species use different resource combinations (Blüthgen & Klein, 2011; Kremen & Miles, 2012). In fact, the loss of plant diversity and flower quantity due to habitat destruction and fragmentation of the landscape is assumed to be responsible for the decline of many bee species (Muller *et al*., 2006). Increasing floral diversity provides a wider array of foraging niches for different functional groups of flower visitors (Fenster, Armbruster, Wilson, Dudash & Thomson, 2004). Large parcels of land devoted to monoculture, especially crops consisting of wind-pollinated plants such as maize and rice sacrifice floral diversity and, consequently, diversity of pollinating insects over large areas.

Several scientific studies have reported that increased areas of semi-natural habitat on farms and within agricultural landscapes favour diversity and abundance of native bees. Greenleaf and Kremen (2006) monitored native bee populations responsible for pollination of tomato and discovered that *Bombus vosnesenskii* was present more often in farms proximate to natural habitats. A research by Kremen *et al*. (2004) in California revealed that both native bee diversity and abundance are significantly related to the proportional area of wild habitat surrounding the farm. Again, a study by Ricketts *et al*. (2008) revealed that crop pollinators inhabit surrounding natural habitat and spill over into agricultural fields during crop bloom. Natural and semi-natural habitats adjacent to crop fields provide floral resources all season and are important to the sustainability of wild bee populations (Carreck & Williams, 1997). Habitats such as wooded areas, hedgerows and herbaceous field margins are crucial for the survival of wild bees as observed in this research. Bees depend on such habitats for the provision of nesting sites, and for food from pollen and nectar in wild flowers. Natural and semi-natural habitats experience less-disturbance and so help maintain overall bee diversity (Fussell & Corbet, 1991). Many wild bees that contribute to pollination require forage sources outside of the crop bloom period (Tuell *et al*., 2008) which is provided for by surrounding natural vegetation. Several entomologists and ecologists have suggested that isolation from critical floral and nesting resources present in wild lands is likely the key factor explaining the decline in abundance and diversity of native bees in crop fields and attendant loss of pollination services (Munyuli, 2012a).

When food crops are out of season, floral resources become scarce in agricultural land. Bees then resort to nearby natural areas to forage. At the landscape scale, natural habitat is necessary to support a diverse pool of wild pollinators and their services to crop fields (Carvalheiro, Seymour, Veldtman & Nicolson, 2010; Klein *et al*., 2012), while at the field scale the addition of floral resources may locally augment bee density and diversity. It is therefore logical to observe in this study that bee diversity in agricultural land did not significantly differ from that of natural vegetation. The two landscape types complement each other by providing the necessary resources at different times to support bee populations. Studies conducted in east Africa by Gikungu (2006) however show that agricultural ecosystems support higher levels of bee diversity and abundance than natural or forested areas.

Bees are extremely diverse in their nesting ecology and include distinct guilds namely miners, carpenters, masons, social nesters and cuckoos (O'Toole & Raw, 1991). The diversity of nesting strategies and the specialization of guilds means that the availability of the correct quantity and quality of resources, both in space and time, are key in determining which species a landscape will support (Tscharntke *et. al*., 2005). Typically, nesting substrate and foraging resources are spatially disparate (Cane, 2001). For example, ground nesting bees require exposed soil for nesting and patches of floral resources for foraging. Similarly, wood nesters can only live successfully in habitats with high tree density and adequate floral resources. These often do not occur in the same area. Bees are forced to traverse a patchwork of unsuitable habitat in order to access desired resources (Cane, 2001). The higher bee diversity observed in agricultural land and natural vegetation might have been due to higher quality and quantity of nesting resources as compared to settlement fringes.

There is evidence that rural open space, hedgerows, and undeveloped fields surrounding urban centres will help to maintain floral diversity and thereby augment bee diversity (Osborne *et al*., 1991; O'Toole, 1993; Osborne & Corbet, 1994; Steffan-Dewenter *et al*., 2002). The fringes of many rural settlements in Ghana lack the horticultural plants that provide forage resources as are commonly found in cities or urban areas. These settlements suffer persistent interference from grazing, unsustainable waste disposal and burning which make them highly unstable. This may have contributed to the low bee diversity observed in settlement fringes. Although wild bees do benefit from some degree of disturbance, which promotes the growth of herbaceous plants and wildflowers, too much human-caused disturbance can have negative impacts (Williams *et al*., 2010b).

General Variation in Bee Species Abundance and Diversity Across Subzones

A number of reasons could account for the difference observed in bee species diversity among subzones. Among the three subzones, tree density and diversity are highest in the Lower FSTZ and lowest in the Upper FSTZ. The proportion of woodland habitat on or near farms has been related to the pollination services provided by native bees (Kremen *et al*., 2002, Kremen *et al*., 2004). In the Mediterranean, both mature pine forests and mixed oak woodland were shown to be essential ingredients required by wild bees to maintain pollination services in adjacent areas of agricultural crops (Potts *et* *al*., 2006). Again, a study in five European countries found that bee diversity was positively enhanced by habitats of broadleaf forest and woodland shrubs (Carré *et al*., 2009). Availability of large, old and hollow trees is beneficial to bees because they provide nesting or resting sites (Gordon *et al*., 2007). Generally both the diversity of crop pollinators and the overall level and stability of their pollination services are positively affected by the proportion and/or proximity of surrounding natural and semi-natural habitats (Garibaldi *et al*., 2011; Kennedy, Lonsdorf, Neel & Williams, 2013; Ricketts *et al*., 2008). In a study by Gikungu (2006), some species of the genus *Xylocopa* were found to prefer the mature forest where abundant and safe nesting sites were available. It is possible that the higher bee diversity observed in the Lower FSTZ was in response to higher tree density and diversity and hence abundance of safe nesting or resting sites. As Munyuli (2011b) puts it "mitigating charcoal burning, grazing intensity, systematic and intensive timber harvests in forest reserves can help to save wood-nest sites for various pollinator species".

As stated earlier, most of the farmers in the Lower FSTZ cultivate more than one crop on the same piece of land. The mixed cropping system practised in the Lower FSTZ often involves two or more of cocoa, oil palm, cassava, cocoyam, plantain, okra, pepper, tomatoes or egg plant. Conversely, monocultures are more common in the Upper FSTZ where crop fields are often cultivated solely with maize, millet, yam, cashew, water melon, groundnut, mango or cowpea. Where different crops are planted on the same piece of land weed communities are more diverse than where crops are grown in a monoculture, which creates more favourable habitat and food conditions for pollinators (Ball, 1992). Bee diversity therefore may have increased down south from the Upper FSTZ to the Lower FSTZ in response to favourable habitat and forage resources.

Consequences of climate change such as increasing temperatures, changes in rainfall patterns, and more erratic or extreme weather events are predicted to impact on pollinator populations including wild bees (UNEP, 2010). The variability and the inconsistency of seasonal weather patterns have often been ascribed as a key factor in bee health, especially in respect of their survival rates (Abou-Shaara & Al-Ghamdi, 2012). For example, species that forage in habitats of high humidity in the understory community are negatively affected by canopy opening (Rincón, Roubik, Finegan, Delgado & Zamora, 2000). Weather conditions differ for the three subzones studied. Whilst the Upper FSTZ is generally characterized by high air temperatures and low relative humidity, the reverse is the case in the Lower FSTZ (see Appendix 3, Table 2). This may be due to the vegetation in the Lower FSTZ which has a higher tree density and enjoys a greater amount of rainfall than the upper and Middle FSTZs. In the present study, mean annual temperature and relative humidity values recorded for the Upper FSTZ were approximately 30 degrees Celcius and 69 percent whilst corresponding values for the Lower FSTZ were 29^{o}C and 84 percent (Figure *8*). High solar radiation can cause flowers to wither while strong winds may force foraging bees down or injure flowers and cause loss of pollen. As indicated by Hegland *et al.* (2009), the generally high solar radiation and wind speed in the Upper FSTZ may have contributed to the lowest bee species abundance and diversity observed in that part of the study area.

The loss or degradation of the landscape by fire can eliminate or reduce the availability of nesting sites as well as the quality and accessibility of food plants, resources that must generally be located within close proximity to nest sites (Gathman *et al*., 2002; Potts *et al*., 2003). Fire causes fragmentation and habitat loss. Habitat destruction is detrimental to bee populations through the loss of floral resources, nesting resources, mating and resting sites, especially since some oligolectic bees require specific flowers (Kearns & Inouye, 1997, Kevan, 1999). Research shows that farmers who leave residues on soil or practise mulching may be inadvertently encouraging wild bees (Shuler *et al*., 2005). One major challenge experienced each year in the study area especially the Upper FSTZ is the high incidence of wildfire. Farmers deliberately set fire to the vegetation for three major reasons: to clear the land for the new planting season, to regenerate fresh forbs for livestock, or for hunting game. Bushfire incidence increases up north from the south in relation to the proportion of trees relative to grasses. The high incidence of bushfire in the Upper FSTZ has probably eliminated some key bee species leading to the low bee diversity in that zone compared to the Lower FSTZ where bushfire occurrence is low.

The degradation of habitats through the massive application of herbicides can have long-term consequences, particularly on the distribution of pollinating insects in agro-environments (UNEP, 2010). Herbicide use affects pollinators by reducing the availability of nectar plants and pollen resources for bees (Kearns *et al*., 1998). Landscape-scale surveys of wild bees and butterflies show that species richness tends to be lower where pesticide loads and cumulative exposure risks are high (Brittain *et al*., 2010). When flowering weeds are eliminated at a time the main crops are not flowering, massive decline of bees occurs in agro-ecosystems due to the lack of suitable nesting sites and alternative food plants (Benedek, 1996). While acknowledging the widespread use of weedicides for agriculture throughout Ghana, it is important to indicate that its application is highest in the Upper FSTZ and this was confirmed through the questionnaire administered (Appendix 5). This may probably be due to the ease with which the land in the Upper FSTZ dominated by grasses (herbs) can be easily cleared by weedicides. This may have contributed to the low bee species diversity in the Upper FSTZ compared to the Lower FSTZ.

The response of bees to grazing is dependent on the intensity of grazing (Winfree *et al*., 2009). Where grazing is associated with a decrease in floral abundance and diversity, it negatively affects bee populations (Vulliamy *et al*., 2006). Gess and Gess (1993) and Sugden (1985) measured the effects of grazing in semi-arid habitats in southern Africa and in California, respectively. Their results indicated that grazing animals trampled bees and compressed the ground making it less suitable for nest sites. In addition, they observed that the foraging done by grazing increased the abundance of plants that were not attractive to bees. A common phenomenon observed during this research was the free movement of livestock in the Upper and Middle FSTZs. During the study, animals such as cattle, sheep and goats were often seen grazing in settlement areas without control. A study by Kearns and Oliveras (2009) found that plots that were routinely grazed were often dry and lacked the abundance of flowers found in other plots. The level of disturbance by livestock in the Upper and Middle FSTZs may have limited the establishment and availability of floral resources. This may have contributed to the low bee diversity in the upper and Middle FSTZs.

Variation in Bee Abundance and Diversity With Relative Humidity and Temperature Across Subzones

High relative humidity may mean availability of water which is one of the resources that are very important to bees. The flowering period is prolonged when water is available which also means food will be available for a longer period. Again, water is an alternative food source for the larvae and may also be used to dilute honey to make it more plentiful (Inouye, 2008). Besides, water is used to create air conditioning in the hive during hot temperatures. These diverse uses of water seem to suggest that bee diversity increases with rising relative humidity. However, this observation requires further studies and analysis.

Variation in Bee Species Abundance and Diversity Across Sampling Months

Though no clear trend in bee abundance and diversity was observed for the different sampling months, the high bee dominance and species diversity in February 2014 could be attributed to abundance of floral resources. February is well situated within the period when most flowers blossom in Ghana (December to March). High precipitation may limit pollinators' foraging activity. Bees collect a lot of pollen and nectar during this period and store them for honey preparation during the major rains. Optimal foraging conditions for pollinators are sunny days with low wind speed and intermediate temperature (Inouye, 2008). It is therefore not unusual to observe the highest bee abundance and diversity in February. The remaining months (April to November) are characterized by frequent precipitation and massive vegetative growth. Fire incidence is highest in the FSTZ in December and this probably accounted for the lowest bee diversity observed in that month. In a study that examined arthropods in prairies of the American Midwest, Harper, Dietrich, Larimore & Tessene (2000) found that overall species richness and the abudance of all but one of the arthropods species measured decreased in burned sites. Their results suggest that burning a small habitat fragment in its entirety could risk extirpating some species because of limited recolonization from adjacent habitat. Nevertheless, pollinators are often quite variable in relation to ambient conditions, and a species that is relatively unimportant in one year may be of greater importance in the next year (Kremen *et al*., 2002).

