DIVERSITY AND ABUNDANCE OF BEES AND THEIR EFFECT ON YIELD OF FRENCH BEANS, ADJACENT MT KENYA FOREST IN LAIKIPIA COUNTY

BY

MASIGA ROSE D. OJWANG’ (B. Ed Sc)
156/CE/12140/07

THESIS SUBMITTED IN PARTIAL FULFILMENT FOR THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN THE SCHOOL OF PURE AND APPLIED SCIENCES (AGRICULTURAL ENTOMOLOGY) OF KENYATTA UNIVERSITY

SEPTEMBER 2017
DECLARATIONS

This thesis is my original work and has not been presented for a degree in any other University or any other award.

Signature: ………………………………… Date: …………………………………

Masiga Rose D. Ojwang’ (BED.Sc)  
Department of Zoological Sciences

Declaration by supervisors:

We confirm that the word reported in this thesis was carried by the candidate under our supervision.

Signature: ……………………………… Date……………………………………

Dr. Jenard Patrick Mbugi  
Department of Zoological sciences, Kenyatta University

Signature: ……………………………… Date……………………………………

Dr. Muo Kasina  
National Sericulture Research Centre,  
Kenya Agricultural and Livestock Research Organization
DEDICATION

This work is dedicated to my late grandmother Miriam Masiga and late mother Milicah Macho for giving me strength, guidance, hope and determination to reach this far. I am grateful to my husband Dr. Charles Nalyanya for the encouragement and financial support. To our loving children, Charity Khainja, Walter Mwalakha and Cindy Nelima for the encouragement and interest they had in my studies. My deepest dedication and glory goes to our almighty Lord for giving me good health, time and necessary resources to read and complete the Master of Science programme.
ACKNOWLEDGMENTS

I would like to thank sincerely Global Environment Facility (GEF), United Nations Environment Programme (UNEP) and Food and Agriculture Organization (FAO) for funding this research. This research was conducted as part of a GEF student sponsored fellowship, rapid survey of the crop pollinators in Kenya, Ghana, South Africa, Japan, Pakistan and Brazil. I further wish to extend my appreciation to Biodiversity monitoring transect analysis in Africa (BIOTA), Kenya Agricultural and Livestock Research Organization-Nairobi Research Laboratories (KALRO-NARL) and Nation Museum of Kenya (NMK) for facilitating this research and training me in angiosperm pollination and bee biology. I wish to extend my heartfelt gratitude to my supervisors, Dr. Jenard Patrick Mbugi (Kenyatta University-K.U) and Dr. Muo Kasina (KALRO-Thika) for their dedication and continued guidance during research work and the writing of this report. Similarly, I thank Mr Odhiambo Chris (NMK) and Dr Wanja Kinuthia (NMK) for the guidance they gave me during field work. My sincere thanks go to Kaitheri and Kangaika (Laikipia County) farmers who gave me access and the use of their farms for this study. My deep appreciations go to extension officers from the Ministry of Agriculture and Frigoken Company for the vital knowledge and support they individually and collectively imparted on me during the research. Finally I would also like to appreciate my Master of Science (MSc) classmates and colleagues at Kenya Agricultural and Livestock Research Organization (KALRO-NARL) for being resourceful academicians as we freely shared academic and social facts.
# TABLE OF CONTENTS

**TITLE** .............................................................................................................................................................................. i

**DECLARATIONS** .................................................................................................................................................................. ii

**DEDICATION** ...................................................................................................................................................................... iii

**ACKNOWLEDGMENTS** ............................................................................................................................................................ iv

**LIST OF TABLES** ................................................................................................................................................................... viii

**LIST OF FIGURES** ................................................................................................................................................................. ix

**LIST OF PLATES** ...................................................................................................................................................................... x

**LIST OF ABBREVIATIONS AND ACRONYMS** .................................................................................................................... xi

**ABSTRACT** ................................................................................................................................................................................ xii

---

**CHAPTER ONE: GENERAL INTRODUCTION** ......................................................................................................................... 1

1.1 Background ........................................................................................................................................................................... 1

1.2 Problem statement ................................................................................................................................................................. 2

1.3 Justification ............................................................................................................................................................................ 3

1.4 Research questions ............................................................................................................................................................... 3

1.5 Hypotheses .............................................................................................................................................................................. 4

1.6 Objectives ............................................................................................................................................................................... 5

1.6.1 General objective .......................................................................................................................................................... 5

1.6.2 Specific objectives ........................................................................................................................................................ 5

1.7 Significance of the study ...................................................................................................................................................... 6

---

**CHAPTER TWO: LITERATURE REVIEW** ............................................................................................................................... 7

2.1 Morphology of French beans ............................................................................................................................................... 7

2.2 Pollination of French beans ............................................................................................................................................... 8

2.3 Bee pollinators in an ecosystem ......................................................................................................................................... 9

2.4 Taxonomy and diversity of bees ......................................................................................................................................... 10

2.4.1 Colletidae (Cellophane bees) ........................................................................................................................................ 10

2.4.2 Andrenidae (Mining bees) ............................................................................................................................................ 12

2.4.3 Halictidae (Sweat bees) ................................................................................................................................................. 13

2.4.4 Megachilidae (Leaf cutter bees) .................................................................................................................................... 13

2.4.5 Melitidae (Carpenter bees) ........................................................................................................................................... 14

2.4.6 Apidae (Honey bees) ...................................................................................................................................................... 16
2.5 Habitats of bee pollinators ................................................................. 17
2.6 The significance of pollination services to biodiversity and agriculture .... 18
2.7 Threats to diversity and abundance of bees ........................................... 20
  2.7.1 Habitat fragmentation and loss ....................................................... 20
  2.7.2 Effect of agricultural Chemicals on bees ....................................... 23
  2.7.3 Effect of natural enemies on bees ................................................. 23
  2.7.4 Effect of climate Change on bees ............................................... 25
2.8 Assessment of abundance and diversity of bees ................................ 26

CHAPTER THREE: MATERIALS AND METHODS .................................. 28
3.1 Study site .............................................................................................. 28
3.2 The survey design for assessing diversity and abundance of bees visiting flowers of French beans along forest-farmland gradient ........... 31
  3.2.1 Assessing diversity of bees visiting flowers of French beans along forest-farmland gradient at North Eastern slopes of Mt Kenya Forest .... 32
  3.2.2 Assessing abundance of bees visiting flowers of French beans along forest-farmland gradient at North Eastern slopes of Mt Kenya Forest .... 33
  3.2.3 Investigating the effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along forest – farmland gradient at North Eastern slopes of Mt Kenya Forest ............ 33
  3.2.4 Determining the effect of time of the day on the trend of the three most common bee species visiting flowers of French beans along a forest-farm gradient at North Eastern slopes of Mt Kenya Forest .................... 34
3.3 Data analysis ......................................................................................... 35

CHAPTER FOUR: RESULTS ..................................................................... 37
4.1 Taxonomic composition and diversity of bees visiting flowers of French beans along forest – farmland gradient .................................................. 37
  4.1.1 Bee species richness ........................................................................ 38
  4.1.2 Diversity of bee communities on farms at 0.2 km and 1 km from the edge of the forest .......................................................... 40
4.2 The abundance of bees visiting flowers of French beans along forest – farmland gradient ................................................................. 41
4.2.1 Mean number of bees sampled in farms at 0.2 km and 1 km from the edge of the forest ............................................................................................ 41
4.2.2 Mean number of bee species sampled on farms at 0.2 km and 1 km from the edge of the forest .............................................................................. 42
4.2.3 Mean number of three most common bee species sampled in farms at 0.2 km and 1 km from the edge of the forest .................................................. 45
4.3 The effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest............................................................. 46
4.3.1 Effect of distance from the edge of forest on the yield of French beans............. 46
4.3.2 Effect of diversity and abundance of bees on the yield of French beans ........ 47
4.3.3 Effect of diversity and abundance of three most common bee species on the yield of French beans ........................................................................... 47
4.3.4 The effect of time of the day on the trends of the most common bee genera visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest................................. 48

CHAPTER FIVE: DISCUSSION, CONCLUSION, RECOMMENDATIONS...52
5.1 Discussion .............................................................................................................. 52
5.1.1 Diversity of bees visiting flowers of French beans along a forest farmland gradient at North Eastern slopes of Mt Kenya Forest .............. 52
5.1.2 Abundance of bees visiting flowers of French beans along a forest farmland gradient at North Eastern slopes of Mt Kenya Forest .............. 55
5.1.3 Effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along a forest – farmland gradient ....... 61
5.1.4 Time of the day on the trends of the most common bee species visiting flowers of French beans along a forest – farmland ........................................... 62
5.2 Conclusion ............................................................................................................. 64
5.3 Recommendations .................................................................................................. 66
REFERENCES........................................................................................................... 69
LIST OF TABLES

Table 4.1: Family, genera and species of bees sampled and identified on farms located at different distance from the edge of the forest in the years 2011 and 2012 ................................................................. 38

Table 4.2: Shannon diversity index for farms at 0.2 km and 1 km from the edge of the forest ................................................................. 41

Table 4.3: Mean number ± SE of bees sampled in farms located at 0.2km and 1km from the edge of the forest .................................................. 42

Table 4.4: Mean number ± SE of each bee species sampled in farms located at 0.2 km and 1 km from the edge of the forest .............................. 44

Table 4.5: Mean number ± S.E. of bees of three most common genera sampled at 0.2 km and 1 km ................................................................. 45

Table 4.6: The mean yields ± S.E. of French beans sampled in farms located at 0.2 km and 1 km from the edge of the forest .............................. 46

Table 4.7: Correlation of 3 most occurring spp of bees and Yield of French beans .................................................. 48
LIST OF FIGURES

Figure 3.1: Map of Laikipia County showing the study area (Kaitheri and Kangaika) .........................................................................................................................30

Figure 3.2: A survey design for assessing diversity and abundance of bees visiting flowers of French beans ..................................................................................32

Figure 3.3: A design for assessing effect of time on foraging activities of A.mellifera, Xylocopa spp and Megachile spp ........................................................................35

Figure 4.1: Species richness curve of bees collected on flowers of French beans in the year 2011 ........................................................................................................39

Figure 4.2: Species richness curve for bees collected on flowers of French beans in the year 2012 ........................................................................................................39

Figure 4.3: The mean number of Apis mellifera visiting flowers of French beans at different times of the day ...............................................................49

Figure 4.4: The mean number of Xylocopa spp visiting flowers of French beans at different times of the day ...............................................................50

Figure 4.5: The mean number of Megachile spp visiting flowers of French beans at different time of the day ...............................................................51
LIST OF PLATES

Plate 2:1: Xylocopa calen visiting flowers of Phaseolus Vulgari................................. 7
Plate 2:2: Collete compactus (Hymenoptera, Colletidae)........................................... 11
Plate 2:3: Andrena spp (Hymenoptera, Andrenidae).................................................... 12
Plate 2:4: Halictus agopostemo (Hymenoptera, Halictidae)........................................ 13
Plate 2:5: Megachilespp. (Hymenoptera, Megachilidae)............................................. 14
Plate 2:6: Xylocopa spp.(Hymenoptera, Melitidae).................................................... 15
Plate 2:7: Xylocopa spp. (Melitidae)............................................................................ 15
Plate 2:8: Apis mellifera (Hymenoptera, Apidae)...................................................... 16
Plate 2:9: Bombus spp (Hymenoptera, Apidae)......................................................... 17
# LIST OF ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>Bio diversity Pro Software</td>
<td>Bio-Diversity Professional Beta software</td>
</tr>
<tr>
<td>GENSTAT</td>
<td>General Statistical Program</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>HCDA</td>
<td>Horticultural Development Authority</td>
</tr>
<tr>
<td>HSD</td>
<td>Honest Significance Difference</td>
</tr>
<tr>
<td>IPM</td>
<td>Integrated Pest Management</td>
</tr>
<tr>
<td>Kgs</td>
<td>Kilograms</td>
</tr>
<tr>
<td>Ksh</td>
<td>Kenya shillings</td>
</tr>
<tr>
<td>NMK</td>
<td>National Museums of Kenya</td>
</tr>
<tr>
<td>Spp</td>
<td>Species</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical package for social science</td>
</tr>
<tr>
<td>$</td>
<td>United State of America Dollar</td>
</tr>
</tbody>
</table>
ABSTRACT