The Knowledge Level of Local Crop Farmers on Pollinators and Pollination

The high level of ignorance among crop farmers on pollinators and pollination is not surprising. Focus on pollination biology commenced earnestly in the mid 90s following reports of honeybee colony losses in several countries including USA, Mexico and Canada (Allen-Wardell *et al*., 1998). Recognition of the widespread loss of pollinators and pollinator services by Conference of the Parties (COP5) to the Convention on Biological Diversity (CBD) led to the formation of the International Pollinator Initiative-IPI (also known as the International Initiative for the Conservation and Sustainable use of Pollinators) in Nairobi, Kenya in May 2000. Only in 2003 did the African branch of the initiative (African Pollinator Initiative-API) through FAO developed and published its Plan of Action based on four components, namely public awareness and education, placing pollination in the mainstream, conservation and restoration, and capacity building. Ghana, Kenya, South Africa, Uganda are the only counties in Africa where extensive pollinator studies are currently being undertaken in the four thematic areas. As was expected, many of the crop farmers indicated that they have not received any training on pollination. One would therefore expect knowledge on pollinators and pollination in communities outside the Global Pollination Project (GPP-Ghana) Study, Training, Evaluation and Promotion (STEP) Sites to be quite low especially among the illiterates. The low level of awareness probably accounts for the high incidence of human-mediated activities taking place in the FSTZ. As observed in this study, crop farmers are more familiar with insects that destroy their crops than beneficial ones like the bees because the services the latter provide are neither visible nor immediate. The observation that almost equal proportions of males and females in the younger age bracket (not more than 50 years) have been involved in crop farming for more than ten years is encouraging. This is because the youth are more energetic and given the right information, training and incentives they can contribute highest to food production in Ghana.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study assessed the influence of landscape type on the abundance and diversity of bees in the FSTZ of Ghana on bi-monthly basis from June 2013 to April 2014. It also evaluated the knowledge level of 190 crop farmers in the study communities on pollinators and pollination.

A total of 34 species of bee represented in three families (Apidae, Halictidae and Megachilidae) were identified from 706 bees collected. The family Apidae was the most speciose whilst Megachilidae was the least speciose family. *Xylocopa*, *Amegilla* and *Lipotriches* were the most common genera whilst *Chalicodoma*, *Thyreus*, *Coelioxys torrida* and *Lithurgus* were represented by single individuals. Four bee species were found in only agricultural land (*Amegilla nila*, *Xylocopa torrida*, *Lipotriches cirrita* and *Lithurgus sparganotes*), two in only settlement fringes (*Thyreus nitidulis* and *Lipotriches tetraloniformis*) and three in only natural vegetation (*Meliponula bocandei, Coelioxys torrida, Chalocodoma cinta*). With subzones, one species was limited to the Upper FSTZ (C*ompsomelissa* sp.) and four to the Lower FSTZ (*Xylocopa nigrita*, *Lipotriches nigrociliata*, *Megachile semierma* and *Megachile bituberculata*). No bee was found in only the Middle FSTZ.

Unlike species abundance, significant variations were observed in bee species diversity across landscape types within the Upper FSTZ. Bees were most diverse in natural vegetation and least diverse in settlement fringes. In the Middle FSTZ, bee diversity was highest in agricultural land and lowest in settlement fringes. As with the Upper FSTZ, there was no significant difference in bee species abundance across landscape types. In the Lower FSTZ, there were significant differences among landscape types for both species abundance and diversity. Agricultural land recorded the highest bee species diversity in the Lower FSTZ whilst natural vegetation recorded the lowest. Bees were however more abundant in natural vegetation than in either agricultural land or settlement fringes. Comparing the performance of each landscape type in the three subzones, species abundance significantly varied for only natural vegetation. The Lower FSTZ had the highest bee abundance whilst the Upper FSTZ recorded the lowest. Species diversity however significantly varied across subzones for all the three landscape types and was in all cases highest in the lower FSTZ. Lowest species diversity for agricultural land was recorded in the Upper FSTZ but for both settlement fringes and natural vegetation, lowest diversity occurred in the Middle FSTZ. Thus regardless of landscape type, the Lower FSTZ was by far the subzone most preferred by bees.

Overall, bee species diversity varied significantly across landscape types with agricultural land and natural vegetation recording more bee species than settlement fringes. Agricultural landscape and natural vegetation provide a wide range of floral resources to attract different foraging bees hence the diversity recorded whilst settlement fringes in rural communities do not present diverse food resources to attract different bees. Bee species abundance however remained the same across the landscape types probably due to the predominance of *Apis mellifera*. Though bee species abundance did not differ across subzones, the study indicated that bee species diversity is significantly influenced by percent tree to grass proportions. There were more bee species in the lower FSTZ (area with the highest percent tree cover) than in either the middle or upper FSTZ.

The interview revealed that a large majority of rural crop farmers lack adequate information on pollinators and pollination. For example, most of the farmers interviewed knew that the presence of flowers on crops signal plant reproductive maturity but were ignorant about the fact that flowers help in pollination and hence crop yield.

Conclusions

Altogether, 34 species of bee comprising 18 species from the family Apidae, 11 species from Halictidae and 5 species from Megachilidae were identified from 706 bees collected from the FSTZ of Ghana between June 2013 and April 2014. The results of bee species abundance and diversity across landscape types were mixed when compared within and among subzones. Put together, bee species abundance was the same across landscape types but diversity varied with agricultural land recording the highest number of bee species in the FSTZ whilst settlement fringes obtained the lowest. Again, bee species abundance did not differ across subzones but species diversity did. The Lower FSTZ recorded the highest number of bee species whilst the Upper FSTZ obtained the lowest. This means that bee species diversity declines moving from the south towards the northern part of the FSTZ. Availability of crop fields as well as higher tree density and diversity are probably the most significant factors accounting for these observations. It has been established that the inter-dependence of agricultural land and natural vegetation ensures the survival of diverse bee species. On farmers’ knowledge and perception about pollinators and pollination, the study revealed a high level of ignorance among the local crop farmers which perhaps is the reason for their high involvement in the use of pollinator unfriendly practices such as agro-chemical application, bush burning and logging. It is concluded from this study that landscape type significantly influences bee species diversity in the FSTZ. The first null hypothesis is therefore rejected whilst the second is upheld.

Recommendations

Farmers around the world can no longer depend on the free services that pollinators provide without taking their needs for survival into consideration. Biodiversity conservation should be a priority for every nation considering the contribution of wild bees to crop production, food sufficiency and livelihood sustenance.

The Global Pollination Project carried out in Ghana (2009-2014) has had a significant positive influence on crop farming through knowledge generation and sharing within the project communities. The observation that four years into the project farmers outside the project communities in Ghana such as those in the FSTZ still have limited information on pollinators and pollination means that more work ought to be done if food production in Ghana is to be improved. It is therefore suggested that follow-up projects be carried out on pollinators and pollination in all major agro-ecological zones of Ghana since agriculture is highly dependent on pollinators. This will provide information on the current status and trends of pollinators so that the necessary interventions can be applied on time. The following recommendations are thus made.

1. Continuous monitoring of bees in the FSTZ
2. Education of the general public on
    a. the importance of pollinators in agriculture
    b. the difference between pests and pollinators and
    c. the need to plant horticultural plants near houses
3. Training of crop farmers to adopt pollinator-friendly conservation and farming practices e.g altering the timing of pesticide application
4. Placing issues of pollinators and pollination on the school curriculum
5. Introducing policy to protect biodiversity through landscape conservation
6. Ecologists to focus attention on pollinator research

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APPENDICES

Appendix 1

Comparison of Biodiversity Factors

Table 1

Species Richness, Abundance, Diversity and Evenness of Bee Assemblages Across 3 Landscape Types

Landscape Type	Species Richness	Abundance	Diversity (H’)	Evenness (E)
Agricultural Land	26.27 ± 3.85$^{\mathbf{a}}$	599.47 ± 325.99$^{\mathbf{a}}$	1.83 ± 0.08$^{\mathbf{a}}$	0.21 ± 0.11$^{\mathbf{a}}$
Settlement Fringes	21.08 ± 4.29$^{\mathbf{a}}$	621.72 ± 375.72$^{\mathbf{a}}$	1.19 ± 0.09$^{\mathbf{b}}$	0.34 ± 0.17$^{\mathbf{a}}$
Natural Vegetation	16.56 ± 2.81$^{\mathbf{a}}$	840.33 ± 420.02$^{\mathbf{a}}$	1.54 ± 0.11$^{\mathbf{a}}$	0.18 ± 0.10$^{\mathbf{a}}$

Table 2

Species Richness, Abundance, Diversity and Evenness of Bee Assemblages Across 3 Subzones

Landscape Type	Species Richness	Abundance	Diversity (H’)	Evenness (E)
Upp. Trans. Zone	20.06 ± 3.51$^{\mathbf{a}}$	876.20 ± 595.41$^{\mathbf{a}}$	1.16 ± 0.03$^{\mathbf{b}}$	0.46 ± 0.25$^{\mathbf{a}}$
Mid. Trans. Zone	21.57 ± 4.25$^{\mathbf{a}}$	755.50 ± 506.20$^{\mathbf{a}}$	1.23 ± 0.07$^{\mathbf{b}}$	0.78 ±0.43$^{\mathbf{a}}$
Low. Tran Zone	28.43 ± 4.46$^{\mathbf{a}}$	1024.61 ± 532.10$^{\mathbf{a}}$	2.14 ± 0.11$^{\mathbf{a}}$	0.48 ±0.30$^{\mathbf{a}}$

Table 3

Species Richness, Abundance, Diversity and Evenness of Bee Assemblages Across Sampling Rounds

ROUNDS OF DATA COLLECTION	Measure of Biodiversity			
	Species Richness	Abundance	Diversity (H')	Evenness (E)
R1 (JUNE)	30.98 ± 4.80^{a}	843.51 ± 98.43^{a}	1.67 ± 0.12^{ab}	0.31 ± 0.17^{a}
R2 (AUGUST)	26.72 ± 3.15^{ac}	779.85 ± 95.01^{a}	1.40 ± 0.13^{a}	0.16 ± 0.09^{a}
R3 (OCTOBER)	29.35 ± 3.76^{a}	848.55 ± 48.64^{a}	1.42 ± 0.09^{a}	0.21 ± 0.11^{a}
R4 (DECEMBER)	16.95 ± 1.06^{bc}	731.01 ± 23.51^{a}	1.62 ± 0.08^{ab}	0.27 ± 0.16^{a}
R5 (FEBRUARY)	19.34 ± 1.30^{c}	920.77 ± 83.98^{a}	1.84 ± 0.10^{b}	0.38 ± 0.20^{a}
R6 (APRIL)	26.65 ± 2.88^{ac}	750.41 ± 87.56^{a}	1.45 ± 0.10^{a}	0.23 ± 0.12^{a}

Within each column, means (x ± se) followed by the same letter are not significantly different at P > 0.05 level as determined with Fisher's protected least significant difference (LSD) test for means comparisons

Appendix 2

Statistical Output of Biodiversity Factors

Table 1

Descriptive Statistics of Measures of Biodiversity Across Landscape types in the Upper Transition Zone

Biodiversity	Landscape	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Agricultural	109	1.0860	.19210	.01840	1.0495	1.1224
	Settlement	105	.5749	.10752	.01049	.5541	.5957
	Natural	72	1.1929	.24111	.02841	1.1363	1.2496
	Total	286	.9252	.32542	.01924	.8874	.9631
Abundance	Agricultural	109	167.4510	931.48038	89.21964	-9.3978	344.2998
	Settlement	105	89.1464	627.20330	61.20877	-32.2329	210.5257
	Natural	72	279.1479	1252.75168	147.63820	-15.2343	573.5301
	Total	286	166.8223	932.05527	55.11358	58.3410	275.3036
Richness	Agricultural	109	12.0045	3.61852	.34659	11.3175	12.6915
	Settlement	105	6.2370	1.86208	.18172	5.8766	6.5973
	Natural	72	10.3583	3.43019	.40425	9.5523	11.1644
	Total	286	9.4726	3.95796	.23404	9.0120	9.9333
Evenness	Agricultural	109	.4950	.23843	.02284	.4498	.5403
	Settlement	105	.2670	.15182	.01482	.2377	.2964
	Natural	72	.5525	.24224	.02855	.4956	.6094
	Total	286	.4258	.24443	.01445	.3974	.4543

Table 2

ANOVA Comparisons of Measures of Biodiversity Across Landscape types in the Upper Transition Zone

Biodiversity		Sum of Squares	df	Mean Square	F	Sig.
Diversity	Between Groups	20.865	2	10.433	316.949	.000
	Within Groups	9.315	283	.033		
	Total	30.180	285			
Abundance	Between Groups	1541992.846	2	770996.423	.887	.413
	Within Groups	246045209.491	283	869417.701		
	Total	247587202.338	285			
Richness	Between Groups	1854.518	2	927.259	100.537	.000
	Within Groups	2610.124	283	9.223		
	Total	4464.642	285			
Evenness	Between Groups	4.325	2	2.162	48.173	.000
	Within Groups	12.703	283	.045		
	Total	17.028	285			

Table 3

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Landscape types in the Upper Transition zone

Dependent Variable	(I) Landscape	(J) Landscape	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Agricultural	Settlement	.51111*	.02481	.000	.4623	.5599
		Natural	-.10695*	.02755	.000	-.1612	-.0527
	Settlement	Agricultural	-.51111*	.02481	.000	-.5599	-.4623
		Natural	-.61806*	.02776	.000	-.6727	-.5634
	Natural	Agricultural	.10695*	.02755	.000	.0527	.1612
		Settlement	.61806*	.02776	.000	.5634	.6727
Abundance	Agricultural	Settlement	78.30463	127.50089	.540	-172.6658	329.2751
		Natural	-111.69691	141.60351	.431	-390.4267	167.0329
	Settlement	Agricultural	-78.30463	127.50089	.540	-329.2751	172.6658
		Natural	-190.00154	142.67240	.184	-470.8353	90.8322
	Natural	Agricultural	111.69691	141.60351	.431	-167.0329	390.4267
		Settlement	190.00154	142.67240	.184	-90.8322	470.8353
Richness	Agricultural	Settlement	5.76754*	.41528	.000	4.9501	6.5850
		Natural	1.64616*	.46121	.000	.7383	2.5540
	Settlement	Agricultural	-5.76754*	.41528	.000	-6.5850	-4.9501
		Natural	-4.12138*	.46469	.000	-5.0361	-3.2067
	Natural	Agricultural	-1.64616*	.46121	.000	-2.5540	-.7383
		Settlement	4.12138*	.46469	.000	3.2067	5.0361
Evenness	Agricultural	Settlement	.22800*	.02897	.000	.1710	.2850
		Natural	-.05745	.03218	.075	-.1208	.0059
	Settlement	Agricultural	-.22800*	.02897	.000	-.2850	-.1710
		Natural	-.28545*	.03242	.000	-.3493	-.2216
	Natural	Agricultural	.05745	.03218	.075	-.0059	.1208
		Settlement	.28545*	.03242	.000	.2216	.3493

*The mean difference is significant at the 0.05 level.

Table 4

Descriptive Statistics of Measures of Biodiversity across Landscape types in the Middle Transition zone

Biodiversity	**Landscape**	**N**	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**	
						Lower Bound	**Upper Bound**
Diversity	Agricultural	48	1.4329	.32659	.04714	1.3381	1.5277
	Settlement	54	.4880	.12077	.01644	.4550	.5209
	Natural	44	.8582	.20494	.03090	.7959	.9205
	Total	146	.9102	.45829	.03793	.8352	.9852
Abundance	Agricultural	48	682.4042	2067.36358	298.39823	82.1044	1282.7040
	Settlement	54	157.3822	847.12355	115.27891	-73.8380	388.6024
	Natural	44	342.3434	1271.93600	191.75157	-44.3605	729.0473
	Total	146	385.7339	1475.31643	122.09806	144.4120	627.0558
Richness	Agricultural	48	9.1779	2.71104	.39130	8.3907	9.9651
	Settlement	54	5.4113	2.15897	.29380	4.8220	6.0006
	Natural	44	6.7705	2.86641	.43213	5.8990	7.6419
	Total	146	7.0592	3.00753	.24890	6.5673	7.5512
Evenness	Agricultural	48	.7108	.29903	.04316	.6240	.7977
	Settlement	54	.2950	.14989	.02040	.2541	.3359
	Natural	44	.4398	.20906	.03152	.3762	.5033
	Total	146	.4753	.28462	.02356	.4288	.5219

Table 5

ANOVA Comparisons of Measures of Biodiversity Across Landscape types in the Middle Transition zone

		Sum of Squares	Df	Mean Square	F	Sig.
Diversity	Between Groups	22.862	2	11.431	215.302	.000
	Within Groups	7.592	143	.053		
	Total	30.454	145			
Abundance	Between Groups	7123278.581	2	3561639.290	1.651	.195
	Within Groups	308477714.020	143	2157186.811		
	Total	315600992.601	145			
Richness	Between Groups	365.780	2	182.890	27.653	.000
	Within Groups	945.778	143	6.614		
	Total	1311.559	145			
Evenness	Between Groups	4.474	2	2.237	43.983	.000
	Within Groups	7.273	143	.051		
	Total	11.747	145			

Table 6

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Landscape types in the Middle Transition zone

Dependent Variable	(I) Landscape	(J) Landscape	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Agricultural	Settlement	.94495*	.04571	.000	.8546	1.0353
		Natural	.57473*	.04809	.000	.4797	.6698
	Settlement	Agricultural	-.94495*	.04571	.000	-1.0353	-.8546
		Natural	-.37022*	.04680	.000	-.4627	-.2777
	Natural	Agricultural	-.57473*	.04809	.000	-.6698	-.4797
		Settlement	.37022*	.04680	.000	.2777	.4627
Abundance	Agricultural	Settlement	525.02194	291.35768	.074	-50.9025	1100.9464
		Natural	340.06076	306.54260	.269	-265.8796	946.0011
	Settlement	Agricultural	-525.02194	291.35768	.074	-1100.9464	50.9025
		Natural	-184.96119	298.28657	.536	-774.5819	404.6595
	Natural	Agricultural	-340.06076	306.54260	.269	-946.0011	265.8796
		Settlement	184.96119	298.28657	.536	-404.6595	774.5819
Richness	Agricultural	Settlement	3.76662*	.51016	.000	2.7582	4.7751
		Natural	2.40746*	.53675	.000	1.3465	3.4685
	Settlement	Agricultural	-3.76662*	.51016	.000	-4.7751	-2.7582
		Natural	-1.35916*	.52230	.010	-2.3916	-.3267
	Natural	Agricultural	-2.40746*	.53675	.000	-3.4685	-1.3465
		Settlement	1.35916*	.52230	.010	.3267	2.3916
Evenness	Agricultural	Settlement	.41583*	.04474	.000	.3274	.5043
		Natural	.27106*	.04707	.000	.1780	.3641
	Settlement	Agricultural	-.41583*	.04474	.000	-.5043	-.3274
		Natural	-.14477*	.04580	.002	-.2353	-.0542
	Natural	Agricultural	-.27106*	.04707	.000	-.3641	-.1780
		Settlement	.14477*	.04580	.002	.0542	.2353

*. The mean difference is significant at the 0.05 level.

Table 7

Descriptive Statistics of Measures of Biodiversity across Landscape types in the Lower Transition zone

Biodiversity	Landscape	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Agricultural	140	1.9335	.30996	.02620	1.8817	1.9853
	Settlement	99	1.6609	.30474	.03063	1.6001	1.7217
	Natural	35	1.5109	.37912	.06408	1.3806	1.6411
	Total	274	1.7810	.35591	.02150	1.7387	1.8234
Abundance	Agricultural	140	322.2396	1603.16581	135.49224	54.3474	590.1319
	Settlement	99	351.9312	1548.89531	155.66984	43.0095	660.8529
	Natural	35	1219.7231	3190.97337	539.37294	123.5854	2315.8608
	Total	274	447.6097	1877.69827	113.43590	224.2894	670.9300
Richness	Agricultural	140	21.6953	5.57857	.47148	20.7631	22.6275
	Settlement	99	16.6262	4.82770	.48520	15.6633	17.5890
	Natural	35	8.2837	2.58403	.43678	7.3961	9.1714
	Total	274	18.1506	6.69410	.40441	17.3544	18.9467
Evenness	Agricultural	140	.9844	.51615	.04362	.8982	1.0707
	Settlement	99	.8656	.38651	.03885	.7885	.9426
	Natural	35	.6689	.30618	.05175	.5637	.7740
	Total	274	.9012	.46030	.02781	.8464	.9559

Table 8

ANOVA Comparisons of Measures of Biodiversity Across Landscape Types in the Lower Transition zone

Biodiversity		Sum of Squares	Df	Mean Square	F	Sig.
Diversity	Between Groups	7.238	2	3.619	35.868	.000
	Within Groups	27.343	271	.101		
	Total	34.581	273			
Abundance	Between Groups	23972325.006	2	11986162.503	3.461	.033
	Within Groups	938557637.828	271	3463312.317		
	Total	962529962.834	273			
Richness	Between Groups	5396.579	2	2698.290	106.956	.000
	Within Groups	6836.827	271	25.228		
	Total	12233.406	273			
Evenness	Between Groups	2.985	2	1.492	7.373	.001
	Within Groups	54.858	271	.202		
	Total	57.843	273			

Table 9

ANOVA Multiple Comparisons (LSD) of Biodiversity Across Landscape types in the Lower Transition zone

Dependent Variable	(I) Landscape	(J) Landscape	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Agricultural	Settlement	.27259*	.04171	.000	.1905	.3547
		Natural	.42264*	.06003	.000	.3045	.5408
	Settlement	Agricultural	-.27259*	.04171	.000	-.3547	-.1905
		Natural	.15005*	.06246	.017	.0271	.2730
	Natural	Agricultural	-.42264*	.06003	.000	-.5408	-.3045
		Settlement	-.15005*	.06246	.017	-.2730	-.0271
Abundance	Agricultural	Settlement	-29.69157	244.37860	.903	-510.8135	451.4303
		Natural	-897.48350*	351.69550	.011	-1589.8862	-205.0808
	Settlement	Agricultural	29.69157	244.37860	.903	-451.4303	510.8135
		Natural	-867.79193*	365.97095	.018	-1588.2995	-147.2843
	Natural	Agricultural	897.48350*	351.69550	.011	205.0808	1589.8862
		Settlement	867.79193*	365.97095	.018	147.2843	1588.2995
Richness	Agricultural	Settlement	5.06912*	.65957	.000	3.7706	6.3677
		Natural	13.41157*	.94921	.000	11.5428	15.2803
	Settlement	Agricultural	-5.06912*	.65957	.000	-6.3677	-3.7706
		Natural	8.34245*	.98774	.000	6.3978	10.2871
	Natural	Agricultural	-13.41157*	.94921	.000	-15.2803	-11.5428
		Settlement	-8.34245*	.98774	.000	-10.2871	-6.3978
Evenness	Agricultural	Settlement	.11887*	.05908	.045	.0026	.2352
		Natural	.31557*	.08503	.000	.1482	.4830
	Settlement	Agricultural	-.11887*	.05908	.045	-.2352	-.0026
		Natural	.19670*	.08848	.027	.0225	.3709
	Natural	Agricultural	-.31557*	.08503	.000	-.4830	-.1482
		Settlement	-.19670*	.08848	.027	-.3709	-.0225

*. The mean difference is significant at the 0.05 level.