French bean (Phaseolus vulgaris L.) is an important crop with high impact on rural employment and livelihood. In Kenya, the crop is grown for export by small scale farmers in high potential areas of Central, Rift valley and Western regions. These regions are densely populated leading to intensive farming and land fragmentation, which research has reported to be among the major threats of bee pollinators. However, amongst the known constraints, pollination has not featured amidst many farmers, a fact associated with lack of knowledge on the same. The crop benefits from bee pollination through improved pod set and pod quality. The objectives of this study were to assess the taxonomic composition and diversity of bees visiting flowers of French beans, assess the abundance of bees visiting flowers of French beans, investigate the effect of diversity and abundance of bees on the yield of French beans, determine the effect of time of the day on the trends of the most common bee genera visiting flowers of French beans. Field surveys were conducted on Julie cultivar of French beans in Kaitheri and Kangaika locations of Timau division (Lipikia County). The study design was based on a protocol developed and agreed upon by global partners for testing pollination deficit in crops. Ten farms were selected along a 3 km transect, where five farms were located at 0.2 km from the edge the forest and other five were at 1 km distance. Sampling was done on a plot measuring 760 m², once a week, between 8.00 to 10.00 h and 11.00 to 2.00 h, three times a season at a weekly interval, in the years 2011 and 2012. Sampling was done on 6 rows each measuring 25 m x 2 m for 30 minutes. Sampling of bees to assess taxonomic composition and diversity was done using sweep net. Sampling of bees to assess abundance was done using two scanners, where one scanner counted newly opened flowers and another one counted bees in the flowers. Effect of diversity and abundance of bees on yields of French beans was done by daily weighing and recording of production inputs and outputs of French beans. Observation of bees to determine the effect of time of the day on the trends of the bees was done on six farms, where, each group of two farms was at 0.2 km, 0.8 km and 1 km from the edge of the forest. Bees were observed from 06.00 h to 18.00 h and recorded on hourly basis. Results on diversity of bees revealed five families, nine genera and twelve species of bees during the study period of two years. Total diversity of bees sampled on farm located at 0.2 km and 1 km were not significantly different (P=0.161). Mean numbers of bees sampled on farms located at 0.2 km and 1 km were not significantly different (P=0.821). The mean number of Apis mellifera was higher than those of all other bee species. The mean number of Apis spp was higher than those of Xylocopa spp and Megachile spp. The total diversity and abundance of bees did not significantly affect the total yield of French beans. Yield of French beans only correlated significantly with the abundance of Xylocopa spp. Bees of Apis spp foraged on flowers of French beans between 08.20 h and 17.00 h, with a peak activity between 10.30 h to 11.00 h. Bees of Xylocopa spp foraged on flowers of French beans between 08.20 h and 15.00 h, with the peak activity at 14.00 h. Bees of Megachile spp foraged on flowers of French beans between 09.00 h and 16.00 h, with the peak activity at 13.00 h. Thus, this study recommends implementation of bee friendly practices and measures to enhance pollination of crops.
CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

French bean (*Phaseolus vulgaris* L.) belongs to the family Leguminosae and is cultivated in the tropics, sub tropics and temperate regions (Silbernagele *et al.*, 1991). The crop originated from Central and South America (Smart, 1969). In Kenya, the crop is grown for export particularly to European markets by small scale farmers in high potential areas of central, rift valley and western Kenya e.g. Nyeri, Laikipia and Vihiga Counties, respectively (HCDA, 2013). It is grown throughout the year in periods of low rainfall as its growth and productivity is negatively affected by high rainfall. Flooding and sprinkler irrigation systems are commonly used to supplement rains. High amounts of farm inputs are used to maximize the yields in order to sustain the livelihood of the farmers (Monda *et al.*, 2003; Nyakundi *et al.*, 2010; Masiga *et al.*, 2014).

Bees belong to the Order Hymenoptera, Sub-order Apocrita, Super-family Apinae, Clade Anthophila and they are of monophyletic lineage. There are nearly 20,900 known species of bees in eleven recognized biological families, though many are undescribed and the actual number is probably higher. Out of eleven bee families six are found in Africa namely, Apidae, Megachilidae, Melitidae, Andrenidae, Colletidae and Halictidae (Michener, 2000). Bees are found on every continent except Antarctica, in every habitat on the planet that contains insect-pollinated flowering plants. They are adapted for feeding on nectar and pollen, the former primarily as an energy source and the latter primarily for protein and other nutrients. Most pollen is used as food for larvae (Ascher *et al.*, 2008). Bees range in size from tiny stingless bee species (*Trigona minima*) (Hymenoptera, Stenotritidae),
whose workers are less than 2 millimeters long, to large species of leafcutter bee (*Megachile Pluto*) (Hymenoptera, Melitidae), whose females can attain a length of 39 millimeters (Michener, 2000; Ascher *et al*., 2008). Most bees are polylectic (generalist) meaning they collect pollen from a range of flowering plants, however, some are oligoleges (specialists), in that they only gather pollen from one or a few species or genera of closely related plants. Specialist pollinators also include bee species which gather floral oils instead of pollen, and male orchid bees, which gather aromatic compounds from orchids. Bees are able to sense the presence of desirable flowers through ultraviolet patterning on flowers, floral odors, and even electromagnetic fields. Once landed, a bee then uses nectar quality and pollen taste to determine whether to continue visiting similar flowers. In rare cases, a plant species may only be effectively pollinated by a single bee species. There is, however, a pronounced tendency for oligolectic bees to be associated with common, widespread plants which are visited by multiple pollinators (Michener, 2000; Ascher *et al*., 2008).

### 1.2 Problem statement

Pollinators especially bees are currently under great threat worldwide, mainly from climate change and anthropogenic activities. Human activities include land fragmentation, alteration of habitats, change in land use patterns, modern agronomic practices and misuse of agrochemicals (Kearns *et al*., 1998). Dramatic decline in the diversity and abundance of bee pollinators and a reduction in yield of the crops they pollinate have been reported in many countries, including North America (Williams *et al*., 2001) and Europe (Allen-Wardell *et al*., 1998; Cane and Tepedino, 2001; Goulson *et al*., 2008). However, in Kenya little research has been carried out on the diversity and abundance of bee pollinators and their effects on French bean production (Kasina
et al., 2009a). Laikipia County for instance, is characterized by high population, which has led to deforestation, agricultural intensification and land fragmentation which research confirmed affect bee pollinators negatively (Schaab and Lung, 2006). Thus, the objective of this study was to examine if distance from the forest (a possible reservoir for bee pollinators) affects the abundance and diversity of bees visiting flowers of French beans and its yields.

1.3 Justification

In Kenya, currently, the production of French beans is hampered by high input costs, climate change, reduced land holdings, pests and pathogens ((HCDA, 2013). However, amongst those known constraints, pollination has not featured amidst many farmers, a fact associated with lack of knowledge on the same. Sufficient pollination of French beans is responsible for high seed set that result in uniform pods. Such well-formed and shaped pods are of the highest grade while malformed pods are not marketable, resulting in lower farm income. In addition, well-pollinated flowers produce pods of higher weight, which provide farmers with better income. Therefore, there was a need to carry out this research on diversity and abundance of bee pollinators and their effects on yield of French beans in Laikipia County.

1.4 Research questions

(i) How does distance from the forest affect taxonomic composition and diversity of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya?
(ii) How does distance from the forest affect abundance of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya?

(iii) How does diversity and abundance of bees affect the yield of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya?

(iv) How does time of the day affect the trends of the most common bee species visiting flowers of French beans along forest – farmland gradient at North Eastern slopes of Mt Kenya

1.5 Hypotheses

(i) Distance from the forest does not affect the taxonomic composition and diversity of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya

(ii) Distance from the forest does not affect abundance of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya

(iii) Diversity and abundance of bees visiting flowers of French beans do not affect the yield of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya
(iv) Time of the day does not affect the trends of the most common bee species visiting flowers of French beans along forest – farmland gradient at North Eastern slopes of Mt Kenya

1.6 Objectives

1.6.1 General objective
To assess taxonomic composition, diversity and abundance of bees and their effects on the yield of French beans along a forest- farmland gradient at the North-Eastern slopes of Mt Kenya Forest.

1.6.2 Specific objectives

(i) To assess the taxonomic composition and diversity of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest.

(ii) To assess the abundance of bees visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest.

(iii) To investigate the effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest.

(iv) To determine the effect of time of the day on the trends of the most common bee species visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest.
1.7 Significance of the study

Bees are among the main pollinators in agri-ecosystem, as they rely almost exclusively on flowers for their food requirements. Reduced diversity and abundance of bees, results in pollination deficit of flowering crops, which decreases sexual reproduction of the crops. Decrease in product sizes, color, nutritional content, taste and germination and maturity rates of seeds or fruits will decrease the output of that crop. Pollinators visit and pollinate crops during the day but reside in natural and non-crop habitats around the farmland or within the forest. A decrease in natural and non-crop habitats affects the abundance and diversity of bee pollinators resulting in reduced crop productivity.

The findings for the study therefore, will contribute to the existing literature in the field of conservation of bee pollinators. Future scholars may use this study as a reference material in conducting other related academic studies on the issues at stake. The government officers (Ministry of agriculture, environment etc) may use the study as a guide to offer advisory services to the public, as the study highlights on the importance of pollinators in provision of ecosystem service. In the long run, reduced pollination service ends up affecting all living things including man in that ecosystem. In addition, the findings of the study will be published in technical handbooks for future advisory purposes to the farmers, government agencies, and academicians.
CHAPTER TWO: LITERATURE REVIEW

2.1 Morphology of French beans

Majority of the cultivars of French beans are bush type annuals that reach a height of about 2.5 feet. The leaves are dense, heart-shaped and 3-6 inches long. The fruit is a pod, straight or slightly curved, 4-8 inches long, with a prominent beak. The seeds may be white to red, brown speckled or blue black, globular to oblong and from \( \frac{1}{4} \) to 1 inch long. Pods contain 1-12 seeds. The flower is usually whitish, but may be tinged to deep violet, purple or red and it is \( \frac{1}{2} - \frac{3}{4} \) inch long. The keel is prolonged in a spirally twisted beak. The style follows the spiral of the keel. There are 10 stamens; the upper one is free while the other 9 are united into a tube enclosing the long ovary and part of the style (Graham and Ranalli, 1997). The flowers open between 7-8 am and never close (Michener, 2007). Plate 2.1 below shows Xylocopa spp bee in the flower of Phaseolus vulgaris.

Plate 2.1: Xylocopa calen visiting flowers of Phaseolus Vulgaris

Author: Kingha, et al., 2012.
2.2 Pollination of French beans

There are no records on the pollination needs of the ‘Julia’ variety of French beans cultivated in Kenya, but carpenter bees (Xylocopa spp) (Hymenoptera, Melitidae) visit and pollinate different cultivars of P. vulgaris grown for dry seeds in Cameroon (Kingha et al., 2012) and in Puerto Rico (Bliss, 1980). In the USA, Ibarra-Perez et al. (1999) found that bumble bees (Bombus spp) (Hymenoptera, Apidae) were the most effective pollinators of P. vulgaris and their flower visits had a significant positive effect on seed production in two determinate varieties. Honey bees (Apis mellifera) (Hymenoptera, Apidae) are abundant visitors on flowers of common beans in Kenya (Kasina et al., 2009a). However, exposure of bean plants to A. mellifera pollination did not result in higher pod yield of dry seeds in the UK nor in the USA (Free, 1966; McGregor, 1976; Delaplane and Mayer, 2000). However, the study by Kasina et al., (2009a) found that cross-pollinated common beans resulted in increased seed set and nutrition improvement of the dry harvested seeds. French bean marketing quality is based on individual pod weight, size as well as uniformity in pod shape, commercial yield might therefore be affected by insect pollination. Indeed, there is no parthenocarpy nor apomixis in P. vulgaris (Bliss, 1980) as pod uniformity is influenced by seed set constancy. Parthenocarpy is the natural or artificially induced production of fruits without fertilization of ovules while apomixis is the cross pollination of flowering plants. On fertilization of all ovules, the pods grow uniformly and produce a first-grade product. Poor pollination results in less developed ovules, leading to curved pods that are rejected during marketing.
Farmers in Kenya do not usually manage bee pollinators (Kasina et al., 2009a; Masiga et al., 2014) and conservation is incidental. Farmers bordering the Mt Kenya forest carry out some farm practices that may have positive impact on bee pollinators such as keeping hedgerows, setting-aside land with natural vegetation, and growing diverse crop species within small farms. The Mt Kenya forest is an area protected by the Kenya government though it has shrunk over the years as a result of the expanding human settlement (Mugo, 2007). Given the high degree of land fragmentation into intensively managed small agricultural farms, the Mt Kenya forest is an important reservoir of bee pollinators on the farms in Laikipia County. On this transect, could be a forest- farmland gradient where bee pollinator availability may differ. Therefore, this provides the potential for pollination deficit at some areas on the farms.

2.3 Bee pollinators in an ecosystem

All pollinators including bees require undisturbed habitats for provision of floral resources, nesting place and materials and refugee area during harsh environmental conditions (Kasina et al., 2007). If bees are isolated through habitat lose, it is harder for them to find mates, have enough nesting sites and eat enough food within a limited area (Kremen et al., 2002). Bees that experience habitat losses suffer from nutritional stress as it is more difficult for them to locate valuable food sources (Kremen et al., 2002).

In Kenya, most flowering crops rely on wild pollinators from nearby habitats for pollination (Kasina et al., 2007). However, the ability of these habitats to continuously support pollinators has been interfered with by human activities. Natural and semi natural ecosystems have been continuously destroyed to avail land for
farming, infrastructure and human settlements. Rapid human population growth coupled with increasing demand for food has led to land fragmentation and agricultural intensification, which are the most serious threats to the biodiversity of bees in agro-ecosystems (Benton et al., 2003). The aforementioned anthropogenic activities have led to the replacement of indigenous plants that provide good forage for bees with exotic trees. Indigenous plants have co-evolved with native bee pollinators for a long time (Schaab and Lung, 2006). In addition, farming systems that encourage shifts from intensive to large-scale monocultures, soil compaction, burning crop litter and loss of hedgerows end up destroying food resources and nesting sites for ground nesting bees (Kinuthia and Njoroge, 2004). Large implements such as mowers and ploughs destroy ground nests of bees and floral resources.

**2.4 Taxonomy and diversity of bees**

The classification of bees into various families is based on their mouth parts and other microscopic characteristics. However, the bees in each family have descriptive features, including body size, nesting and foraging behaviors, body hairs, length of the tongue, location and form of pollen carrying structure (Scopa) and other microscopic features which distinguish them into different taxonomic units (Michener, 2000). The antenna of bees has 13 segments in male and 12 segments in female.

**2.4.1 Colletidae (Cellophane bees)**

They are large, robust, hairless or hairy, with short forked tongues. Colletid bees resemble closely wasps. Some have bright green or blue colors. Scopa is on hind
femur or metasomal sterna, but poorly developed. Some store pollen and nectar internally in the crop, which is the depression on the ventral part of the thorax. Metasomal stern is the third ventral sclerite of the segments of the sternum and scopa is the pollen-collecting apparatus of a bee. Facial fovea is usually absent or not well defined. Stigma is shorter or longer than pre-stigma. Stigma or pterostigma is a small coloured area near the wing-tip and prestigma is a coloured area situated just before the stigma on fore wing of a bee. Vein r arises near the middle or before the apex. The margin of stigma in marginal cell is concave or straight or convex. Sub marginal cells are cells which border the front margin of the wing in the outer region. The bees are slender and their episternal groove extends far below scrobal groove. Episternal groove is the thoracic sclerite just in front of a pleural suture. The basal vein is feebly formed leaving arcuate glossa bilobed. Basal vein is the dark, tubular thickening on the upper part of the fore wing. Thus, their glossa is broad truncated, bilobed, bifid and short. *Collete* spp bees are 8 to 13mm in size, with distinct bands of white hair on the abdomen. They line their nest tunnels and larval cells with a secretion that hardens into a cellophane-like membrane (Michener, 2007; Ascher *et al.*, 2008). Plate 2.2 below shows a *Collete* spp bee

![Plate 2.2: Collete compactus (Hymenoptera, Colletidae)](image)

2.4.2 Andrenidae (Mining bees)

Andrenid bees are either solitary or communal, living in separate but nearby nests. They are 6 to 15 mm in size. They have velvet patches (Foveae) on their faces. Facial fovea is one of the paired depressions on each side of the vertex with or without hair. The bees are metallic reddish-brown or brown black in color. They are very hairy especially on the abdomen and thorax. Sometimes the hairs are feather like. The tongue is short. On the hind leg the scopa is on tibia and basitarsus or on the stern. Tibia is the fourth segment of the leg of an insect. Scopa of the femur is not well developed. Femur is the third and largest segment of the leg of an insect. On addition, their two sub antennal sutures are well separated on clypeal margin below antenna. Antennae are the appendicular, sensory organs on the head of an insect. However, the apex of marginal cell is pointed. Apex is the joint where the costal vein and the outer margin of the fore wing meet. They may have shallow depressions between their eyes and antennae. Their nests are made of soil and have many chambers, each ending in one or many cells. (Michener, 2007; Ascher et al., 2008).

Plate 2.3 below shows andrenid bee.

Plate 2.3: *Andrena spp* (Hymenoptera, Andrenidae)

Author: Thorms, 2000.
2.4.3 Halictidae (Sweat bees)

These bees measure 3.5 to 12 mm in size. They have metallic black, blue, copper, green or gold colors with little hair. Some have markings of yellow, copper, gold or black. They lack facial foveae. The glossa is acute and short. The scopa is on hind femur, trochanter, tibia and basitarsus and metasomal sterna. Stigma is longer than prestigma and vein r arises near its middle or at least before apex. The margin of the stigma in marginal cell is straight or convex and much longer than width of the stigma. They have three or two sub-marginal cells and are slender bees. Halictinae or Halictus bees have ginger hairs on the thorax and with elongated abdomen. The abdomen has hair bands. They nest in the ground and live in communal. Halictus measure 9 to 12 mm in size. (Michener, 2007; Ascher et al., 2008). Plate 2.4 below shows Halictus spp bee

Plate 2.4: Halictus agopostemo (Hymenoptera, Halictidae)
Author: Michener, et al., 2007.

2.4.4 Megachilidae (Leaf cutter bees)

They have long tongue and the scopa is well developed on metasomal sterna. They have two sub-marginal cells of about equal length on both wings. Megachile spp may have dark robust bodies with dark or light hairs and measure 7 to 15mm. Some have rather pointy abdomens. Head is as broad as the thorax with large mouthparts
used to cut leaves. They are solitary bees which nest in aggregations in the ground or in pre-existing holes. They cut circular pieces from leaves and use them to line their nests in pre-existing or excavated cavities in the ground, stems or wood. (Michener, 2007; Ascher et al., 2008). Plates 2.5 shows *Megachile* spp bee

Plate 2.5: *Megachile* spp. (Hymenoptera, Megachilidae)

Author: Bob-Moul, 2008.

**2.4.5 Melitidae (Carpenter bees)**

Melitid bees fall into large *Xylocopa* spp and small *Ceratina* spp. They are fast-flying, fuzzy and nest in the ground solitarily or in dense clusters or may excavate nests in the wood. The scopa is on the hind legs and stern. The scopa on the leg is usually on the hind tibia and basitarsus. Facial fovea may be vaguely defined or well defined or absent. There is one or two sub-antennal suture. They have short-tongues and the first two segments of labial pulps are similar with subsequent segments. Episternal groove is not well developed. Forewing has three sub marginal cells. Their second sub marginal cell is irregular and malar space is absent or present (Michener, 2007; Ascher et al., 2008). Large *Xylocopa* spp have black bodies with metallic black, blue, green or purple hairs. They measure 15 to 23mm in size. Abdomen is shiny and mostly lack hair. They have round face with yellowish area (male). Nests are
burrowed into wood, often in roof eaves. Small *ceratina* spp have dark blue-Green and shiny bodies. They appear hairless on all body segments. The scopa is on hind legs. Their bodies are slender with shield-shaped abdomen. They have pale yellow marks on the face which is in form of a vertical bar (females) and inform of inverted T (male) (Michener, 2007; Ascher *et al.*, 2008). Plates 2.6 and 2.7 below show examples of *Xylocopa* spp bees

Plate 2.6: *Xylocopa* spp. (Hymenoptera, Melitidae)
Author: Michener, *et al.*, 2007

Plate 2.7: *Xylocopa* spp. (Hymenoptera, Melitidae)
2.4.6 Apidae (Honey bees)

Apidae family bees make intricate nests and live in complex societies. They are fuzzy, stout bees which measure 12 to 23mm in size. They have big mandibles to chew materials. The scopa is on hind legs and on stern. The facial fovea is absent or present. They may have one or two sub-antennal suture. They are long-tongued bees and their first two segments of labial pulps are elongate and flattened. Episternal groove is present and it’s curved to join scrobal groove. They have light to dark brown bodies with brown and dark hair bands on abdomen. They have barrel-shaped abdomen with heart-shaped head. Orchid, bumble, stingless, and Apis are the tribes of this family (Michener, 2007; Ascher et al., 2008). Plates 2.8 and 2.9 below show examples of Apid bees.

Plate 2.8: *Apis mellifera* (Hymenoptera, Apidae)

2.5 Habitats of bee pollinators

Bees require a place to construct nests and flowers to forage on. Kasina et al. (2007) reported that bees also require plants for other uses such as getting nest materials, hiding, mating or just as resting sites. Undisturbed habitats provide the best home for different bees as they provide mud, resins, pebbles or plant materials for nest construction or an area for ground nesting bees to construct nests (O’Toole, 1993).

The main food resource of bees is nectar and pollen, which they get from flowers of different plant species (Kasina et al., 2007). Most bees are generous, although others are specialists (Michener, 2007). Plants and pollinators have co-evolved, in such a way that flowers of different plants would require specific bee pollinator(s) for effective pollination to occur (Michener, 2000; Kasina et al., 2009a). Social bees with long-lived colonies, such as A. mellifera, need flowers blooming throughout the season. Solitary bees have short active period (5 to 6 weeks), and life cycles are synchronized with the blooming of preferred flower species (Michener,
The nest and flower habitats need to be close enough so that the bees can fly between them. The small bees may fly more than 200 to 300 yards while large bees may fly a mile or more from the nest to foraging area. If the flight distance is very long, the bees may find somewhere else to nest or become exhausted and die (Michener, 2007).

2.6 The significance of pollination services to biodiversity and agriculture

Bees are among the main pollinators in most ecosystems, as they rely almost exclusively on flowers for proteins, oils and sugar throughout their life cycle (Michener, 2000). Furthermore, they also exhibit the highest floral visitation rates among all the insects (Klein et al., 2007).

About one third of crops used for human nutrition or 90% of all angiosperms (240,000 species) are dependent on insect pollination particularly bees (Klein, et al., 2007). This includes the majority of fruits, vegetables, seed crops and forage plants fed to livestock. Fruits and fleshy vegetables provide most of the essential micro-nutrients and vitamins needed for good human health. Kasina et al. (2009a) and Free (1993) reported that bees are good pollinators, as they have a lot of body hairs, unique foraging behavior and they collect floral resources as their food compared to other insects which only feed on nectar and pollen, but do not collect them. Bees carry pollen grains and drop them on the stigmas of other flowers as they forage from plant to plant, under a process called cross pollination.

Cross pollination enhances fruiting or seed setting which increases the quality and yield of flowering crops (McGregor, 1976; Free, 1993). Similarly, cross
pollination may also enhance uniform ripening, germination rates and plant vigor in some plants (Kasina, *et al.*, 2007). Therefore, cross-pollination is important for plant genetic diversity which enhances conservation (Michener, 2000). Plant communities with less pollinator visitation rates reduce in population sizes or become extinct due to inbreeding consequences and less seed formation, which leads to reduced propagation (Michener, 2007). Even those plants capable of self-pollination, cross-pollination by animals increases quantity and quality of their produce (Roubik, 2002a). Thus, loss of pollinators can have a negative effect on food quantity, quality, prices and security (Steffan-Dewenter *et al.*, 2002).

Gallai *et al.* (2009) estimated the total economic value of the pollination service provided by insect pollinators, to be Kshs 20 trillion (€153 billion), which amounts to 95% of the total value of global agricultural food production. In Kenya, research conducted in several small-scale farms at Kakamega, estimated economic value of pollination by insects on eight commonly grown vegetable to be Kshs 260 million ($3.12 million) in an area of about 23,000 ha, which was 40% net benefit of their annual value. This amounted to an average of Kshs 85,383 (USD 1025) per household annually as net income (Kasina, 2007).

Pollination can be considered as a farm input because *A. mellifera, Bombus* spp and nine other bee species are purchased or rented out by farmers in many developed countries to supplement the local pollinators (Dag *et al.*, 2006). Other than pollination, *A. mellifera* also provide honey, wax and propolis to humans and other organisms (O’Toole, 1993)
2.7 Threats to diversity and abundance of bees

There are many abiotic and biotic factors which affect abundance and diversity of bees, but the main ones include; habitat fragmentation and loss, agrochemicals, parasites, pathogens and climate change. The above-mentioned threats of bees are discussed below.

2.7.1 Habitat fragmentation and loss

The loss of natural and semi natural habitats due to intensive land use can have significant negative effect on pollinator communities in agricultural landscapes (Tscharntke et al., 2005; Kremen et al., 2007). It acts through many mechanisms that reduce reproduction and survival of bees. These mechanisms include the loss of forage and breeding habitat, population subdivision and genetic drift, and disruption in behavior and interspecific interactions (Fisher and Linden Mayer, 2007). Kremen et al. (2002) indicated that the loss of floral resources and nesting sites associated with deforestation affect bee population with demonstrable economic consequences. Indeed, deforestation affect drastically Apis spp which nest mostly in mature hollow trees, some solitary bees which nest in dead wood and bee species which use natural habitats as a refuge. Mt Kenya forest has not been spared as most of the area that is now cultivated on the slopes of Mount Kenya used to be part of Mt Kenya forest (Mugo, 2007).