Table 10

Descriptive Statistics of Measures of Biodiversity across Landscape Types

Biodiversity	Landscape	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Richness	Agricultural	3	26.2733	6.67380	3.85312	9.6947	42.8520
	Settlement	3	21.0833	7.42884	4.28904	2.6291	39.5376
	Natural	3	16.5567	4.87403	2.81402	4.4489	28.6644
	Total	9	21.3044	6.97143	2.32381	15.9457	26.6632
Evenness	Agricultural	3	.2133	.19425	.11215	-.2692	.6959
	Settlement	3	.3367	.30665	.17704	-.4251	1.0984
	Natural	3	.1833	.16803	.09701	-.2341	.6007
	Total	9	.2444	.21202	.07067	.0815	.4074
Diversity	Agricultural	3	1.8300	.13115	.07572	1.5042	2.1558
	Settlement	3	1.1933	.15011	.08667	.8204	1.5662
	Natural	3	1.5400	.19698	.11372	1.0507	2.0293
	Total	9	1.5211	.30957	.10319	1.2832	1.7591
Abundance	Agricultural	3	599.4733	564.62437	325.98603	-803.1314	2002.0780
	Settlement	3	621.7167	650.76482	375.71924	-994.8728	2238.3061
	Natural	3	840.3333	727.49402	420.01887	-966.8620	2647.5287
	Total	9	687.1744	575.47673	191.82558	244.8239	1129.5250

Table 11

ANOVA Comparisons of Biodiversity Across Landscape Types

Biodiversity		Sum of Squares	df	Mean Square	F	Sig.
Richness	Between Groups	141.840	2	70.920	1.723	.256
	Within Groups	246.967	6	41.161		
	Total	388.807	8			
Evenness	Between Groups	.040	2	.020	.371	.705
	Within Groups	.320	6	.053		
	Total	.360	8			
Diversity	Between Groups	.610	2	.305	11.644	.009
	Within Groups	.157	6	.026		
	Total	.767	8			
Abundance	Between Groups	106301.552	2	53150.776	.125	.884
	Within Groups	2543086.163	6	423847.694		
	Total	2649387.716	8			

Table 12

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Landscape Types

Dependent Variable	(I) Landscape	(J) Landscape	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Richness	Agricultural	Settlement	5.19000	5.23839	.360	-7.6279	18.0079
		Natural	9.71667	5.23839	.113	-3.1012	22.5346
	Settlement	Agricultural	-5.19000	5.23839	.360	-18.0079	7.6279
		Natural	4.52667	5.23839	.421	-8.2912	17.3446
	Natural	Agricultural	-9.71667	5.23839	.113	-22.5346	3.1012
		Settlement	-4.52667	5.23839	.421	-17.3446	8.2912
Evenness	Agricultural	Settlement	-.12333	.18856	.537	-.5847	.3381
		Natural	.03000	.18856	.879	-.4314	.4914
	Settlement	Agricultural	.12333	.18856	.537	-.3381	.5847
		Natural	.15333	.18856	.447	-.3081	.6147
	Natural	Agricultural	-.03000	.18856	.879	-.4914	.4314
		Settlement	-.15333	.18856	.447	-.6147	.3081
Diversity	Agricultural	Settlement	.63667*	.13211	.003	.3134	.9599
		Natural	.29000	.13211	.071	-.0333	.6133
	Settlement	Agricultural	-.63667*	.13211	.003	-.9599	-.3134
		Natural	-.34667*	.13211	.039	-.6699	-.0234
	Natural	Agricultural	-.29000	.13211	.071	-.6133	.0333
		Settlement	.34667*	.13211	.039	.0234	.6699
Abundance	Agricultural	Settlement	-240.86000	531.56856	.666	-1541.5614	1059.8414
		Natural	-22.24333	531.56856	.968	-1322.9447	1278.4581
	Settlement	Agricultural	240.86000	531.56856	.666	-1059.8414	1541.5614
		Natural	218.61667	531.56856	.695	-1082.0847	1519.3181
	Natural	Agricultural	22.24333	531.56856	.968	-1278.4581	1322.9447
		Settlement	-218.61667	531.56856	.695	-1519.3181	1082.0847

*. The mean difference is significant at the 0.05 level.

Table 13

Descriptive Sstatistics of Measures of Biodiversity across Subzones

Biodiversity	Sub-Zones	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Upper TZ	3	1.1600	.06557	.03786	.9971	1.3229
	Middle TZ	3	1.2267	.11676	.06741	.9366	1.5167
	Lower TZ	3	2.1367	.19088	.11020	1.6625	2.6108
	Total	9	1.5078	.48672	.16224	1.1337	1.8819
Abundance	Upper TZ	3	876.2033	1031.27343	595.40599	-1685.6219	3438.0286
	Middle TZ	3	755.5000	876.76705	506.20169	-1422.5101	2933.5101
	Lower TZ	3	1024.6133	921.60642	532.08972	-1264.7839	3314.0106
	Total	9	885.4389	827.05988	275.68663	249.7044	1521.1734
Richness	Upper TZ	3	20.0567	6.08064	3.51066	4.9515	35.1618
	Middle TZ	3	21.5667	7.35701	4.24757	3.2908	39.8425
	Lower TZ	3	28.4300	7.73173	4.46391	9.2233	47.6367
	Total	9	23.3511	7.25652	2.41884	17.7733	28.9290
Evenness	Upper TZ	3	.4633	.43386	.25049	-.6144	1.5411
	Middle TZ	3	.7800	.73912	.42673	-1.0561	2.6161
	Lower TZ	3	.4800	.51856	.29939	-.8082	1.7682
	Total	9	.5744	.52410	.17470	.1716	.9773

Table 14

ANOVA Comparisons of Measures of Biodiversity Across Subzones

Biodiversity		Sum of Squares	df	Mean Square	F	Sig.
Diversity	Between Groups	1.786	2	.893	49.288	.000
	Within Groups	.109	6	.018		
	Total	1.895	8			
Abundance	Between Groups	109016.809	2	54508.404	.061	.941
	Within Groups	5363207.499	6	893867.917		
	Total	5472224.308	8			
Richness	Between Groups	119.498	2	59.749	1.188	.368
	Within Groups	301.759	6	50.293		
	Total	421.257	8			
Evenness	Between Groups	.191	2	.095	.285	.762
	Within Groups	2.007	6	.334		
	Total	2.197	8			

Table 15

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Subzones

Dependent Variable	(I) Subzones	(J) Subzones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Upper TZ	Middle TZ	-.06667	.10992	.566	-.3356	.2023
		Lower TZ	-.97667*	.10992	.000	-1.2456	-.7077
	Middle TZ	Upper TZ	.06667	.10992	.566	-.2023	.3356
		Lower TZ	-.91000*	.10992	.000	-1.1790	-.6410
	Lower TZ	Upper TZ	.97667*	.10992	.000	.7077	1.2456
		Middle TZ	.91000*	.10992	.000	.6410	1.1790
Abundance	Upper TZ	Middle TZ	120.70333	771.95333	.881	-1768.1984	2009.6051
		Lower TZ	-148.41000	771.95333	.854	-2037.3118	1740.4918
	Middle TZ	Upper TZ	-120.70333	771.95333	.881	-2009.6051	1768.1984
		Lower TZ	-269.11333	771.95333	.739	-2158.0151	1619.7884
	Lower TZ	Upper TZ	148.41000	771.95333	.854	-1740.4918	2037.3118
		Middle TZ	269.11333	771.95333	.739	-1619.7884	2158.0151
Richness	Upper TZ	Middle TZ	-1.51000	5.79040	.803	-15.6786	12.6586
		Lower TZ	-8.37333	5.79040	.198	-22.5419	5.7953
	Middle TZ	Upper TZ	1.51000	5.79040	.803	-12.6586	15.6786
		Lower TZ	-6.86333	5.79040	.281	-21.0319	7.3053
	Lower TZ	Upper TZ	8.37333	5.79040	.198	-5.7953	22.5419
		Middle TZ	6.86333	5.79040	.281	-7.3053	21.0319
Evenness	Upper TZ	Middle TZ	-.31667	.47221	.527	-1.4721	.8388
		Lower TZ	-.01667	.47221	.973	-1.1721	1.1388
	Middle TZ	Upper TZ	.31667	.47221	.527	-.8388	1.4721
		Lower TZ	.30000	.47221	.549	-.8555	1.4555
	Lower TZ	Upper TZ	.01667	.47221	.973	-1.1388	1.1721
		Middle TZ	-.30000	.47221	.549	-1.4555	.8555

*. The mean difference is significant at the 0.05 level.

Table 16

Descriptive Statistics of Measures of Biodiversity Across Subzones in Agricultural Land

Biodiversity	Subzones	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Upper TZ	109	1.0860	.19210	.01840	1.0495	1.1224
	Middle TZ	48	1.4329	.32659	.04714	1.3381	1.5277
	Lower TZ	140	1.9335	.30996	.02620	1.8817	1.9853
	Total	297	1.5415	.47595	.02762	1.4872	1.5959
Abundance	Upper TZ	109	167.4510	931.48038	89.21964	-9.3978	344.2998
	Middle TZ	48	682.4042	2067.36358	298.39823	82.1044	1282.7040
	Lower TZ	140	322.2396	1603.16581	135.49224	54.3474	590.1319
	Total	297	323.6401	1493.98737	86.68994	153.0334	494.2468
Richness	Upper TZ	109	12.0045	3.61852	.34659	11.3175	12.6915
	Middle TZ	48	9.1779	2.71104	.39130	8.3907	9.9651
	Lower TZ	140	21.6953	5.57857	.47148	20.7631	22.6275
	Total	297	16.1157	7.02227	.40747	15.3138	16.9176
Evenness	Upper TZ	109	.4950	.23843	.02284	.4498	.5403
	Middle TZ	48	.7108	.29903	.04316	.6240	.7977
	Lower TZ	140	.9844	.51615	.04362	.8982	1.0707
	Total	297	.7606	.45838	.02660	.7083	.8130

Table 17

ANOVA Comparisons of Measures of Biodiversity Across Subzones in Agricultural land

Biodiversity		Sum of Squares	df	Mean Square	F	Sig.
Diversity	Between Groups	44.698	2	22.349	293.944	.000
	Within Groups	22.353	294	.076		
	Total	67.051	296			
Abundance	Between Groups	8837492.543	2	4418746.271	1.993	.138
	Within Groups	651833994.435	294	2217122.430		
	Total	660671486.978	296			
Richness	Between Groups	8511.143	2	4255.572	205.600	.000
	Within Groups	6085.307	294	20.698		
	Total	14596.450	296			
Evenness	Between Groups	14.819	2	7.410	45.985	.000
	Within Groups	47.373	294	.161		
	Total	62.192	296			

Table 18

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Subzones in Agricultural Land

Dependent Variable	(I) Agricultural land	(J) Agricultural land	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Upper TZ	Middle TZ	-.34695*	.04777	.000	-.4410	-.2529
		Lower TZ	-.84754*	.03522	.000	-.9169	-.7782
	Middle TZ	Upper TZ	.34695*	.04777	.000	.2529	.4410
		Lower TZ	-.50058*	.04612	.000	-.5914	-.4098
	Lower TZ	Upper TZ	.84754*	.03522	.000	.7782	.9169
		Middle TZ	.50058*	.04612	.000	.4098	.5914
Abundance	Upper TZ	Middle TZ	-514.95316*	257.93531	.047	-1022.5868	-7.3195
		Lower TZ	-154.78863	190.20295	.416	-529.1205	219.5433
	Middle TZ	Upper TZ	514.95316*	257.93531	.047	7.3195	1022.5868
		Lower TZ	360.16452	249.05148	.149	-129.9851	850.3142
	Lower TZ	Upper TZ	154.78863	190.20295	.416	-219.5433	529.1205
		Middle TZ	-360.16452	249.05148	.149	-850.3142	129.9851
Richness	Upper TZ	Middle TZ	2.82658*	.78810	.000	1.2755	4.3776
		Lower TZ	-9.69079*	.58115	.000	-10.8345	-8.5470
	Middle TZ	Upper TZ	-2.82658*	.78810	.000	-4.3776	-1.2755
		Lower TZ	-12.51737*	.76096	.000	-14.0150	-11.0197
	Lower TZ	Upper TZ	9.69079*	.58115	.000	8.5470	10.8345
		Middle TZ	12.51737*	.76096	.000	11.0197	14.0150
Evenness	Upper TZ	Middle TZ	-.21579*	.06954	.002	-.3526	-.0789
		Lower TZ	-.48938*	.05128	.000	-.5903	-.3885
	Middle TZ	Upper TZ	.21579*	.06954	.002	.0789	.3526
		Lower TZ	-.27360*	.06714	.000	-.4057	-.1415
	Lower TZ	Upper TZ	.48938*	.05128	.000	.3885	.5903
		Middle TZ	.27360*	.06714	.000	.1415	.4057

*. The mean difference is significant at the 0.05 level.