Aguilar et al. (2006) also confirmed that pollination and reproduction of animal-pollinated plants is negatively affected by habitat loss due to decrease in population of pollinators. Reduced diversity and numbers of pollinators results in
reduced yield of the plants they pollinate, and if this is not mitigated it may result in extinction of both groups.

Rapid population growth in Kenya coupled with increasing demand for food has seen excision of large tracts of forest land for agricultural production and human settlements. For example, a spatial analysis of the extent of Kakamega and Kisere forest indicated that forest cover had changed from 18,547 ha in 1967 to 12,287 ha in 2001 (Schaab and Lung, 2006). One of the consequences of habitat destruction and fragmentation is the isolation of pollinators, resulting in reduced genetic vigor, as well as increased genetic drift between isolated populations (Zayed and Packer, 2005). In Ngong forest, the clearing of trees for urban development has led to the hybridization of savanna and mountain bee races, thus posing a serious threat to the survival of *A. mellifera monticola* in its refugia habitats (Zayed and Packer, 2005).

The fragmented nature of modern landscape may also play a role in pollinator population dynamics. The pollinators are likely to be impacted negatively by distance between natural and semi natural habitats and population isolation (Kremen *et al.*, 2002). This has affected species richness, abundance and community structures (Connor *et al.*, 2000). In an isolation experiment with two self-incompatible annuals, it was found that fruit set, quality and size decreased with distance to the nearest natural habitat (Steffan-Dewenter *et al.*, 2002). Pollination deficit may also reduce size, color, flavor or taste, nutritional content, ripening and germination rate of the seeds, and maturity age of the plants grown from those seeds.
The quality and connectivity of the agricultural matrix, including the distance to species-rich habitat, is important for pollinator species richness and plant-animal interactions such as pollination, and seed dispersal. In tropics, the distance of angiosperm crop farms to the nearest forest is known to have affected greatly the diversity of pollinators (Klein et al., 2003). In coffee for example, pollinator diversity and visitation rates declined with increasing isolation from patches of native habitats, and this decline affected yields (Klein et al., 2003; Taylor et al., 2004). This was also seen in matrices of forest and farmlands where wild bee diversity and their visitation rates on coffee in agro-forestry systems were found to diminish with increasing isolation from the forests (Ricketts et al., 2008).

One way of encouraging local pollinators to colonize a given habitat is to ensure that there is an adequate supply of pollen and nectar source throughout the year (Black et al., 2007. Bernhardt et al. (1987) Black et al. (2007) suggested that many Acacia species require the presence of co-blooming nectiferous flowers if bee populations are to be supported. Without enough and continuous food source, pollinators will not persist in the farms as is the case with large scale monocultures where synchronized planting and simultaneous flowering require that managed bees are provided to aid in crop pollination (Kearns et al., 1998). In addition, large areas devoted to the production of cereal crops may support few bees because of the absence of nectar producing flowers. Continuous pollinator requirement can be supplemented with augmentation of flowering trees and bushes as hedgerows to provide nectar and pollen source and nesting sites. In addition, leaving cut wood, allowing reservoirs of natural habitat to persist, and leaving key areas unploughed enhances safe and consistent nesting areas for pollinators (Black et al., 2007). These
measures of habitat improvements for pollinator also benefit other wildlife through provision of food, nesting sites and heterogeneous habitat, particularly in an agricultural setting where crop diversity is low.

2.7.2 Effect of agricultural Chemicals on bees

The use of insecticides affects pollinator populations directly and indirectly, by killing them, altering their behavior and even reducing their mobility (Boulter et al., 2006; Black et al., 2007). The systemic, neo-nicotinoid pesticides which are neurotoxic in nature, such as methylcarbamate, imidacloprid, fipronil, thiametoxam, clothianidin insecticides used in crop production in Europe, persisted in the crops, water and environment at large and changed the biology of bees (Greatti et al., 2006). Fipronil which is now banned in Europe had a profound negative effect on A. mellifara biology. It affected division of labour, foraging behavior, colony development and nest mate recognition of bees (Greatti et al., 2006). Herbicides also affect pollinators indirectly by eliminating non-crop flora which forms a major source of food for pollinators at critical times. Research which was done in Kenya, found out that dimethoate and lambda cyhalothrin insecticides which were applied on blooming sunflower changed the behavior of A. mellifera and reduced their mobility. Reduced abundance of A. mellifera pollinators visiting sunflower flowers lead to reduced pollination which lower the yield (Kasina et al., 2009b). This indicates that improper pesticide use results in reduction in pollination efficiency and bee reproduction.

2.7.3 Effect of natural enemies on bees

Natural enemies, which include pathogens, predators and parasites, play a big role in wild and managed pollinator population dynamics (Meixner, 2010; Elliud et
Bee species especially *A. mellifera* colonies can be affected by a variety of viral, fungal, and bacterial infections, and can also be infested by various insect and mite parasites. Wild populations of pollinators are not threatened by natural enemies with which they have co-evolved with. However, adverse effects of natural enemies may arise when wild populations are stressed by environmental degradation or climate change or monoculture diet (Oldroyd and Wongsiri, 2006).

Anthropogenic movement of bees from one place to another also exposes the native bees to novel natural enemies to which they have no resistance. Eva *et al.* (2009) indicated that the European foul brood viral disease was introduced in Asia together with *A. mellifera* colonies in 1980. Similarly, small hive beetle/ *Aethina tumida* originated from Sub Sahara Africa (Dietemann *et al.*, 2009) and it is now a threat to *A. mellifera* and their relatives in Asia, Australia, USA and Egypt (Mostafa and Williams, 2002). Thus, increase in international trade and porous borders have increased the spread of diseases, and parasites. In addition, Varroa mites (*Varroa destructor*, *V. Jacobson, Acarapis woodi*), small hive beetle *A. tumida* microsporidian and *Nosema ceranae* cause a lot death to *A. mellifera* worldwide thus causing significant economic losses to bee keepers (Downey and Winston, 2001).

In Kenya, the greater wax moth (*Galleria melonella*) has been a serious parasite of *A. mellifera* (Elliud *et al.*, 2014). Nonetheless, the presence of the braconid (*Apanteles galleriae*) a parasitoid of the greater wax moth in Kenya, a candidate of biological control, offers good relief to beekeepers in the country. An American foul brood disease is present at low levels in Kenya (Elliud *et al.*, 2014). *A. mellifera* colonies infested with any parasite or disease should be destroyed, by burning. Import
of hive products or used beekeeping equipment or A. mellifera bees should be prohibited. This help in prevention of introduction of foreign diseases, and parasites to which native bees are not adapted to in the importing Country.

2.7.4 Effect of climate Change on bees

Bee species like any other organism have adapted well to certain ranges of climatic factors (Rainfall, temperature, relative humidity, sunshine, photoperiodism and wind). If these ranges change bee pollinators are affected, leading to their decrease in population or extinct. Among all factors, temperature and rainfall have a marked effect on bees (Kasper et al., 2008). At temperature below 13°C the flight activity will virtually cease. Between 13°C and 19°C, bee activities increase sharply. Above 19°C, activities tend to reach a relatively constant high level. With heavy rainfall, flight activity cease. Under rainy conditions bees fly between showers but only for very short distances, up to 150 m. Strong wind tends to reduce the ground speed of bees and hence reduce the number of flights per day (Doug, 2002). Indirectly, climatic factors also affect bees by either lowering or increasing their food resources (Bernice et al., 2012).

Climate change has threatened pollination timing, globally. Production of flowers comes earlier and the abundance of some flowers change, and this lead to changed synchrony of production of flowers and emergence of pollinators (David-Inouye, 1998). Consequently, this results in reduced reproductive success for both groups and possible extinctions. Much of the world has an unstable climate, with large variations in rainfall. Floods are common in some areas and can wipe out ground nesting bees. Drought coupled with extreme bushfires due to lightening is
predicted to become more frequent and of greater severity, hence causing a lot of consequences on bees and their floral resources (Kremen, 2002). In Australia, many researchers suspect Carpenter (*Xylocopa aerates*) to have become extinct in Victoria due to bushfire (David-Inouye, 1998).

### 2.8 Assessment of abundance and diversity of bees

Different computer softwares are used to statistically analyze the diversity and abundance of bee pollinators. The type selected depends on the type of the data at hand and the choice of the researcher. For instance, Kasina *et al.*, (2007) used SPSS version 14 and Bio Diversity Pro statistical software, Chiawo *et al.*, (2011) used R software, Kingha *et al.*, (2012) and Chantal *et al.*, (2013) used Microsoft Excel 2007. Meanwhile, Masiga *et al.*, (2014) used Genstat Discovery Ed.4. In addition, descriptive and inferential statistics are used in most researches (Kasina *et al.*, 2007; Chiawo *et al.*, 2011; Kingha *et al.*, 2012; Chantal *et al.*, 2013; Masiga *et al.*, 2014).

Analysis of variance (ANOVA) is used to compare means of the different treatments (Kasina *et al.*, 2007; Chiawo *et al.*, 2011; Masiga *et al.*, 2014) at 95% level of confidence. This is expressed in the probability such that a value less than 0.05 are significant. Means are separated by use of standard error (SE) (Chiawo *et al.*, 2011) or standard deviation (SD) (Kasina *et al.*, 2007; Masiga *et al.*, 2014). Means and percentages of samples are compared using Tukey's honest-significance difference test (HSD test) (Chiawo *et al.*, 2011) or Student’s (*t*) test (Chantal *et al.*, 2013; Kingha *et al.*, 2012; Masiga *et al.*, 2014 or F-test (Masiga *et al.*, 2014).
Diversity is determined based on species richness, α Shannon’s diversity index, Renyi diversity (1961) and Evenness index (J) (Kasina et al., 2007; Chiawo et al., 2011; Masiga et al., 2014). Correlation coefficient (r), Pearson moment correlation (R²), Chi-Square (χ²) and simple linear regression are used for the study of the association between variables i.e. abundance and distance (Kasina et al., 2009; Chiawo et al., 2011; Kingha et al., 2012; Chantal et al., 2013)
CHAPTER THREE: MATERIALS AND METHODS

3.1 Study site

Field surveys were conducted on Julia cultivar of French beans on small farms in Kaitheri and Kangaika locations of Timau Division in Likipia County. The farms were selected in the agricultural habitats along transects running from the edge of Mt Kenya forest reserve towards the lower parts of the slopes of North Eastern parts of the region. Farms which were used in the year 2011 matched as far as possible with those of 2012, in terms of size, rainfall, temperature, altitude, soil characteristics, and agronomic and economic practices.

The region stretches across the equator between 0°15’S and 0° 45’N and 36° 11” and 37° 24’ E (Kiome and Muya, 1999). The area is located from 1500 m to 2600 m above sea level. The County cover an area of 9,723 km², bordering the western foot of Mount Kenya (5,199 m). In the south-west, Laikipia is bordered by the Aberdare mountain range and the Great Rift Valley escarpment to the west (Kiome and Muya, 1999). The area has varied relief features that range from low lands to the North dotted by sharply rising hills called inselbergs. The two major rivers Ewaso Ng’iro and Ewaso Narok originate from Mt. Kenya in the South and flow towards North. The average annual rainfall is 450 mm in the North-Western plateau but increases substantially up to 1300 mm on the slopes of Mount Kenya and the Aberdare Range (Kiome and Muya, 1999). Rainfall is bimodal in this area with peaks in October-November and April-June and distinct seasons with little precipitation in-between (Jaetzold and Schmidt, 1983).
The general pattern of soils in the area is chiefly determined by the kind of parent rock and the climate. The parent rocks are mostly phonolite with some basalt. There are three main kinds of soils in this area. One consists of deep, dark greyish dense compact clayey soils that crack extensively when dry and expand when wet (Jaetzold and Schmidt, 1983). These soils are moderately well drained and are medium to high in natural fertility. The other type of soil is deep, dark brown to reddish brown, clay loamy. These soils are medium to high in natural fertility and take in water at moderate to slow rates. Other soils on the volcanic plateaus and uplands are shallow loamy and gravelly soils (Kiome and Muya, 1999).

The vegetation is characteristic of African savannas, predominantly grassy savanna bush land, with patches of woodland and open grassland. Dominant trees include species in the genera Acacia (*Mimosaceae*), Euphorbia (*Euphorbiaceae*), Balanites (*Balanitaceae*), and Boscia (*Capparaceae*) (Kiome and Muya, 1999).

The high and medium potential agricultural land form 20.5% of the total County land area while the rest 79.5% is low potential. The prevailing pattern of small scale agriculture in Laikipia and the larger Mt. Kenya region is a mixed system of crop and livestock production mainly for subsistence. In the high potential, land use is characterized by intensive cultivation on settled, small-scale plots which provide varying densities of domestic livestock. The main crops grown are maize, beans and potatoes; minor crops are sorghum, peas and millet among others. Nearly all farmers grow maize intercropped with beans and to a lesser degree with peas or potatoes.
Along the rivers, irrigation for vegetables and horticultural crops like tomatoes, cabbages, green pepper or French beans are grown for local as well as urban markets. Many farmers have set aside small portions of their land for fruit trees and fodder crops to supplement subsistence and household family income. Livestock productions consist of cattle, sheep, goats and poultry. Some agro-forestry is practiced and trees are grown for shade, fuel wood and general purposes. Large scale farms in the semi-humid regions of the Eastern and North-Eastern mainly grow cash crops like wheat, barley, oat, and silage crops. The semi-arid lowlands of the central and North Western part of Laikipia are mainly used for cattle ranching. The figure 3.1 below shows

Figure 3.1: Map of Laikipia County showing the study area (Kaitheri and Kangaika)
Source: Britannica Encyclopedia, 2011
3.2 The survey design for assessing diversity and abundance of bees visiting flowers of French beans along forest-farmland gradient

The study design was based on a protocol developed and agreed upon by global partners for testing pollination deficit in crops (Vaissière et al., 2011) (Figure 3.2 and 3.3). Ten small scale farms with French beans, Var. Julie, were selected randomly from 50 farms already selected by Global positioning system (GPS). The ten farms were along a transect of 3 km, running from the edge of the forest towards the lower parts of the North-Eastern parts of the region.

Five farms were at 0.2 km or less and five farms at 1 km, or more from the edge of the forest. The farms which were near the forest were in Kaiteri location and those which were far from the forest were in Kangaika location. On each farm sampling was done on two plots, each measuring 20 m x 19 m, once a week, between 08:00 h to 10:00 h and 11:00 h to 14:00 h. Each farm was sampled three times at an interval of one week. The farms were managed in a similar manner throughout the study i.e. in terms of inputs (Seeds and agrochemicals), weed and pest control methods, planting and harvesting practices. The crop was grown from May to August. Flowering started one month after planting and extended for 5 to 6 weeks. The pods were ready for picking two months after planting and the picking continued for a month. Sampling was done under good weather conditions to ensure presence of bees i.e. temperatures were more than 15°C, low winds, no rain, no clouds and dew and when 10% of the plants had bloomed (Westphal et al., 2008). Shown below is the layout of the sampling design.
Farms near the forest (Kaitheri)                   Farms far from the forest (Kangaika)

3 km transect

One farm showing French bean units, each measuring 20m x 19m

3.2.1 Assessing diversity of bees visiting flowers of French beans along forest-farmland gradient at North Eastern slopes of Mt Kenya Forest

Sampling started one month after germination and extended for 5 to 6 weeks. The site was selected randomly on two units each measuring 20 m x 19 m (760m²) every time of sampling on each farm. Six rows measuring 25 m x 2 m were demarcated. Bees visiting flowers of French beans were target netted by a sweep net for 30 minutes. Bee specimens were killed in ethyl acetate. The first identification
was done in the field using identification key guide and hand lenses. Identified bees were cleaned, pinned and labeled. The labels indicated the date of collection, location, plant species, bee species and the name of the collector. Unidentified specimens were stored in 70% ethanol and the containers labeled. The labels indicated the date of collection, location, host plant species and the name of the collector. The second identification was done in the office of the step manager at Nanyuki. Hand lenses, microscope, photographs and identification key guide were used. Then identified and unidentified bees were taken to NMK.

3.2.2 Assessing abundance of bees visiting flowers of French beans along forest-farmland gradient at North Eastern slopes of Mt Kenya Forest

Counting bees inside the flowers and newly opened flowers was carried out using two tallying counters a long six rows each measuring 25 mx2 m, on two units (760 m²) of each farm. Sampling was not done on consecutive rows to avoid counting one bee more than once. One tallying counter was used to count flowers and the other, bees inside those flowers, for 30 minutes. Each farm was sampled 3 times at an interval of a week. Numbers of bees per species per row were recorded on a data sheet.

3.2.3 Investigating the effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along forest – farmland gradient at North Eastern slopes of Mt Kenya Forest

Recording of agronomic and economic activities carried out on each plot (760 m²) started from the time land was prepared up to the end of marketing of pods. That
was from the month of April up to August. The amounts and costs of fertilizers, seeds, pesticides and labour which were used per day on each plot (760 m²) per farm were recorded. French beans were planted in May and harvesting started at the begging of July. Harvesting was done 7 to 12 times on each farm during the cropping season. Harvested pods were sorted out into two grades. The first grade, were pods which were straight and measuring between 24cm – 27cm in length, tender and of the medium thickness. The rejects or second grade were pods which were attacked by pests, diseases or too mature, small, hard, curved, rotten or soiled. High quality and rejects were weighed in kilograms (kgs) separately and recorded. Rejects were sold in the local market while high quality pods were delivered to the collection center of Frigoken Company for export. This information on input and output was used to calculate, yield, production costs and net revenue per plot.

3.2.4 Determining the effect of time of the day on the trend of the three most common bee species visiting flowers of French beans along a forest- farm gradient at North Eastern slopes of Mt Kenya Forest

Six small scale farms with French beans, Var. Julie were selected along the above mentioned transect, in the year 2012. Two farms were at 0.2 km, the next two farms were at 0.8 km, and the last two farms were at 1 km from the edge of the forest. Sampling of the three most common species of bees was done for three days per farm in a quadrant measuring 2 m². Direct observation of bee visitors in flowers of French beans started from 06.00 h and ended at 18.00 h. Recording of bees was done at an interval of one hour. Unknown bees were netted after leaving quadrant area, for proper identification. The site of sampling in each plot was randomly selected each day. Flower visitors were watched from a short distance to avoid disturbing them.
Dull or dark colored clothing was worn and unnecessary movement was avoided. The scientific name of bee species and numbers of visitations per species seen per hour on a quadrant were recorded on a data sheet. Shown below is the layout of the sampling design.

**Farms near the forest**

![Diagram of farms near the forest](image)

One farm showing a quadrant measuring 2 m x 2m

Figure 3.3: A design for assessing effect of time on foraging activities of *A. mellifera, Xylocopa* spp and *Megachile* spp

### 3.3 Data analysis

The data on diversity was analyzed by using Shannon-Wiener diversity indices (H-values). H value of was calculated using a given below formula:

\[
S \\
H' = - \sum P_i \ln P_i
\]

Where \( P_i \) is the proportion of species \( i \) and \( \ln \) is the natural logarithm of the proportion with \( i = 1, 2 \ldots S \) is the total number of species present. Diversity and abundance data of bees from 0.2 km and 1 km farms were compared using one-way analysis of variance (ANOVA), student’s (t) test, F test and standard error (SE). Diversity and abundance data were subjected to logarithmic transformation whenever
they were found to be skewed. The data on association between the yield and distance, yield and diversity, yield and abundance, yield and the three most common bee species of French beans was analyzed by using correlation coefficient (r) and Pearson moment correlation (R²). The data on the trend in the visitation rate of the three most common bee species on French beans was analyzed using regression analysis.
CHAPTER FOUR: RESULTS

4.1 Taxonomic composition and diversity of bees visiting flowers of French beans along forest – farmland gradient

A total number of five families, nine genera and twelve species of bees were sampled on flowers of French beans during the years 2011 and 2012. Four families, four genera and seven species of bees were sampled in the year 2011 while five families, nine genera and twelve species were sampled in the year 2012 (Table 4.1).

In the year 2011 at 0.2 km farms, four families; Apidae, Mellitidae, Megachilidae and Halictidae were present while at 1 km farms, three families; Apidae, Mellitidae, Megachilidae were present. Genera Apis, Xylocopa, Megachile and Halictus were present at 0.2 km and genera Apis, Xylocopa, and Megachile were at 1 km farms in the year 2011. Species *Apis mellifera*, *Xylocopa caren*, *Xylocopa flavorufa*, *Xylocopa incostans*, *Megachile rufipes* and *Halictus* spp and *Megachile bituberculat* were present at 0.2 km farms while species, *Apis mellifera*, *Xylocopa caren*, *Xylocopa flavorufa*, *Xylocopa incostans*, *Megachile rufipes* and *Megachile bituberculat* were present at 1 km in the year 2011 (Table 4.1).

Five families; Apidae, Mellitidae, Megachilidae, Collitidae and Halictidae were present at 0.2 km farms while four families; Apidae, Mellitidae, Megachilidae and Halictidae were present at 1 km farms in the year 2012. Genera, Apis, Xylocopa, Megachile, Halictus, Amegilla, Ceratina, Melliponula and Collete were present at 0.2 km and genera, Apis, Xylocopa, Megachile, Ceratina, Melliponula, Halictus and *Collete* spp were present at 1 km farms. In the year 2012, species, *Apis mellifera*,...
Xylocopa caren, Xylocopa flavorufa, Xylocopa incostans, Megachile rufipes, Megachile bituberculat, Halictus spp, Amegilla spp, Ceratina spp, Melliponula spp and Collete spp were present at 0.2 km farms while species, Apis mellifera, Xylocopa caren, Xylocopa flavorufa, Xylocopa incostans, Megachile rufipes, Megachile bituberculat, Amegilla spp and Lasioglossum spp were present at 1 km farms (Table 4.1)

Table 4.1: Family, genera and species of bees sampled and identified on farms located at different distance from the edge of the forest in the years 2011 and 2012.

<table>
<thead>
<tr>
<th>Bee Families</th>
<th>Bee species</th>
<th>0.2km</th>
<th>1km</th>
<th>0.2km</th>
<th>1km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apidae</td>
<td>Apis mellifera</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Melliponula spp</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Amegilla spp</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Melitidae</td>
<td>Xylocopa caren</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Xylocopa incostans</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Xylocopa flavorufa</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Ceratina spp</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Megachilidae</td>
<td>Megachile bituberculat</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Megachile Rufipes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Collitidae</td>
<td>Collete spp</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Halictidae</td>
<td>Halictus spp</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Lasioglossum spp</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ implies present
X implies absent

4.1.1 Bee species richness

A plot of the number of bee species against pooled bee samples gave a gentle slope (not asymptote curve) in the year 2011. This indicates that the number of bee
species was still increasing as the curve did not reach a plateau to indicate saturation (Figure 4.1)

![Species Richness](image1.jpg)

Figure 4.1: Species richness curve of bees collected on flowers of French beans in the year 2011

In the year 2012, a plot of the number of bee species against pooled bee samples gave a gentle slope at first and thereafter ended with a fully horizontal line (Asymptote curve). This indicates that the number of bee species had stopped increasing as the curve reached a plateau to indicate saturation (Figure 4.2).

![Species Richness](image2.jpg)

Figure 4.2: Species richness curve for bees collected on flowers of French beans in the year 2012
4.1.2 Diversity of bee communities on farms at 0.2 km and 1 km from the edge of the forest

According to Shannon diversity index, in the year 2011, farms near the forest had an H value of 0.948 compared to the farms which were 1 km away from the edge of the forest, which had an H value of 0.898. However, the differences in H values of near and far farms from the edge of the forest above were not statistically significant (t = 6.731, df = 23, P = 0.0604) (Table 4.3). In the year 2012, farms near the forest had an H value of 0.861 compared to the farms which were 1 km away from the edge of the forest, which had an H value of 0.776. However, the differences in H values of near and far farms from the edge of the forest above were not statistically significant (t = 5.97, df = 16, P = 0.106) (Table 4.2). The overall total diversity index of all near farms was 0.942 compared to overall total diversity index of all far farms from the edge of the forest, which was 0.921. The differences in H values of overall total diversity of near and far farms from the edge of the forest above were not statistically significant (t = 3.86, df = 9, P = 0.161). This implies that there were no significant differences in the total diversity of bees between the near and the farms far away from the edge of the forest (Table 4.2). The total diversity index of H value of 0.822 for the year 2011 was significantly lower than H value of 0.911 of the year 2012. This implies that in the year 2011 farms had a significantly lower diversity of bees compared to those of the year 2012 (t = 6.329, df = 2, P = 0.017) (Table 4.2).
Table 4.2: Shannon diversity index for farms at 0.2 km and 1 km from the edge of the forest

<table>
<thead>
<tr>
<th>Year</th>
<th>Distance</th>
<th>2011</th>
<th>2012</th>
<th>Overall for farms at 0.2 and 1km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2 km (Near)</td>
<td>H= 0.948</td>
<td>H= 0.861</td>
<td>H= 0.942</td>
</tr>
<tr>
<td></td>
<td>1 km (Far)</td>
<td>H= 0.898</td>
<td>H= 0.776</td>
<td>H= 0.921</td>
</tr>
<tr>
<td></td>
<td>Overall for each year</td>
<td>H= 0.822</td>
<td>H= 0.911</td>
<td></td>
</tr>
</tbody>
</table>

H stands for Shannon diversity index.