Table 19

Descriptive Statistics of Measures of Biodiversity Across Subzones in Settlement Fringes

Biodiversity	Subzones	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Upper TZ	105	.5749	.10752	.01049	.5541	.5957
	Middle TZ	54	.4880	.12077	.01644	.4550	.5209
	Lower TZ	99	1.6609	.30474	.03063	1.6001	1.7217
	Total	258	.9734	.58274	.03628	.9020	1.0449
Abundance	Upper TZ	105	89.1464	627.20330	61.20877	-32.2329	210.5257
	Middle TZ	54	157.3822	847.12355	115.27891	-73.8380	388.6024
	Lower TZ	99	351.9312	1548.89531	155.66984	43.0095	660.8529
	Total	258	204.2643	1111.88158	69.22272	67.9484	340.5803
Richness	Upper TZ	105	6.2370	1.86208	.18172	5.8766	6.5973
	Middle TZ	54	5.4113	2.15897	.29380	4.8220	6.0006
	Lower TZ	99	16.6262	4.82770	.48520	15.6633	17.5890
	Total	258	10.0507	6.19452	.38565	9.2913	10.8101
Evenness	Upper TZ	105	.2670	.15182	.01482	.2377	.2964
	Middle TZ	54	.2950	.14989	.02040	.2541	.3359
	Lower TZ	99	.8656	.38651	.03885	.7885	.9426
	Total	258	.5026	.39166	.02438	.4545	.5506

Table 20

ANOVA Comparisons of Measures of Biodiversity Across Subzones in Settlement Fringes

Biodiversity		Sum of Squares	df	Mean Square	F	Sig.
Diversity	Between Groups	76.197	2	38.099	877.108	.000
	Within Groups	11.076	255	.043		
	Total	87.273	257			
Abundance	Between Groups	3668908.559	2	1834454.280	1.490	.227
	Within Groups	314055220.506	255	1231589.100		
	Total	317724129.066	257			
Richness	Between Groups	6969.923	2	3484.961	307.316	.000
	Within Groups	2891.698	255	11.340		
	Total	9861.621	257			
Evenness	Between Groups	21.195	2	10.598	148.253	.000
	Within Groups	18.228	255	.071		
	Total	39.423	257			

Table 21

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Subzones in Settlement Fringes

Dependent Variable	(I) Settlement Fringes	(J) Settlement Fringes	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Upper TZ	Middle TZ	.08689*	.03490	.013	.0182	.1556
		Lower TZ	-1.08605*	.02920	.000	-1.1435	-1.0286
	Middle TZ	Upper TZ	-.08689*	.03490	.013	-.1556	-.0182
		Lower TZ	-1.17295*	.03526	.000	-1.2424	-1.1035
	Lower TZ	Upper TZ	1.08605*	.02920	.000	1.0286	1.1435
		Middle TZ	1.17295*	.03526	.000	1.1035	1.2424
Abundance	Upper TZ	Middle TZ	-68.23584	185.84032	.714	-434.2132	297.7415
		Lower TZ	-262.78483	155.46612	.092	-568.9459	43.3762
	Middle TZ	Upper TZ	68.23584	185.84032	.714	-297.7415	434.2132
		Lower TZ	-194.54899	187.74317	.301	-564.2736	175.1756
	Lower TZ	Upper TZ	262.78483	155.46612	.092	-43.3762	568.9459
		Middle TZ	194.54899	187.74317	.301	-175.1756	564.2736
Richness	Upper TZ	Middle TZ	.82566	.56391	.144	-.2849	1.9362
		Lower TZ	-10.38921*	.47175	.000	-11.3182	-9.4602
	Middle TZ	Upper TZ	-.82566	.56391	.144	-1.9362	.2849
		Lower TZ	-11.21487*	.56969	.000	-12.3368	-10.0930
	Lower TZ	Upper TZ	10.38921*	.47175	.000	9.4602	11.3182
		Middle TZ	11.21487*	.56969	.000	10.0930	12.3368
Evenness	Upper TZ	Middle TZ	-.02795	.04477	.533	-.1161	.0602
		Lower TZ	-.59851*	.03745	.000	-.6723	-.5247
	Middle TZ	Upper TZ	.02795	.04477	.533	-.0602	.1161
		Lower TZ	-.57056*	.04523	.000	-.6596	-.4815
	Lower TZ	Upper TZ	.59851*	.03745	.000	.5247	.6723
		Middle TZ	.57056*	.04523	.000	.4815	.6596

*. The mean difference is significant at the 0.05 level.

Table 22

Descriptive Statistics of Measures of Biodiversity Across Subzones in Natural Vegetation

Biodiversity	Subzones	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	Upper TZ	72	1.1929	.24111	.02841	1.1363	1.2496
	Middle TZ	44	.8582	.20494	.03090	.7959	.9205
	Lower TZ	35	1.5109	.37912	.06408	1.3806	1.6411
	Total	151	1.1691	.35780	.02912	1.1115	1.2266
Abundance	Upper TZ	72	279.1479	1252.75168	147.63820	-15.2343	573.5301
	Middle TZ	44	342.3434	1271.93600	191.75157	-44.3605	729.0473
	Lower TZ	35	1219.7231	3190.97337	539.37294	123.5854	2315.8608
	Total	151	515.5766	1914.66316	155.81308	207.7047	823.4485
Richness	Upper TZ	72	10.3583	3.43019	.40425	9.5523	11.1644
	Middle TZ	44	6.7705	2.86641	.43213	5.8990	7.6419
	Lower TZ	35	8.2837	2.58403	.43678	7.3961	9.1714
	Total	151	8.8320	3.44575	.28041	8.2779	9.3861
Evenness	Upper TZ	72	.5525	.24224	.02855	.4956	.6094
	Middle TZ	44	.4398	.20906	.03152	.3762	.5033
	Lower TZ	35	.6689	.30618	.05175	.5637	.7740
	Total	151	.5466	.26154	.02128	.5046	.5887

Table 23

ANOVA Comparisons of Measures of Biodiversity Across Subzones in Natural Vegetation

Biodiversity		Sum of Squares	Df	Mean Square	F	Sig.
Diversity	Between Groups	8.382	2	4.191	57.326	.000
	Within Groups	10.820	148	.073		
	Total	19.203	150			
Abundance	Between Groups	22698904.480	2	11349452.240	3.186	.044
	Within Groups	527191346.398	148	3562103.692		
	Total	549890250.879	150			
Richness	Between Groups	365.258	2	182.629	19.092	.000
	Within Groups	1415.724	148	9.566		
	Total	1780.983	150			
Evenness	Between Groups	1.028	2	.514	8.237	.000
	Within Groups	9.233	148	.062		
	Total	10.261	150			

Table 24

ANOVA Multiple Comparisons (LSD) of Measures of Biodiversity Across Subzones in Natural Vegetation

Dependent Variable	(I) Nat. Vegetation	(J) Nat. vegetation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	Upper TZ	Middle TZ	.33473*	.05174	.000	.2325	.4370
		Lower TZ	-.31794*	.05572	.000	-.4280	-.2078
	Middle TZ	Upper TZ	-.33473*	.05174	.000	-.4370	-.2325
		Lower TZ	-.65268*	.06124	.000	-.7737	-.5317
	Lower TZ	Upper TZ	.31794*	.05572	.000	.2078	.4280
		Middle TZ	.65268*	.06124	.000	.5317	.7737
Abundance	Upper TZ	Middle TZ	-63.19549	361.15172	.861	-776.8755	650.4845
		Lower TZ	-940.57523*	388.90623	.017	-1709.1016	-172.0489
	Middle TZ	Upper TZ	63.19549	361.15172	.861	-650.4845	776.8755
		Lower TZ	-877.37973*	427.47081	.042	-1722.1144	-32.6451
	Lower TZ	Upper TZ	940.57523*	388.90623	.017	172.0489	1709.1016
		Middle TZ	877.37973*	427.47081	.042	32.6451	1722.1144
Richness	Upper TZ	Middle TZ	3.58788*	.59183	.000	2.4184	4.7574
		Lower TZ	2.07462*	.63731	.001	.8152	3.3340
	Middle TZ	Upper TZ	-3.58788*	.59183	.000	-4.7574	-2.4184
		Lower TZ	-1.51326*	.70051	.032	-2.8975	-.1290
	Lower TZ	Upper TZ	-2.07462*	.63731	.001	-3.3340	-.8152
		Middle TZ	1.51326*	.70051	.032	.1290	2.8975
Evenness	Upper TZ	Middle TZ	.11273*	.04779	.020	.0183	.2072
		Lower TZ	-.11636*	.05147	.025	-.2181	-.0147
	Middle TZ	Upper TZ	-.11273*	.04779	.020	-.2072	-.0183
		Lower TZ	-.22908*	.05657	.000	-.3409	-.1173
	Lower TZ	Upper TZ	.11636*	.05147	.025	.0147	.2181
		Middle TZ	.22908*	.05657	.000	.1173	.3409

*. The mean difference is significant at the 0.05 level.

Table 25

Descriptive Statistics of Measures of Biodiversity Across Rounds of Data Collection

Biodiversity	Rounds of data collection	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Diversity	JUNE	3	1.8500	.16703	.09644	1.4351	2.2649
	AUGUST	3	1.7267	.16921	.09770	1.3063	2.1470
	OCTOBER	3	1.5600	.18330	.10583	1.1047	2.0153
	DECEMBER	3	1.9167	.19218	.11096	1.4393	2.3941
	FEBRUARY	3	2.2233	.16503	.09528	1.8134	2.6333
	APRIL	3	1.5667	.15503	.08950	1.1816	1.9518
	Total	18	1.8072	.27589	.06503	1.6700	1.9444
Abundance	JUNE	3	820.1767	182.12634	105.15069	367.7498	1272.6036
	AUGUST	3	846.5167	216.86863	125.20916	307.7851	1385.2482
	OCTOBER	3	648.5467	219.81549	126.91053	102.4947	1194.5986
	DECEMBER	3	664.3467	90.70988	52.37137	439.0108	889.6825
	FEBRUARY	3	940.7667	41.45557	23.93438	837.7853	1043.7480
	APRIL	3	727.0800	200.72856	115.89069	228.4426	1225.7174
	Total	18	774.5722	180.36096	42.51149	684.8808	864.2636
Richness	JUNE	3	28.5967	6.35913	3.67145	12.7997	44.3936
	AUGUST	3	39.8233	12.35178	7.13131	9.1398	70.5069
	OCTOBER	3	29.5233	9.19707	5.30993	6.6766	52.3701
	DECEMBER	3	21.1300	4.78561	2.76298	9.2419	33.0181
	FEBRUARY	3	27.4933	3.71093	2.14251	18.2749	36.7118
	APRIL	3	40.6333	15.12741	8.73381	3.0548	78.2119
	Total	18	31.2000	10.71133	2.52468	25.8734	36.5266
Evenness	JUNE	3	.2800	.24576	.14189	-.3305	.8905
	AUGUST	3	.2667	.24440	.14111	-.3405	.8738
	OCTOBER	3	.2033	.18448	.10651	-.2549	.6616
	DECEMBER	3	.3467	.35529	.20513	-.5359	1.2293
	FEBRUARY	3	.4133	.35921	.20739	-.4790	1.3057
	APRIL	3	.2367	.20551	.11865	-.2738	.7472
	Total	18	.2911	.24151	.05692	.1710	.4112

*. The mean difference is significant at the 0.05 level.

Table 26

ANOVA Comparisons of Measures of Biodiversity Across Rounds of Data Collection

Biodiversity		Sum of Squares	Df	Mean Square	F	Sig.
Diversity	Between Groups	.937	5	.187	6.307	.004
	Within Groups	.357	12	.030		
	Total	1.294	17			
Abundance	Between Groups	195491.960	5	39098.392	1.312	.322
	Within Groups	357519.312	12	29793.276		
	Total	553011.272	17			
Richness	Between Groups	864.247	5	172.849	1.910	.166
	Within Groups	1086.206	12	90.517		
	Total	1950.453	17			
Evenness	Between Groups	.088	5	.018	.234	.940
	Within Groups	.903	12	.075		
	Total	.992	17			

*. The mean difference is significant at the 0.05 level.