4.2 The abundance of bees visiting flowers of French beans along forest – farmland gradient

The mean number of bee species at 0.2 km and 1km farms in the year 2011 and 2012 were compared and findings were as follows;

4.2.1 Mean number of bees sampled in farms at 0.2 km and 1 km from the edge of the forest

Mean number of bees sampled in farms at 0.2 km and 1km in the year 2011 were not significantly different \((t = 0.17, \ df = 10, \ P = 0.865)\). Similarly, in the year 2012, mean number of bees in farms at 0.2 km and 1 km were also not significantly different \((t = 0.16, \ df = 12, \ P = 0.877)\). The overall mean number of bees of farms at 0.2 km did not differ significantly from overall mean number of bees of farms at 1 km \((t = 0.16, \ df = 29, P=0.821)\) (Table 4.3).
Table 4.3: Mean number ± SE of bees sampled in farms located at 0.2km and 1km from the edge of the forest

<table>
<thead>
<tr>
<th>Distance</th>
<th>Year</th>
<th>Bee mean number</th>
<th>Bee overall mean number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2 km</td>
<td></td>
<td>194 ± 18.3 aA</td>
<td>179 ± 1.48 a</td>
</tr>
<tr>
<td>1.0 km</td>
<td></td>
<td>243 ± 2.13 aA</td>
<td>189 ± 16.1a</td>
</tr>
<tr>
<td>T-value</td>
<td></td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>P-value</td>
<td></td>
<td>0.865</td>
<td>0.821</td>
</tr>
<tr>
<td>df</td>
<td></td>
<td>10</td>
<td>29</td>
</tr>
</tbody>
</table>

Means donated by the same lower case letters in the same column are not significantly different at P= 0.05. Means donated by the upper-case letters in the same row are not significantly different at P= 0.05

4.2.2 Mean number of bee species sampled on farms at 0.2 km and 1 km from the edge of the forest

*Apis mellifera* had significantly the highest mean number in the study followed by *X. caren, M. bituberculat* and *X. incostans* in that order. The mean number of *A. mellifera* was significantly more abundant on farms which were at 0.2 km compared to those at 1 km in the year 2012. Distance did not significantly affect the mean number of *A. mellifera, X. Caren, X. flavorufa* (in the year 2011), *X. Caren, M. rufipes, Lasioglossum* spp and *Amegilla* spp (in the year 2012). The mean number of *X. incostans, M. bituberculat, M. rufipes* (2011), *X. flavorufa*, and *M. bituberculat* (2012) increased from the forest towards the farmland. The mean number of *X. incostans, Halictus* spp, *Ceratina* spp, *Melliponula* spp and *Collete* spp (2012) decreased from the forest towards the farmland (Table 4.4)
The mean number of *Melipoluna* spp, *Amegilla* spp, *X. calens*, *X. incostans*, *X. flavorufa*, *Ceratina* spp, *M. rufipes*, *M. bituberculat*, *Collete* spp, *Halictus* spp and *Lasioglosum* spp were significantly very low compared to those of *A. mellifera* species. This was portrayed by the few number of these bee species sampled at each site, and sometimes no bee was recorded during the sampling. However, quite high number of *A. mellifera* species was sampled at each site (Table 4.4)
Table 4.4: Mean number± SE of each bee species sampled in farms located at 0.2 km and 1 km from the edge of the forest

<table>
<thead>
<tr>
<th>Bee species</th>
<th>Distance</th>
<th>Distance</th>
<th>Year</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2 km</td>
<td>1 km</td>
<td>0.2 km</td>
<td>1 km</td>
</tr>
<tr>
<td><em>Apis mellifera</em></td>
<td>257.8 ± 4.94aA</td>
<td>262.0 ± 6.52aA</td>
<td>336.2 ± 1.83aA</td>
<td>208.4 ± 4.74aB</td>
</tr>
<tr>
<td><em>Xylocopa caren</em></td>
<td>8.00 ± 3.24bA</td>
<td>8.00 ± 4.11bA</td>
<td>21.60 ± 6.85bA</td>
<td>22.20 ± 6.18bA</td>
</tr>
<tr>
<td><em>Xylocopa incostans</em></td>
<td>1.60 ± 0.75bA</td>
<td>5.60 ± 2.06bB</td>
<td>16.60 ± 6.75bA</td>
<td>10.60 ± 3.83cB</td>
</tr>
<tr>
<td><em>Xylocopa flavorufa</em></td>
<td>1.20 ± 0.97bA</td>
<td>1.80 ± 1.20bA</td>
<td>2.60 ± 1.69cA</td>
<td>6.80 ± 2.20cB</td>
</tr>
<tr>
<td><em>Megachile bituberculat</em></td>
<td>1.60 ± 0.40bA</td>
<td>7.40 ± 2.77bB</td>
<td>6.00 ± 2.28 cA</td>
<td>18.60 ± 4.74bB</td>
</tr>
<tr>
<td><em>Megachile rufipes</em></td>
<td>1.00 ± 0.63bA</td>
<td>4.60 ± 1.72bB</td>
<td>0.20 ± 0.20cA</td>
<td>0.60 ± 0.60cA</td>
</tr>
<tr>
<td><em>Halicuts</em> spp</td>
<td>-</td>
<td>-</td>
<td>2.00 ± 0.84cA</td>
<td>-</td>
</tr>
<tr>
<td><em>Collete</em> spp</td>
<td>-</td>
<td>-</td>
<td>12.00 ± 3.70cA</td>
<td>-</td>
</tr>
<tr>
<td><em>Lasioglosum</em> spp</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.40 ± 0.25cA</td>
</tr>
<tr>
<td><em>Amegilla</em> spp</td>
<td>-</td>
<td>-</td>
<td>1.00 ±0.42cA</td>
<td>0.60 ± 0.60cA</td>
</tr>
<tr>
<td><em>Ceratina</em> spp</td>
<td>-</td>
<td>-</td>
<td>2.80 ± 1.35cA</td>
<td>-</td>
</tr>
<tr>
<td><em>Melliponula</em> spp</td>
<td>-</td>
<td>-</td>
<td>2.00 ± 0.84cA</td>
<td>-</td>
</tr>
<tr>
<td>F –value</td>
<td>26.83</td>
<td>13.65</td>
<td>34.57</td>
<td>12.89</td>
</tr>
<tr>
<td>P – value</td>
<td>0.00118</td>
<td>0.0125</td>
<td>0.267</td>
<td>0.0034</td>
</tr>
<tr>
<td>df</td>
<td>48</td>
<td>39</td>
<td>171</td>
<td>16</td>
</tr>
</tbody>
</table>

Mean donated by the same lower case letters in the same column are not significantly different at P= 0.05. Mean donated by the same Upper case letters in the same row are not significantly different at P= 0.05.
4.2.3 Mean number of three most common bee species sampled in farms at 0.2 km and 1 km from the edge of the forest

*Apis* spp had significantly the most abundant mean number followed by *Xylocopa* spp and *Megachile* spp respectively. This was reflected by the higher mean number of *Apis* spp sampled on farms at each sampling site in both years (Table 4.5).

Distance did not significantly affect the mean number of *Apis* spp (in the year 2011) and *Xylocopa* spp (in the year 2012). This implies that there were small differences in mean number of these species between farms at 0.2 km and 1 km from the edge of the forest. Mean number of *Megachile* spp in the year 2011 and 2012 increased significantly from the forest towards the farmland. Mean number of *Xylocopa* spp (in the year 2011) and *Apis* spp in the year 2012 decreased significantly from the forest towards the farmland (Table 4.5).

Table 4.5: Mean number ± S.E. of bees of three most common genera sampled at 0.2 km and 1 km

<table>
<thead>
<tr>
<th>Genus</th>
<th>Distance</th>
<th>Year</th>
<th>Distance</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2 km</td>
<td>1 km</td>
<td>0.2 km</td>
<td>1 km</td>
</tr>
<tr>
<td><em>Apis</em></td>
<td>257.8±4.94aA</td>
<td>262.0±6.52aA</td>
<td>336.2±1.83aA</td>
<td>208.4±4.74aB</td>
</tr>
<tr>
<td><em>Xylocopa</em></td>
<td>3.9±1.22bA</td>
<td>5.1±1.86bB</td>
<td>13.9±4.15bA</td>
<td>13.2±3.52bA</td>
</tr>
<tr>
<td><em>Megachile</em></td>
<td>1.3±0.51cA</td>
<td>6.0±2.24bB</td>
<td>3.10±1.24cA</td>
<td>9.6±2.67cB</td>
</tr>
<tr>
<td>F-value</td>
<td>117.0434</td>
<td>14.49137</td>
<td>28.51</td>
<td>8.049174</td>
</tr>
<tr>
<td>P-value</td>
<td>0.00000134</td>
<td>0.000799</td>
<td>0.00118</td>
<td>0.006607</td>
</tr>
<tr>
<td>df</td>
<td>21</td>
<td>7</td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

Means donated by the same lower case letters in the same column are not significantly different at P= 0.05. Means donated by the same Upper case letters in the same row are not significantly different at P= 0.05.
4.3 The effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest

Effect of distance on French beans and effect of diversity and abundance of bees on the yield of French beans were assessed and the results shown below;

4.3.1 Effect of distance from the edge of forest on the yield of French beans

The result showed that there were no significant differences in the total yield between farms at 0.2 km and 1 km from the edge of the forest, in the year 2011 (t = 0.87, df = 16, P = 0.408). In the year 2012, the result showed that, there were no significant differences in the total yield between farms at 0.2 km and 1 km from the edge of the forest (t = 0.08, df = 29, P = 0.940) (Table 4.6). The total yield for the 0.2 km farms in the year 2011 did not significantly differ from the total yield for 0.2 km farms in the year 2012. The total yield for the 1 km farms in the year 2011 did not significantly differ from the total yield for 1 km farms in the year 2012 (Table 4.6).

Table 4.6: The mean yields ± S.E. of French beans sampled in farms located at 0.2 km and 1 km from the edge of the forest

<table>
<thead>
<tr>
<th>Distance</th>
<th>Year</th>
<th>Mean yield in kgs</th>
<th>Mean yield in kgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 km</td>
<td>2011</td>
<td>481 ± 12.7aA</td>
<td>514.0 ± 7.36aA</td>
</tr>
<tr>
<td>1 km</td>
<td>2011</td>
<td>456.2 ± 3.99aA</td>
<td>475.6 ± 6.91aA</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td>0.87</td>
<td>0.08</td>
</tr>
<tr>
<td>P – value</td>
<td></td>
<td>0.408</td>
<td>0.940</td>
</tr>
<tr>
<td>Df</td>
<td></td>
<td>16</td>
<td>29</td>
</tr>
</tbody>
</table>

Means donated by the same lower case letters in the same column are not significantly different at P= 0.05. Means donated by the same Upper case letters in the same row are not significantly different at P= 0.05.
4.3.2 Effect of diversity and abundance of bees on the yield of French beans

To establish the relationship in the diversity, bee mean number and the yield of French beans in 2011 and 2012, a Pearson moment correlation was carried out on the two factors against the yield. The diversity was not significantly related to the yield ($r = 0.236, P = 764$). This implied that the diversity of the bee species could only account for 5.5% of the crop yield. Similarly, the mean number of bees visiting farms was not significantly affecting the crop yield ($r = -0.241, P = 0.759$). The presence of the bees in the farms did not significantly increase the yield of French beans in the farms as it counted for only 5.8% of the yield. However, the negative correlation value indicated that, farms which had recorded more bees visiting the French bean flowers recorded a slight reduction in the yields.