Table 27

ANOVA Multiple Comparisons (LSD) of Species Diversity across Rounds of Data Collection

Dependent Variable	(I) Rounds of collection	(J) Rounds of collection	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Diversity	JUNE	AUGUST	.12333	.14077	.398	-.1834	.4300
		OCTOBER	.29000	.14077	.062	-.0167	.5967
		DECEMBER	-.06667	.14077	.644	-.3734	.2400
		FEBRUARY	-.37333*	.14077	.021	-.6800	-.0666
		APRIL	.28333	.14077	.067	-.0234	.5900
	AUGUST	JUNE	-.12333	.14077	.398	-.4300	.1834
		OCTOBER	.16667	.14077	.259	-.1400	.4734
		DECEMBER	-.19000	.14077	.202	-.4967	.1167
		FEBRUARY	-.49667*	.14077	.004	-.8034	-.1900
		APRIL	.16000	.14077	.278	-.1467	.4667
	OCTOBER	JUNE	-.29000	.14077	.062	-.5967	.0167
		AUGUST	-.16667	.14077	.259	-.4734	.1400
		DECEMBER	-.35667*	.14077	.026	-.6634	-.0500
		FEBRUARY	-.66333*	.14077	.001	-.9700	-.3566
		APRIL	-.00667	.14077	.963	-.3134	.3000
	DECEMBER	JUNE	.06667	.14077	.644	-.2400	.3734
		AUGUST	.19000	.14077	.202	-.1167	.4967
		OCTOBER	.35667*	.14077	.026	.0500	.6634
		FEBRUARY	-.30667	.14077	.050	-.6134	.0000
		APRIL	.35000*	.14077	.029	.0433	.6567
	FEBRUARY	JUNE	.37333*	.14077	.021	.0666	.6800
		AUGUST	.49667*	.14077	.004	.1900	.8034
		OCTOBER	.66333*	.14077	.001	.3566	.9700
		DECEMBER	.30667	.14077	.050	.0000	.6134
		APRIL	.65667*	.14077	.001	.3500	.9634
	APRIL	JUNE	-.28333	.14077	.067	-.5900	.0234
		AUGUST	-.16000	.14077	.278	-.4667	.1467
		OCTOBER	.00667	.14077	.963	-.3000	.3134
		DECEMBER	-.35000*	.14077	.029	-.6567	-.0433
		FEBRUARY	-.65667*	.14077	.001	-.9634	-.3500

Table 28

ANOVA Multiple Comparisons (LSD) of Species Abundance across Rounds of Data Collection

Dependent Variable	(I) Rounds of collection	(J) Rounds of collection	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Abundance	JUNE	AUGUST	-26.34000	140.93326	.855	-333.4072	280.7272
		OCTOBER	171.63000	140.93326	.247	-135.4372	478.6972
		DECEMBER	155.83000	140.93326	.291	-151.2372	462.8972
		FEBRUARY	-120.59000	140.93326	.409	-427.6572	186.4772
		APRIL	93.09667	140.93326	.521	-213.9705	400.1639
	AUGUST	JUNE	26.34000	140.93326	.855	-280.7272	333.4072
		OCTOBER	197.97000	140.93326	.185	-109.0972	505.0372
		DECEMBER	182.17000	140.93326	.220	-124.8972	489.2372
		FEBRUARY	-94.25000	140.93326	.516	-401.3172	212.8172
		APRIL	119.43667	140.93326	.413	-187.6305	426.5039
	OCTOBER	JUNE	-171.63000	140.93326	.247	-478.6972	135.4372
		AUGUST	-197.97000	140.93326	.185	-505.0372	109.0972
		DECEMBER	-15.80000	140.93326	.913	-322.8672	291.2672
		FEBRUARY	-292.22000	140.93326	.060	-599.2872	14.8472
		APRIL	-78.53333	140.93326	.588	-385.6005	228.5339
	DECEMBER	JUNE	-155.83000	140.93326	.291	-462.8972	151.2372
		AUGUST	-182.17000	140.93326	.220	-489.2372	124.8972
		OCTOBER	15.80000	140.93326	.913	-291.2672	322.8672
		FEBRUARY	-276.42000	140.93326	.073	-583.4872	30.6472
		APRIL	-62.73333	140.93326	.664	-369.8005	244.3339
	FEBRUARY	JUNE	120.59000	140.93326	.409	-186.4772	427.6572
		AUGUST	94.25000	140.93326	.516	-212.8172	401.3172
		OCTOBER	292.22000	140.93326	.060	-14.8472	599.2872
		DECEMBER	276.42000	140.93326	.073	-30.6472	583.4872
		APRIL	213.68667	140.93326	.155	-93.3805	520.7539
	APRIL	JUNE	-93.09667	140.93326	.521	-400.1639	213.9705
		AUGUST	-119.43667	140.93326	.413	-426.5039	187.6305
		OCTOBER	78.53333	140.93326	.588	-228.5339	385.6005
		DECEMBER	62.73333	140.93326	.664	-244.3339	369.8005
		FEBRUARY	-213.68667	140.93326	.155	-520.7539	93.3805

Table 29

ANOVA Multiple Comparisons (LSD) of Species Richness across Rounds of Data Collection

Dependent Variable	(I) Rounds of collection	(J) Rounds of collection	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Richness	JUNE	AUGUST	-11.22667	7.76819	.174	-28.1521	5.6988
		OCTOBER	-.92667	7.76819	.907	-17.8521	15.9988
		DECEMBER	7.46667	7.76819	.355	-9.4588	24.3921
		FEBRUARY	1.10333	7.76819	.889	-15.8221	18.0288
		APRIL	-12.03667	7.76819	.147	-28.9621	4.8888
	AUGUST	JUNE	11.22667	7.76819	.174	-5.6988	28.1521
		OCTOBER	10.30000	7.76819	.210	-6.6254	27.2254
		DECEMBER	18.69333*	7.76819	.033	1.7679	35.6188
		FEBRUARY	12.33000	7.76819	.138	-4.5954	29.2554
		APRIL	-.81000	7.76819	.919	-17.7354	16.1154
	OCTOBER	JUNE	.92667	7.76819	.907	-15.9988	17.8521
		AUGUST	-10.30000	7.76819	.210	-27.2254	6.6254
		DECEMBER	8.39333	7.76819	.301	-8.5321	25.3188
		FEBRUARY	2.03000	7.76819	.798	-14.8954	18.9554
		APRIL	-11.11000	7.76819	.178	-28.0354	5.8154
	DECEMBER	JUNE	-7.46667	7.76819	.355	-24.3921	9.4588
		AUGUST	-18.69333*	7.76819	.033	-35.6188	-1.7679
		OCTOBER	-8.39333	7.76819	.301	-25.3188	8.5321
		FEBRUARY	-6.36333	7.76819	.429	-23.2888	10.5621
		APRIL	-19.50333*	7.76819	.027	-36.4288	-2.5779
	FEBRUARY	JUNE	-1.10333	7.76819	.889	-18.0288	15.8221
		AUGUST	-12.33000	7.76819	.138	-29.2554	4.5954
		OCTOBER	-2.03000	7.76819	.798	-18.9554	14.8954
		DECEMBER	6.36333	7.76819	.429	-10.5621	23.2888
		APRIL	-13.14000	7.76819	.117	-30.0654	3.7854
	APRIL	JUNE	12.03667	7.76819	.147	-4.8888	28.9621
		AUGUST	.81000	7.76819	.919	-16.1154	17.7354
		OCTOBER	11.11000	7.76819	.178	-5.8154	28.0354
		DECEMBER	19.50333*	7.76819	.027	2.5779	36.4288
		FEBRUARY	13.14000	7.76819	.117	-3.7854	30.0654

*. The mean difference is significant at the 0.05 level.

Table 30

ANOVA Multiple Comparisons (LSD) of Species Evenness across Rounds of Data Collection

Dependent Variable	(I) Rounds of collection	(J) Rounds of collection	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Evenness	JUNE	AUGUST	.01333	.22402	.954	-.4748	.5014
		OCTOBER	.07667	.22402	.738	-.4114	.5648
		DECEMBER	-.06667	.22402	.771	-.5548	.4214
		FEBRUARY	-.13333	.22402	.563	-.6214	.3548
		APRIL	.04333	.22402	.850	-.4448	.5314
	AUGUST	JUNE	-.01333	.22402	.954	-.5014	.4748
		OCTOBER	.06333	.22402	.782	-.4248	.5514
		DECEMBER	-.08000	.22402	.727	-.5681	.4081
		FEBRUARY	-.14667	.22402	.525	-.6348	.3414
		APRIL	.03000	.22402	.896	-.4581	.5181
	OCTOBER	JUNE	-.07667	.22402	.738	-.5648	.4114
		AUGUST	-.06333	.22402	.782	-.5514	.4248
		DECEMBER	-.14333	.22402	.534	-.6314	.3448
		FEBRUARY	-.21000	.22402	.367	-.6981	.2781
		APRIL	-.03333	.22402	.884	-.5214	.4548
	DECEMBER	JUNE	.06667	.22402	.771	-.4214	.5548
		AUGUST	.08000	.22402	.727	-.4081	.5681
		OCTOBER	.14333	.22402	.534	-.3448	.6314
		FEBRUARY	-.06667	.22402	.771	-.5548	.4214
		APRIL	.11000	.22402	.632	-.3781	.5981
	FEBRUARY	JUNE	.13333	.22402	.563	-.3548	.6214
		AUGUST	.14667	.22402	.525	-.3414	.6348
		OCTOBER	.21000	.22402	.367	-.2781	.6981
		DECEMBER	.06667	.22402	.771	-.4214	.5548
		APRIL	.17667	.22402	.446	-.3114	.6648
	APRIL	JUNE	-.04333	.22402	.850	-.5314	.4448
		AUGUST	-.03000	.22402	.896	-.5181	.4581
		OCTOBER	.03333	.22402	.884	-.4548	.5214
		DECEMBER	-.11000	.22402	.632	-.5981	.3781
		FEBRUARY	-.17667	.22402	.446	-.6648	.3114

Appendix 3

Measurement of Physical Factors

Table 1

Measurement of Physical Factors: June 2013 to April 2014

(a) 11th – 13th June 2013-Upper Transition Zone

PARAMETER MEASURED	COMMUNITY: AWISA			COMMUNITY: SUBINSO		
	SAMPLING SITES			SAMPLING SITES		
	AGRIC	NATURAL	SET'MENT	AGRIC	NATURAL	SET'MENT
HUMIDITY (%)	89	79	85	69	70	70
TEMPERATURE (^{o}C)	28	30	29	30	32	32
START (DAY 1)	9.00	10.48	9.53	11.52	1.38	12.40
END (DAY 1)	9.30	11.30	10.22	12.25	2.05	1.22
START(DAY 3)	9.00	10.46	9.58	11.39	1.46	12.57
END (DAY 3)	9.33	11.17	10.22	12.20	2.23	1.25

(b) 14th – 16th June 2013-Middle Transition Zone

PARAMETER MEASURED	COMMUNITY: KOBEDI			COMMUNITY: YAWHIMA		
	SAMPLING SITES			SAMPLING SITES		
	AGRIC	NATURAL	SET'MENT	AGRIC	NATURAL	SET'MENT
HUMIDITY (%)	72	70	70	62	62	65
TEMPERATURE (^{o}C)	30	30	31	31	32	32
START(DAY 1)	9.00	10.05	10.50	12.27	1.35	11.39
END (DAY 1)	9.35	10.30	11.23	12.59	2.12	12.05
START(DAY 3)	9.00	9.43	10.41	12.44	1.38	11.43
END (DAY 3)	9.26	10.17	11.13	1.12	2.19	12.18

(c) 18th – 20th June 2013-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	74	74	74	68	68	64
TEMPERATURE (^{o}C)	26	26	28	30	32	32
START(DAY 1)	10.07	10.58	9.00	12.22	1.15	2.04
END (DAY 1)	10.39	11.35	9.32	1.47	1.44	2.36
START(DAY 3)	10.00	10.58	9.00	11.46	12.41	1.28
END (DAY 3)	10.28	11.17	9.32	12.16	1.05	1.56

(d) : 4th – 6th August 2013-Upper Transition Zone

PARAMETER MEASURED	**COMMUNITY: AWISA**			**COMMUNITY: SUBINSO**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MNT**	**AGRIC**	**NATURAL**	**SET'MNT**
HUMIDITY (%)	64	76	76	68	70	68
TEMPERATURE (^{o}C)	33	31	31	31	30	30
START (DAY 1)	12:45	9:46	9:00	10:35	12:00	11:25
END (DAY 1)	1:07	10:07	9:23	10:52	12:23	11:43
START (DAY 3)	1:40	10:00	9:00	10:45	12:35	11:50
END (DAY 3)	2:15	10:22	9:35	11:20	1:25	12:20
	285	295	286	249	187	177
G. P. S. READING	07 47 953 02 06 056	07 49 330 02 05 704	07 48 784 02 05 944	07 54 540 02 03 870	07 55 692 02 03 517	07 55 453 02 03 501

(e) : 8th – 10th August 2013-Middle Transition Zone

PARAMETER MEASURED	**COMMUNITY: KOBEDI**			**COMMUNITY: YAWHIMA**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET’MENT**	**AGRIC**	**NATURAL**	**SET’MENT**
HUMIDITY (%)	87	74	72	74	78	70
TEMPERATURE (^{O}C)	30	24	24	25	28	28
START (DAY 1)	1:50	9:00	9:50	11:45	12:50	10:40
END (DAY 1)	2:25	9:25	10:22	12:24	1:23	11:07
START (DAY 3)	1:35	9: 00	9:55	11:46	12:38	10:52
END (DAY 3)	2:02	9:31	10:22	12:10	1:08	11:21
	274	315	303	299	220	332
G. P. S. READING	07 21 705	07 21 846	07 22 012	07 20 162	07 21 168	07 20 770
	02 13 143	02 13 269	02 13 152	02 14 404	02 15 314	02 15 078

(f) 12th – 14th June 2013-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET’MENT**	**AGRIC**	**NATURAL**	**SET’MENT**
HUMIDITY (%)	74	94	94	96	88	88
TEMPERATURE (^{O}C)	27	24	32	27	30	32
START (DAY 1)	9.00	10.02	2.03	11.05	12.18	1.10
END (DAY 1)	9.22	10.37	2.35	11.37	12.42	1.32
START (DAY 3)	9.00	10.15	2.28	11.22	12.25	1.28
END (DAY 3)	9.34	10.48	2.54	11.54	12.57	1.57
	205	186	270	236	206	232
G. P. S. READING	06 47 934	06 48 543	06 48 212	06 51 165	06 51 238	06 51 080
	01 52 981	01 52 680	01 52 320	01 54 701	01 54 281	01 54 533

(g) 11th -13th October 2013-Upper Transition Zone

PARAMETER MEASURED	**COMMUNITY: AWISA**			**COMMUNITY: SUBINSO**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MNT**	**AGRIC**	**NATURAL**	**SET'MNT**
HUMIDITY (%)	71	74	74	76	75	77
TEMPERATURE (^{o}C)	33	28	34	28	28	30
START (DAY 1)	12.20	9.12	1.15	9.56	11.26	10.40
END (DAY 1)	12.43	9.35	1.43	10.19	11.48	11.03
START (DAY 3)	12.52	9.00	1.50	9.51	11.52	10.50
END TIME (DAY 3)	1.28	9.28	2.27	10.32	12.23	11.29

(h) 14th -16th October 2013-Middle Transition Zone

PARAMETER MEASURED	**COMMUNITY: KOBEDI**			**COMMUNITY: YAWHIMA**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	79	83	82	83	84	83
TEMPERATURE (^{o}C)	33	33	27	28	28	27
START (DAY 1)	12.20	1.08	9.00	10.32	11.31	9.44
END (DAY 1)	12.42	1.32	9.23	10.58	11.54	10.05
START (DAY 3)	12.56	1.53	9.00	10.49	11.48	9.52
END (DAY 3)	1.32	2.35	9.33	11.26	12.21	10.28

(i) 17th -19th October 2013-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	NATURAL	SET'MENT	AGRIC	NATURAL	SET'MENT
HUMIDITY (%)	82	82	77	83	85	85
TEMPERATURE (°C)	32	28	32	29	29	30
START (DAY 1)	1.32	9.05	12.40	9.57	10.46	11.47
END (DAY 1)	1.56	9.32	1.08	10.25	11.18	12.12
START (DAY 3)	1.46	9.00	12.52	9.55	10.48	11.45
END (DAY 3)	2.22	9.27	1.23	10.27	11.21	12.19

(j) 2nd – 4th December 2013-Upper Transition Zone

PARAMETER MEASURED	**COMMUNITY: AWISA**			**COMMUNITY: SUBINSO**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	61	61	60	64	65	64
TEMPERATURE (°C)	32	34	34	28	27	28
START (DAY 1)	11.45	1.36	12.48	9.00	10.56	9.47
END (DAY 1)	12.20	2.05	1.16	9.26	11.25	10.19
START (DAY 3)	11.01	1.57	11.53	9.00	10.57	9.58
END (DAY 3)	11.34	2.32	12.26	9.32	11.33	10.25

(k) 5th – 7th December 2013-Middle Transition Zone

PARAMETER MEASURED	**COMMUNITY: KOBEDI**			**COMMUNITY: YAWHIMA**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	83	83	82	74	74	81
TEMPERATURE (°C)	32	33	33	29	28	29
START (DAY 1)	11.50	12.38	1.28	9.51	10.55	9.00
END (DAY 1)	12.17	1.09	1.56	10.24	11.27	9.24
START (DAY 3)	12.15	1.15	2.10	9.58	10.58	9.00
END (DAY 3)	12.44	1.48	2.44	10.31	11.36	9.32

(l) 9th – 11th December 2013-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	80	78	78	95	92	95
TEMPERATURE (°C)	30	32	28	24	26	28
START (DAY 1)	12.52	1.46	11.55	9.00	9.58	10.56
END (DAY 1)	1.20	2.14	12.21	9.31	10.31	11.24
START (DAY 3)	1.06	2.17	12.04	9.00	10.01	10.58
END (DAY 3)	1.45	2.49	12.33	9.32	10.34	11.29

(m) 1st – 3rd February 2014-Upper Transition Zone

PARAMETER MEASURED	**COMMUNITY: AWISA**			**COMMUNITY: SUBINSO**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	73	70	74	69	69	61
TEMPERATURE (°C)	27	32	30	33	26	26
START (DAY 1)	10.38	12.18	11.25	1.03	9.50	9.05
END (DA 1)	11.02	12.41	11.54	1.27	10.13	9.27
START (DAY 3)	10.55	12.35	11.45	1.28	9.48	9.00
END (DAY 3)	11.20	1.03	12.13	1.52	10.20	9.23

(n) 4th – 6th February 2014-Middle Transition Zone

PARAMETER MEASURED	**COMMUNITY: KOBEDI**			**COMMUNITY: YAWHIMA**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	62	62	63	69	72	64
TEMPERATURE (°C)	26	28	30	26	26	34
START (DAY 1)	10.30	11.15	12.02	9.00	9.45	12.50
END (DAY 1)	10.52	11.37	12.23	9.21	10.05	1.15
START (DAY 3)	10.22	11.24	12.20	9.00	9.46	1.22
END (DAY 3)	10.57	11.51	12.47	9.23	10.10	1.50

(o) 7th – 9th February 2014-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	60	84	79	84	85	85
TEMPERATURE (°C)	30	32	28	32	27	28
START(DAY 1)	11.23	12.10	10.33	12.57	9.00	9.46
END(DAY 1)	11.47	12.34	10.54	1.23	9.23	10.09
START (DAY 3)	11.45	12.32	10.48	1.29	9.00	9.55
END (DAY 3)	12.11	1.05	11.18	1.49	9.28	10.23

(p) 4th – 6th April 2014-Upper Transition Zone

PARAMETER MEASURED	**COMMUNITY: AWISA**			**COMMUNITY: SUBINSO**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET'MENT**	**AGRIC**	**NATURAL**	**SET'MENT**
HUMIDITY (%)	78	70	70	72	75	77
TEMPERATURE (°C)	29	32	29	30	27	32
START (DAY 1)	9.50	11.25	10.35	12.15	9.00	12.58
END (DAY 1)	10.13	11.47	10.58	12.36	9.23	1.24
START (DAY 3)	9.48	11.12	10.31	12.00	9.00	12.47
END (DAY 3)	10.10	11.35	10.50	12.23	9.20	1.18

(q) 8th – 10th April 2014-Middle Transition Zone

PARAMETER MEASURED	**COMMUNITY: KOBEDI**			**COMMUNITY: YAWHIMA**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET’MENT**	**AGRIC**	**NATURAL**	**SET’MENT**
HUMIDITY (%)	78	78	78	66	88	68
TEMPERATURE (°C)	27	27	28	32	26	31
START (DAY 1)	9.47	10.28	11.12	1.15	9.00	12.31
END (DAY 1)	10.08	10.49	11.37	1.41	9.23	12.53
START (DAY 3)	9.53	10.43	11.28	1.03	9.00	12.12
END (DAY 3)	10.22	11.04	11.49	1.33	9.29	12.38

(r) 12th – 14th April 2014-Lower Transition Zone

PARAMETER MEASURED	**COMMUNITY: MANKRANSO**			**COMMUNITY: NYAMEADOM**		
	SAMPLING SITES			**SAMPLING SITES**		
	AGRIC	**NATURAL**	**SET’MENT**	**AGRIC**	**NATURAL**	**SET’MENT**
HUMIDITY (%)	82	75	77	72	72	98
TEMPERATURE (°C)	30	29	29	32	32	27
START (DAY 1)	10.33	11.20	9.40	12.17	12.56	9.00
END (DAY 1)	10.55	11.54	10.15	12.33	1.25	9.21
START (DAY 3)	10.32	11.21	9.51	12.12	12.56	9.00
END (DAY 3)	10.58	11.46	10.11	12.32	1.22	9.28

Table 2:

Mean Bi-monthly Temperature and Relative Humidity Values recorded in the FSTZ of Ghana from June 2013 to April 2014

	Upper		**Middle**		**Lower**	
Sampling month	**Temperature** (^{O}C)	**Humidity** (%)	**Temperature** (^{O}C)	**Humidity** (%)	**Temperature** (^{O}C)	**Humidity** (%)
June 2013	30.17	77.00	31.00	66.83	29.00	70.33
August 2013	31.00	70.33	26.50	75.83	28.67	89.00
October 2013	30.17	74.50	29.33	82.33	30.00	82.33
December 2013	30.50	62.50	30.67	79.50	28.00	86.33
February 2014	29.00	69.33	28.33	65.33	29.50	79.50
April 2014	29.83	62.00	28.50	76.00	29.83	79.33
Annual means	**30.11**	**69.28**	**29.06**	**74.30**	**29.17**	**81.14**

APPENDIX 4

Ten (10) Dominant Plant Species Identified From 18 Communities in the FSTZ of Ghana

Awisa Agricultural land

	Name of Plant	Author	Family
1.	*Anacardium occidentale*	Linn	Anacardiaceae
2.	*Chromolaena odorata*	Linn	Asteraceae
3.	*Trichilia prieureana*	A. Juss.	Meliaceae
4.	*Capsicum frutescens*	Linn.	Solanaceae
5.	*Carica papaya*	Linn.	Caricaceae
6.	*Solanum torvum*	Linn.	Solanaceae
7.	*Vernonia cinerea*	(Linn.) Less	Asteraceae
8.	*Oldenladia corymbos*a	Linn.	Rubiaceae
9.	*Bidens pilosa*	Linn.	Asteraceae
10.	*Ageratum conyzoide*s	Linn.	Asteraceae

Awisa Natural vegetation

	Name of Plant	Author	Family
1.	*Agelaea obliqua*	P. Beauv	Connaraceae
2.	*Vernonia corolata*	Drake	Compositae
3.	*Sporobbolus pyramidalis*	P. Beauv.	Poaceae
4.	*Drypetes afzelli*	(Pax) Hutch.	Euphorbiaceae
5.	*Rauwolfia vomitoria*	Afzel	Apocynaceae
6.	*Ficus capensis*	Thumb	Moraceae
7.	*Talinum triangulare*	(Jacq.) Willd.	Portulacaceae
8.	*Boerhavia diffusa*	Linn.	Nyctaginaceae

9. *Baphia nitida*	Lodd.	Papilionaceae
10. *Chromolaena odorata*	(L.) R. M. King & Robinson	Asteraceae

Awisa Settlement fringes

1. *Anacardium occidentale*	Linn.	Anarcardiaceae
2. *Eupatorium odoratum*	Linn	Asteraceae
3. *Nauclea latifolia*	Smith	Rubiaceae
4. *Leucaniodiscus cupanoides*	Planch ex Benth	Sapindaceae
5. *Mangifera indica*	Planch ex Benth	Anacardiiaceae
6. *Sida acuta*	Burm f.	Malvaceae
7. *Solanum torvum*	Swartz	Solanaceae
8. *Enydra fluatuans*	Louk	Compositae
9. *Cleome viscosa*	Linn.	Cleomaceae
10. *Cucumeropsis manii*	Naud	Cucurbitaceae

Subinso Agricultural land

1. *Anacardium occidentale*	Linn.	Anacadiaceae
2. *Tectonia grandis*	Linn.	Verbenaceae
3. *Rauwolfia vomitoria*	Afzel	Apocynaceae
4. *Cassia siamea*	Lam	Caesalpinaceae
5. *Phyllanthus amarus*	Schum et Thonn	Euphorbiaceae
6. *Vernonia cinerea*	(Linn.) Less	Asteraceae
7. *Euphorbia hirta*	Linn	Euphorbiaceae
8. *Leucaena glauca*	Bent	Mimosaceae
9. *Portulaca orelacea*	Linn.	Portulacaceae
10. *Solanum torvum*	Swartz	Solanaceae

Subinso Settlement fringes

1. *Jatropha curcas*	Linn.	Euphorbiaceae

2. *Delonix regia*	Raf.	Caesalpinaceae
3. *Alternanthera ripens*	(Linn)Link	Amaranthaceae
4. *Azadirachta indica*	A. Juss.	Meliaceae
5. *Boerhavia diffusa*	Linn.	Nyctaginaceae
6. *Sida acuta*	Burm. f.	Malvaceae
7. *Malvastrum coromandelianum*	(Linn.) Garcke	Malvaceae
8. *Tectonia grandis*	Linn. f.	Verbanaceae
9. *Chromolaena odorata*	Linn.	Asteraceae
10. *Sesamum indica*	Linn.	Pedaliaceae