4.3.3 Effect of diversity and abundance of three most common bee species on the yield of French beans

The mean number of *Apis* spp, *Xylocopa* spp and *Megachile* spp in the year 2011 and 2012 were significantly correlated with the yield and results were as stated below. The negative correlation between the yield and mean number of *Apis* spp, and the yield and mean number of *Megachile* spp in both years shows that as the mean number of those two-bee species increased, the yield of French beans decreased. The positive correlation between the mean number of *Xylocopa* spp in both years indicates that as its mean number increased the yield also increased (Table 4.7)
Table 4.7: Correlation of 3 most occurring spp of bees and Yield of French beans

<table>
<thead>
<tr>
<th>Bee species</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Apis</em> spp</td>
<td>-0.20581</td>
<td>-0.22019</td>
</tr>
<tr>
<td><em>Megachile</em> spp</td>
<td>-0.24803</td>
<td>-0.112733</td>
</tr>
<tr>
<td><em>Xylocopa</em> spp</td>
<td>+0.430258347</td>
<td>+0.0540507</td>
</tr>
</tbody>
</table>

4.3.4 The effect of time of the day on the trends of the most common bee genera visiting flowers of French beans along a forest – farmland gradient at North Eastern slopes of Mt Kenya Forest

*Apis* spp started foraging at 8.20 h and their visitation rates increased slowly to reach the higher peak between 10.00 h and 11.00 h. Their visitation rates decreased slowly and then increased and reached the lower peak between 14.00 h and 15.00 h. Thereafter, they decreased from 15.00 h and stopped at 17.00 h. This implies that bees of *Apis* spp did not forage before 8.20 h and after 17.00 h. The highest peak was between 10.00 h to 11.00 h. However, its lowest visitation rates were at 17.00 h (Figure 4.3)

When using regression analysis on the visitation rate of the *Apis* spp, the result showed a significant trend in the regression equation of the number of these bees visiting flowers of French beans (44.467 – 3.121 x time). This implies that as the time increased in the day, the number of *Apis* spp visiting flowers of French beans decreased.
Figure 4.3: The mean number of *Apis mellifera* visiting flowers of French beans at different times of the day

*Xylocopa* spp appeared at 8.20 h and their visitation rates increased up to 9.00 h. Then they dropped up to 10.00 h. Thereafter they increased slowly up to 12.00 h, where they neither increased nor decreased up to 13.00 h. Then they increased and reached the peak at 14.00 h. Their visitation rates then dropped sharply up to 15.00 h. Thereafter, they increased slightly and stopped at 16.00 h. This implies that bees of *Xylocopa* spp foraged from 8.20 h to 16.00 h. The peak visitation rates were at 14.00 h. Their lowest visitation rates were at 8.20 h (Figure 4.4).

When using regression analysis on the visitation rate of the *Xylocopa* spp, the result showed that there was no significant trend in the regression equation of the number of bees of *Xylocopa* spp visiting flowers of French beans (Number of *Xylocopa* spp = 5.867 + 0.0242 x time).
Figure 4.4: The mean number of *Xylocopa* spp visiting flowers of French beans at different times of the day

*Megachile* spp appeared at 08. 30 h and their visitation rates increased up to 9.00 h. Then they dropped sharply from 9.00 h and reached zero at 11.00 h. They reappeared at 12.00 h and visitation rates increased sharply and reached the peak at 13.20 h. Then their visitation rates decreased sharply and stopped foraging at 15.00 h. This implies that *Megachile* spp foraged from 8.30 h and stopped at 15.10 h. The peak visitation rates were at 13.00 h. Their lowest visitation rates were at 11.00 h where visitation rates dropped to zero (Figure 4.5)

When using regression analysis on the visitation rate of the *Megachile* spp, the result showed a significant trend in the regression equation of number of *Megachile* spp visiting flowers of French beans (Number of *Megachile* spp = 1.133 - 0.006 x time)
Figure 4.5: The mean number of *Megachile* spp visiting flowers of French beans at different time of the day.
CHAPTER FIVE: DISCUSSION, CONCLUSION, RECOMMENDATIONS

5.1 Discussion

5.1.1 Diversity of bees visiting flowers of French beans along a forest farmland gradient at North Eastern slopes of Mt Kenya Forest

Taxonomic composition of bees showed that five families, nine genera and twelve species of bees visited flowers of French beans during the study period of two years (2011 to 2012). They were as follows: Family Apidae was represented by *A. mellifera*, *Melipoluna* spp and *Amegilla* spp, family Melitidae was represented by *X. calens*, *X. incostans*, *X. flavorufa* and *Ceratina* spp, family Megachilidae was represented by *M. rufipes* and *M. bituberculata*, family Colletidae was represented by *Collete* spp and family Halictidae was represented by *Halictus* spp and *Lasioglossum* spp.

This finding agrees with the study by Masiga et al. (2014) on French beans at the North-Eastern slopes of Mt Kenya which recorded bees in five families, five genera and eight species on flowers of French beans. They were Apidae (*A. mellifera*), Melitidae (*X. calens*, *X. flavorufa* and *Ceratina* spp), Megachilidae (*M. rufipes* and *M. bituberculata*) Colletidae (*Colletes* spp) and Halictidae (*Halictus* spp). The finding also concurs with the study by Kasina et al. (2007) on common beans in Western Kenya which identified five families, eight genera and twenty species of bees on flowers of common beans (*P. vulgaris*). The authors reported, family Apidae (*A. mellifera*, *Melipoluna* spp and *Amegilla* spp); family Melitidae (*X. calens*, *X. incostans*, *X. flavorufa*, *X. nigrata* and *Ceratina* spp; family Megachilidae (*M. rufipes* and *M. bituberculata*); family Collitidae (*Collete* spp); family Halictidae (*Halictus* spp and *Lasioglossum* spp).
There was a decrease in the number of bee species in the studies which were conducted around Mt Kenya compared to those which were recorded in Western Kenya and Cameroon. For instance, the study by Masiga et al. (2014) on slopes of Mt Kenya on French beans recorded eight species while that by Kasina et al. (2007) in Western Kenya identified twenty species of bees on flowers of common beans. However, the study by Gikungu et al. (2006) in Western Kenya recorded seventeen bee species visiting non-crop Fabaceae plants, which are closely related to *P. vulgaris*. Similarly, Kingha et al. (2012) and Chantal et al. (2013) in Cameroon each recorded seventeen species of bees on flowers of *P. vulgaris* crops. Probably, land intensification and fragmentation around Mt Kenya affects bees negatively and have reduced the number of species especially solitary bees. This is in line with the study by Roubik et al. (2000) which reported that diversity of bee pollinators visiting flowers of a crop vary with the cultivar, geographical location and season.

The bee species sampled in the year 2011 did not adequately represent the number of bee species visiting flowers of French beans on the farmland, as the species richness curve did not reach a plateau to indicate saturation. This implies that more bee species could have been recorded if the sampling time was extended. However, in the year 2012, the asymptote curve which was obtained implies that bee species which were sampled on flowers of French beans adequately represented the number of bee species that visit flowers of French beans in the farmland, because the species richness curve reached the plateau to indicate saturation. There is a possibility that the number of bee species would have been even higher if other crops and weeds had been considered during the study. This concurs with the findings of the study by Kasina et al. (2007), Masiga et al. (2014) and Chiawo et al. (2011) in Kenya who
reported that when asymptote curve is obtained it’s an indication that the sample collected adequately represents the number of bee species that visit flowers of that plant in that area. The difference shown between the 2011 and 2012 in species accumulation curves is based on the species recorded per observation period. The difference in years could probably be due to several reasons; plenty of resources in 2011 for bees to choose from, presence of a better floral patch in 2011 compared with French beans or just biological dynamics across the years.

There was no significant difference in the diversity of bees on farms which were located at near and far from the edge of the forest in both years. This was attributed to presence of wide range of flowering crops and shrub lands a cross the farmland. If these shrubs were well managed the farmlands would support high diversity of bees (Masiga et al., 2014). This conforms to the findings by Masiga et al. (2014), Chiawo et al. (2011), Klein et al. (2007) and Banaszak (1992) who reported that there was no significant change in bee diversity on farms located at varying distances from the edge of the forest. It also agrees with the findings of a similar research done at Las Cruces forest in Southern Costa Rica in which the overall diversity of bees in farmlands did not vary significantly with distance from the forest (Brosi et al., 2007). Those studies attributed their findings to heterogeneity and abundance of floral resources in all habitats which were located at varying distance from the forest.
5.1.2 Abundance of bees visiting flowers of French beans along a forest farmland gradient at North Eastern slopes of Mt Kenya Forest

Increasing distance from the edge of the forest towards the farmland had no significant effect on the mean number of bees in both years. This was due to the practice of bee friendly activities across the farmland. For instance, apiculture increased the mean number of *A. mellifera* in both habitats. Diverse flowering crops and wild flowers on hedgerows were found on all farms. If hedgerows in these habitats were well managed, they would support more abundance of bees (Masiga *et al.* 2014). This agrees with the findings of the study by Masiga *et al.* (2014) on French beans which reported that the interaction between year of observation and distance from the forest edge was not significant for all bees, with or without *A. mellifera*, nor for any group of bees. This also conforms to the findings by Klein *et al.* (2007) and Banaszak (1992) who reported that there was no change in bee abundance on farms which were located at varying distances from the edge of the forest. These authors still attributed their findings to heterogeneity and abundance of floral resources in all habitats which were located at varying distance from the forest.

5.1.2.1 Effect of distance on abundance of individual bee species sampled on farms at 0.2 km and 1 km from the edge of the forest

This study found that the mean number of some bee species did not change significantly as distance increased from the forest towards the farmland. This was due to the presence of their nesting sites and host plants across the farmland. This suggestion concurs with the study by Kremen *et al.* (2002) on watermelons in California, which found that non-crop habitats across the farmland enhanced the
abundance of solitary and social bees as they provided diverse floral resources and nesting sites for wild bees (Horner, et al., 2003; Baszanak, 1992).

The tendency of mean number of some bee species decreasing from the forest edge towards the farmland was due to the fact that the forest acted as the main habitat. The forest provides the bees with good sites for bee nests, resting, hiding and mating as well as foraging. Bees forage in the farmland and return to the forest to rest. This is in line with the studies by Kasina et al. (2007) and Klein et al. (2003b) who attributed the decreasing of some bee populations from the edge of the forest towards the farmland to the presence of the forest. The authors explained that the forest is the main habitat of bees therefore acts as a reservoir of bees.

Mean number of some bee species increased from the edge of the forest towards the farmland. The sunny and open conditions and presence of host plants on far farms from the edge of the forest may have attracted these bees. This correlates to the study by Kremen et al. (2002) and Baszanak (1992) who reported that open and sunny conditions enhance the dispersion of bees in agriecosystem. On addition, Baszanak (1992) reported that distribution of host plants determines dispersion of bees especially solitary bees on the farmland. For instance, the distribution of bees of *Xylocopa* spp is determined by presence of some plants belonging to asteraceae, bignoniaceae, caesalpiniaceae, fabaceae, lamiaceae, meliaceae and verbenaceae families (Schlindwein, 1998).
The higher mean number of *A. mellifera* than those of other bee species at all sampling sites was attributed to practice of apiculture in the study area. Bee keeping was widely practiced across the farmland and in the forest, with *A. mellifera* being the bee species kept. This concurs with the study at the Coast region of Kenya by Chiawo et al. (2011) and the study by Masiga et al. (2014) who reported that *A. mellifera* was abundant across the habitat. These authors explained that *A. mellifera* bees are long distance foragers with advanced foraging behavior, making them explore diverse nectariferous flowers across different habitats. This finding is in line with the study in Western Kenya by Kasina et al. (2009c) who reported that *A. mellifera* was the most abundant species on flowers of common beans. Similarly, *A. mellifera adansonii* was shown to be the most abundant floral visitor of *P. coccineus* in Yaoundé, Cameroon (Pando et al., 2011a) and *P. vulgaris* in Ngaoundéré, Cameroon (Chantal et al., 2013). However, Kasina et al. (2007) argued that *A. mellifera* does not pollinate *P. vulgaris* better than other species of bees for they only pierce the lower part of the flower and get the floral resources without touching the stigma or anther heads. French bean flowers also do not provide many resources and so they are not very attractive to *A. mellifera* and their foraging on bean flowers may be reduced whenever a patch of more attractive floral resource is available at the same time that French beans flower (Masiga et al., 2014).

The mean number of *collet* spp, *M. rufipes*, *Halictus* spp, *Lasioglosum* spp, *Amegilla* spp, *Ceratina* spp, and *Melliponula* spp were quite low. This was confirmed by the low mean number of bees of these species sampled at each site. This agrees with the study by Gikungu (2006) in Western Kenya who attributed low abundance of solitary bees to agricultural matrix of not providing the bees with the temporal and
spatial needs required. This includes diversity of flora throughout the year and minimal disturbance to accommodate bee sites for nesting, mating, hiding or just resting.

The low mean number of small bee species such as *Ceratine* spp, *Halictus* spp, *Meliponula* spp, *collete* spp, *Lasioglosum* spp and *Amegilla* spp may be also attributed to their lack of strength to crush and open the complicated structure of the flowers of French beans and access floral resources. This concurs with the studies by Gikungu (2006) and Kasina *et al.* (2007) in Western Kenya who reported that small bees had low abundance because they lack enough strength to buzz the complicated structures of flowers of *P. vulgaris*. The authors also explained that only few small bees follow large bees to scavenge on their left-over floral resources.