Subinso Natural vegetation

1. *Cassia siamea*	Lam.	Caesalpinaceae.
2. *Eupatarium odorata*	Linn.	Asteraceae
3. *Commelina benghalens*is	Linn.	Commelinaceae
4. *Momordica charantia*	Linn.	Cucurbitaceae
5. *Jatropha gossyppiifoli*a	Linn.	Euphorbiceae
6. *Hoslundia opposita*	Vahl.	Lamiaceae
7. *Vernonia corolata*	Drake	Compositae
8. *Justasia flava*	(Forsk)Vahl	Acanthaceae
9. *Securinega virosa*	(Roxb. exWilld) Baill	Euphorbiaceae
10. *Mimosa pudica*	Linn.	Mimosaceae

Kobedi Agricultural land

1. *Manihot esculentum*	Crantz	Euphorbiaceae
2. *Theobroma cacao*	(Sterculiaceae) L.	Malvaceae
3. *Colocasia esculentum*	(Linn) Schott	Araceae
4. *Musa paradisiaca*	Linn.	Musaceae
5. *Solanum torvum*	Swartz	Solanaceae
6. *Baphia nitida*	Lodd.	Papilionaceae
7. *Rauwolfia vomitora*	Afzel.	Apocynaceae

8. *Balanites aegyptiaca*	(Linn)Delile	Zygophyllaceae
9. *Antiaris Africana*	Welwitschil	Moraceae
10. *Kyaya ivorensis*	A. chev	Meliaceae

Kobedi Natural vegetation

1. *Tectonia grandis*	L. F.	Verbenaceae
2. *Leucaniodiscus cupanoid*es	Planch ex Benth.	Sapindaceae
3. *Kyaya ivorensis*	A. Chev.	Meliaceae
4. *Baphia pubescens*	Hooke .f.	Papilionaceae
5. *Chromolaena odoarata*	Linn.	Asteraceae
6. *Picrilima nitida*	Stapf) T. Durand & H. Durand	Apocynaceae
7. *Dienbollia pinnata*	Schumach & Thonn.	Sapindaceae
8. *Paullina pinnata*	Linn	Sapindaceae
9. *Terminalia superba*	Engl & Daniels	Combretaceae
10. *Miltia excelsa*	(Welw)C.C. Berg	Moraceae

Kobedi Settlement fringes

1. *Canna indica*	Linn.	Cannaceae
2. *Alstonia boonei*	De Willd	Apocynaceae
3. *Jatropha gossypiifolia*	Linn.	Euphorbiaceae
4. *Cascabela thevetia*	(Linn)Lippold	Apocynaceae
5. *Malacantha alnifolia*	(Bak) Pierre	Sapotaceae
6. *Caesalpinia pulcherim*a	(Baill) Herendeen & Zuracchi	
7. *Mangifera indica*	Linn	Anacardiaceae
8. *Waltheria indica*	Linn .	Sterculiaceae
9. *Cassia occidentalsi*	Linn.	Caesalpiniaceae
10. *Pupalia lappacea*	(Linn) Juss.	Amaranthaceae

Yawhima Agricultural land

1. *Baphia nitida*	Lodd.	Papilionaceae
2. *Persia Americana*	Mill.	Laureaceae

3. *Manihot esculentum*	Crantz	Euphorbiaceae
4. *Kyaya senegalensis*	(Desr.)A. Juss.	Meliaceae
5. *Talinum triangulare*	(Jacq.) Willd.	Portulacaceae
6. *Cassia occidentalis*	Linn	Caesalpinaceae
7. *Musa paradisiaca*	Linn.	Musaceae
8. *Mangifera indica*	Linn.	Anacardiaceae
9. *Cassia siamea*	Lam.	Caesalpinaceae
10. *Tectonia grandis*	L. F.	Verbenaceae

Yawhima Settlement fringes

1. *Mangifera indica*	Linn.	Anarcadiaceae
2. *Delonix regia*	Raf.	Caesalpinaceae
3. *Cassia siamea*	Lam.	Caesalpinaceae
4. *Malacantha alnifolia*	(Bak.) Pierre	Sapotaceae
5. *Antiaris africana*	Welwitschil	Moraceae
6. *Vernonia corolata*	Drake	Compositae
7. *Chromolaena odorata*	Linn	Asteraceae
8. *Talinum triangulare*	(Jack)	Portulaceae
9. *Securienega virosa*	(Roxb. Ex Willd) Baill	Euphorbiaceae
10. *Rauwolfia vommitoria*	Afzel	Apocynaceae

Yawhima Natural vegetation

1. *Anopysis klaeineana*	(Pierre) Engl.	Rhizophoraceae
2. *Psydrax subcordata*	(DC) Bridson	Rubiaceae
3. *Milicia excelsa*	(Welw) CC Berg	Moraceae
4. *Bridelia ferruginea*	Benth	Euphorbiaceae
5. *Terminalia superba*	Engl & Diels	Combretaceae
6. *Anthocleista nobilis*	(ex Loganiaceae). G. Don.	Gentianaceae
7. *Alchornia cordifolia*	(Schumach & Thonn) Mull Arg	Euphorbiaceae

8. *Ficus exasperate*	Vahl.	Moraceae
9. *Morinda lucida*	Benth	Rubiaceae
10. *Rauwolfia vomitoria*	Afzel.	Apocynaceae

Mankranso Agricultural land

1. *Chromolaena odorata*	(l.) R. M. King & Robinson	Asteraceae
2. *Eleaeis guineensis*	(=Arecaceae) Jacq.	Palmae
3. *Abelmoschus moschatus*	(Linn) Medic.	Malvaceae
4. *Capsicum frutescens*	Linn.	Solanaceae
5. *Solanum torvum*	Swartz	Solanaceae
6. *Euphorbia heterophyll*a	Linn.	Euphorbiaceae
7. *Eclipta alba*	(Linn.)	Asteraceae
8. *Musa paradisaica*	Linn.	Musaceae
9. *Carica papaya*	Linn.	Caricaceae
10. *Aspilia africana*	(Pers)CD. Adams	Asteraceae

Mankranso Natural vegetation

1. *Bridelia ferruginea*	Benth	Euphorbeaceae
2. *Griffonia simplicifolia*	(Vahl ex DC) Baill.	Leguminosae
3. *Baphia nitida*	Lodd.	Papilionaceae
4. *Leucanoidiscus cupan*oides	Planch. ex Benth	Sapindaceae
5. *Leucaena glauca*	Benth	Mimosaceae
6. *Thalia geniculata*	Linn.	Marantaceae
7. *Ceiba pentandra*	Gaertn.	Malvaceae
8. *Cassia siamea*	Lam.	Caesalpinaceae
9. *Chromolaena odorata*	(L.) R.M. King & Robinson	Asteraceae
10. *Casuarina equisitifoli*a	Forst.	Casuarinaceae

Mankranso Settlement fringes

1.	*Moringa oleifera*	Lam	Moringaceae
2.	*Milletia thonningii*	Baker Ash	Papilionaceae
3.	*Cassia siamea*	Lam	Caesalpiniaceae
4.	*Mangifera indica*	Linn.	Anarcadiaceae
5.	*Chloris pilosa*	Schumach	Poaceae
6.	*Gomphrena celoisoides*	Mart	Amaranthaceae
7.	*Citrus sinensis*	Osbeck	Rutaceae
8.	*Lagestroemia speciosa*	P. xciv	Lythraceae
9.	*Casuarina equisitifoli*a	Forst.	Casuarinaceae
10.	*Mangifera indica*	Linn.	Anarcardiaceae

Nyameadom Agricultural vegetation

1.	*Sida acuta*	Burm f.	Malvaceae
2.	*Cassia occidentalis*	Linn.	Caesalpiniaceae
3.	*Centrosema pubescens*	DC.	Papilionaceae
4.	*Mangifera indica*	Linn.	Anarcadiaceae
5.	*Croton lobatus*	Linn.	Euphorbiaceae
6.	*Euphorbia hirta*	Linn.	Euphorbiaceae
7.	*Panicum maximum*	Jacq.	Poaceae
8.	*Aspilia Africana*	(Pers)C. D. Adams	Asteraceae
9.	*Capiscum frutescens*	Linn.	Solanaceae
10.	*Erigeron floribunda*	(H.B. & K) Sch. Bip.	Asteraceae

Nyameadom Natural vegetation

1.	*Thespesia populnea*	(L) Soland ex Correa	Malvaceae
2.	*Myrianthus arboreus*	P. Beauv.	Cecropiaceae
3.	*Hyphaene guinensis*	(Schult.) K. Schum	Palmae
4.	*Gmelina arborea*	Roxb.	Verbedeceae
5.	*Pcynanthus angolensis*	(Welw.) Warb.	Myristiacaceae

6. *Mareya micrantha*	(Benth)Mull. Arg.	Euphorbiaceae
7. *Newbouldia laevis*	(P. Beauv) Seemann ex Bureau	Bignoniaceae
8. *Nauclea latifolia*	Smith	Rubiaceae
9. *Leucaena glauca*	Benth	Mimosaceae
10. *Cassuarina equisitifo*lia	Forst.	Cassuarinaceae

Nyameadom Settlement fringes

1. *Cassia occidentalis*	Linn.	Caesalpiniaceae
2. *Vernonia corolata*	Drake	Compositae
3. *Musa paradiasica*	Linn.	Musaceae
4. *Chromolaena odorata*	Linn	Asteraceae
5. *Delonix regia*	Raf.	Caesalpinaceae
6. *Euphorbia hirta*	Linn.	Euphorbiaceae
7. *Sida acuta*	Burm f.	Malvaceae
8. *Cassia siame*	Raf.	Caesalpinaceae
9. *Kyaya senegalensis*	(Desr.) A.Juss	Meliaceae
10. *Citrus sinensis*	Osbeck	Rutaceae

APPENDIX 5

UNIVERSITY OF CAPE COAST
SCHOOL OF BIOLOGICAL SCIENCES
DEPARTMENT OF ENTOMOLOGY AND WILDLIFE

Questionnaire on Crop Farmers' Knowledge of Pollinators and Pollination Within the FSTZ of Ghana

Introduction: This questionnaire is intended to obtain information from crop farmers on their level of awareness of pollinators and pollination within their communities. Please respond to the questions honestly as the responses you provide will be treated with utmost confidentiality.

A. Background Information

1. Community name ……………………………………..
2. Age ……………………………………..
3. Sex ……………………………………..
4. Educational background a. Illiterate b. Basic level
   c. Sec/Tec level d. Tertiary

5. How long have you been a crop farmer
   a. 0-5 yrs
   b. 6-10 yrs
   c. More than 10 yrs

B. The Farmers' Knowledge of their Crops

6. Name three common crops you grow and indicate their maturity period (planting to flowering)

No	Name of the crop	Maturity Period (from planting to – flowering)
1		
2		
3		

7. Which of the following parts of a crop do you know of?

a. Root b. Stem c. branches d. leaves

e. flower f. fruits

8. What is the importance of the flower to your crop?

…………………………………………………………………………
…………………………………………………………………………

Farmers' Knowledge of Pollinators/Pollination

9. Which season of the year are insects most abundant on your crop?

a. The wet season
b. The dry season
c. Throughout the year

10. During which stage of growth are insects most abundant on your crop?

a. Before flowering b. During flowering

c. when flowers have been shed d. throughout growth

11. Which part of the crop and time of day do you find any of the insects listed here? (Pictures of under listed insects accompany questionnaire)

	Insect identified	**Part of Crop**	**Time of Day**
A	*Apis melifera*		
B	*Xylocopa* sp.		
C	*Amegilla* sp.		
D	*Meliponula bocandei*		
E	Housefly		
F	Butterfly		
G	Grasshopper		
H	Praying mantis		
I	Ant		

12 What do you see the insects doing to your crop when they visit?

a. destroying the plant b.collecting nectar/pollen/feeding

c. building nest d. resting

e. others(specify)…………………………………………………………

13 What do you think will happen to the crop if no insect visits the flower?

a. no food will form c. nothing will happen
b. yield will increase d. yield will decrease

C. Farmers' Knowledge of Pollinator Conservation

14. What do you do when you see insects on the flowers of your crop?

a. I drive them away c. I spray chemicals to kill them

b. I leave them untouched

d. Others (specify)……………………………………………….

15. Do you think insects that visit flowers of your crops need to be protected?

Yes ☐ No ☐

16. Give reasons for your answer to question 16 above.

…………………………………………………………………………………
…………………………………………………………………………………
……..

17. If your answer to 16 above is yes, in what ways can insects that visit our crops be protected and conserved?

…………………………………………………………………………………
…………………………………………………………………………………
……...

18. Have you received any training on pollinators and their conservation?

Yes ☐ No ☐