### 5.1.2.2 Abundance of the most common species of bees along forest- farm gradient in the year 2011 and 2012

The non-significant difference in mean number of *Apis* spp sampled near and far from the forest in the year 2011 was attributed to the presence of their nests (Apiculture) across the farmland. However, the significant decrease in mean numbers of *Apis* spp in the year 2012, as distance increased from the forest towards the farmland was attributed to presence of more nests (Apiculture) on near farms to the forest compared to far farms. This finding concurs with the study in Western Kenya by Kasina *et al.* (2007) which attributed more *A. mellifera* in the north than in the south to increased number of hives in the north.
Low mean number of *Apis* spp sampled on far farms from the forest compared to near farms could also be due to their foraging behavior. Probably most of these bees were foraging on high quality forage on farms which were near to the forest compared to farms which were far, as *Apis* spp bees forage only on flower patches that provide maximum net gain (Corbet and Osborne, 2002). This concurs with the findings of the studies by Potts *et al.* (2003) at Mt. Carmel and Chiawo *et al.* (2011) at Kenya Coast who reported that the dominance of *Apis* spp was due to its members being long distance foragers and extensively foraging for high quality and quantity nectar and pollen across the habitats.

In the year 2011, mean number of *Xylocopa* spp increased from the forest towards the farmland. However, in the year 2012, the mean number of *Xylocopa* spp did not significantly decrease as distance increased from the edge of the forest towards the farmland. The distribution of their preferred host plants determined their dispersion on the farmland as they were seen foraging on their preferred annual, biennial and perennial flowering plants, despite the distance from the edge of the forest. Once in awhile they would spill over to French beans. This agrees with the findings of the studies by Chiawo *et al.* (2011), Kremens *et al.* (2002) and Klein *et al.* (2002) who reported high abundance of bees of *Xylocopa* spp on plants such as *Cajanus cajan* *Crotalaria emarginata, Agathisanthemum bojeri, Rhynchosia velutina, Vernonia cinerea, Waltheria indica, Julbernardia magnistipulata, Hyptis suaveolens* and *Abutilonzanzi baricum*. Similarly, the study by Potts *et al.* (2003) also found that distribution of *Xylocopa* spp depended on plants rich in both pollen resources despite their location from Mt Carmel forest.
In the years 2011 and 2012, mean number of *Megachile* spp increased significantly from the forest towards the farmlands. This was attributed to the presence of open areas with favourable environmental variables such as temperature, light intensity, humidity and stable nesting grounds adjacent to French bean plots. Once in a while bees of *Megachile* spp would spill over to French beans. This agrees with the findings of the study by Klein *et al.* (2002) who reported that solitary bees build their nests outside the dense forest. This also concurs with study by Liow *et al.*, (2001) who reported that *Megachile* spp prefer less shaded and less humid agro-ecosystems that offer open areas. In this study, open, sunny stable habitat conditions with grass and shrubs next to far farms from the forest may have provided favourable nesting sites for *Megachile* spp.

The significantly higher mean number of *Apis* spp was compared to *Xylocopa* spp and *Megachile* spp was attributed to the fact that some farmers were practicing apiculture on the farmland and in the forest. The significantly *Xylocopa* spp had second highest mean number on the farmland. This concurs with the findings of the study by Kasina *et al.* (2007) and Kasina *et al.* (2009c) which reported that *Apis* spp was first and *Xylocopa* spp second most common bee species on dry beans. On the other hand *Xylocopa* spp has been reported to be the most abundant visitor to cultivars of *P. vulgaris* grown for dry seeds in Cameroon (Kingha *et al.*, 2012) and in Puerto Rico (Bliss, 1980). However, Kingha *et al.* (2012) argues that where other species of bees rather than *Xylocopa* spp are more abundant on *P. vulgaris*, it means that *Xylocopa* spp has low abundance. *Megachile* spp had significantly the third highest mean number compared to that of *Xylocopa* spp and *Apis* spp.
5.1.3 Effect of diversity and abundance of bees visiting flowers of French beans on the yield of French beans along a forest – farmland gradient

There was no significant difference in yield of French beans between farms near and far from the forest. Probably yield of French beans followed the trends of its bee pollinators, as diversity and mean number of bees in this study did not significantly differ between farms near and far from the forest. This disagrees with the findings of the study by Masiga et al. (2014) on North Eastern slopes of Mt Kenya, which reported that farms located more than 1km from the edge of the forest had significantly higher yield of French beans compared to farms which were closer to the forest. The difference between the two studies is attributed to the amount of data on the yield which was analyzed. In this study the total data of for both the year 2011 and 2012 was analyzed while in the study by Masiga et al. (2014) only the data on yield of the year 2011 was analyzed. Similarly, diversity and mean number of bees visiting farms in this study did not significantly affect French bean yield. This agrees with the findings of the study by Masiga et al. (2014) on French beans which reported that correlation analysis did not show a significant relationship between any bee groups and yield component, except for the mean number of Xylocopa spp and the yield.

In this study, correlation analysis did not show a significant relationship between the yield and mean number of Megachile spp or the yield and mean number of Apis spp. However, it showed a significant relationship between the yield and mean number of Xylocopa spp. This agrees with the study by Masiga et al. (2014) which reported that correlation analysis showed a significant relationship between the mean number of Xylocopa spp and the yield. It would be essential to conduct further studies to confirm whether the yield of French beans is positively affected by visitation by
Xylocopa spp bees. Other studies have already revealed that *P. vulgaris* e.g. common beans are pollinated by bees of *Xylocopa* spp, *Apis mellifera* and *Bombus* spp as explained below. The studies by Kingha *et al.* (2012) in Cameroon and Bliss (1980) in Puerto Rico reported that bees of *Xylocopa* spp visited and pollinated different cultivars of *P. vulgaris* grown for common seeds. On the contrary, Ibarra-Perez *et al.* (1999) in USA found that bees of *Bombus* spp (Apidae) were the most effective pollinators of *P. vulgaris* and their flower visits had a significant positive effect on seed production in two determinate varieties. In addition, Kasina *et al.* (2009c) found that cross-pollinated common beans by *A. mellifera* resulted in increased seed set and nutrition improvement of the dry harvested seeds. However, the exposure of bean plants to *A. mellifera* did not result in higher dry seeds in the UK and USA (Free, 1966; McGregor, 1976; Delaplane and Mayer, 2000).

5.1.4 Time of the day on the trends of the most common bee species visiting flowers of French beans along a forest – farmland

The results showed that bees of *Apis* spp, *Xylocopa* spp and *Megachile* spp did not forage between 17.00 h and 08.20 h, but foraged after 8.20 h and stopped before 17.00 h. This was probably due to variations in temperature, dew, light and amount of floral resources of French beans. This conforms to the study by Kevan (2002) which reported that variations in weather conditions during bloom of a crop affect abundance activities of insect pollinators. On addition, Chantal *et al.* (2013) in Cameroon reported that foraging activities of *Apis mellifera adansonii* on flowers of *P. vulgaris* were influenced by climatic conditions and availability of nectar.
Bees belonging to *Apis* spp foraged on flowers of French beans after 08.20 h and stopped before 17.00 h. This finding agrees with the study by Chantal *et al.* (2013) in Cameroon which reported that *A. m. adansonii* bees foraged on flowers of *P. vulgaris* throughout the day. The peak activity of bees of *Apis* spp was 10.30 h to 11.00 h which differs with the peak activity of *A. m. adansonii* which was between 7.00 h to 8.00 h in the study by Chantal *et al.* (2013) in Cameroon. Differences in peak periods of this study and that in Cameroon could be attributed to the regional variations of environmental conditions. Low temperatures around Mt Kenya probably made *Apis* spp bees reach the peak later compared to those in Cameroon. This is supported by Roubik, 2000 who reported that foraging activity and diversity of flowering insects of a plant species vary with region. On the contrary, the drop of visitation rates of bees of *Apis* spp between 11.30 h and 13.00 h was probably due to high temperatures. This agrees with the findings of the study by Chantal *et al.* (2013) which reported that *A. m. adansonii* decreased in activity from 11.00 to 13.00 h due to increased temperatures in the experimental fields. Similarly, the study by Kasper *et al.* (2008) also reported that bee foragers prefer warm or sunny days and high presence of floral resources.

In this study, bees of *Xylocopa* spp foraged on flowers of French beans after 08.20 h and stopped at 15.00 h, with the peak activity at 14.00 h. This concurs with the empirical study by Kingha *et al.* (2013) on flowers of *P. vulgaris* in Cameroon which reported that *Xylocopa olivacea* foraged on *P. vulgaris* flowers throughout the day, with a peak activity between 10.00 h and 13.00 h. The authors reported that activity of *X. olivacea* was influenced by climatic conditions as the correlation between the numbers of *X. olivacea* visitation rates and weather conditions
(Temperature and humidity) was positive and highly significant. In this study, the low visitation rates of bees of *Xlocopa* spp between 09.00 h to 11.00 h was attributed to high abundance of aggressive bees of *Apis* spp, as it was the time its visitation rates were at the highest peak. On the contrary, the decrease in visitation rates of bees of *Xylocopa* spp from 15.00 h was due to increase in visitation rates of bees of *Apis* spp and decreasing temperature. This agrees with the findings of the study by Kingha *et al.* (2013) which attributed the decrease in visitation rates of *X. olivacea* on flowers of *P. vulgaris* between 16.00 to 17.00 h to decreasing temperatures in the experimental fields.

Bees of *Megachile* spp foraged on flowers of French beans after 09.00 h and stopped at 16.00 h, with the peak activity at 13. 00 h. This is in line with the study by Kevan (2002) on flowers of *P. vulgaris* in Asia which attributed the peak activity of *Megachile* spp between 10.00 h to 14.00 h to increased temperatures in the study sites. The low visitation rates of bees of *Megachile* spp between 09.00 h and 11.00 h was attributed to high abundance of aggressive bees of *Apis* spp as it was its highest peak. On the contrary, the decrease in visitation rates of bees of *Megachile* spp from 13.00 h to 15.00 h was probably due to decreasing temperatures (Kevan, 2002).

### 5.2 Conclusion

Habitat heterogeneity is among important factors that influence diversity and abundance of bees on farmlands. Farmlands with high heterogeneity have the highest capacity to satisfy the diverse ecological requirements of bee pollinators. In this study the wide range of flowering crops and shrub lands which existed on both near and far farms from the edge of the forest made these habitats have almost equal diversity and
abundance of bees. However, these farmlands did not support high diversity and abundance of bees probably due to the high intensification of agriculture with no consideration for bees and natural habitats. Therefore, the proper management of these heterogeneous habitats in these farmlands is required for them to support high bee diversity and overall pollinator abundance.

The forest and farmlands are all important in the conservation of bees and complement each other in the conservation of the species. The bees reside in the forest and forage in the farmlands. Bees which fly short distance forage on flowering plants and crops near the forest while those which fly long distance forage on wild plants and crops near and far from the forest. If farmlands have undisturbed non-crop habitats some bees may nest in the farmlands and fail to return to the forest. There is need to manage and conserve bees in the farmlands as well as conserve the forest.

*A. mellifera* (Honey bees) was the most frequent visitor on flowers of French beans. However, pollination efficiency of *A. mellifera* on French beans is not clear. Many studies have reported that flowers of French beans do not provide many resources and so they are not very attractive to *A. mellifera* and their foraging on bean flowers may be reduced whenever a patch of more attractive floral resources is available at the same time that French beans flower. It is also reported that *A. mellifera* pierces the lower part of the complicated structure of the flowers of *P. vulgaris* and collects floral resources without touching the stigma and anther heads. Therefore, there is need to increase the diversity of pollinators in these farmlands but not to rely on *A. mellifera*. 
5.3 Recommendations

Results indicate that farmlands in the study area do not support high diversity and abundance of bees, especially solitary bees. Therefore, this study suggests that the adoption of bee-friendly agricultural practices in this area would be useful to conserve bee species and also increase their populations to enhance pollination for improved crop yields. Such practices and policies are discussed below;

1. There should be proper management of hedgerows (live fences) to form areas of floral and structural diversity to accommodate the temporal and spatial needs of different bees. The floral diversity in the hedgerows would ensure bee forage is available throughout the year especially during off-season periods. Floral diversity should be maintained in these structures, by having mixtures of annuals, biennials and perennial bee forage plants. Trimming should be done only after flowering and only occasionally to prevent dense structures, which are not attractive to bees.

2. The sole bee species whose visitation was positively correlated to yields and quality of French bean production in the Mt Kenya region was *Xylocopa* spp. It would be essential to conduct further studies to confirm or inform whether the green pod yield of French beans is positively affected by visitation by *Xylocopa* spp. If confirmed then the Methods that increase the population of these bees, such as habitat management and adoption of good agricultural practices should be promoted.
3. Some land on farms should be set aside and left undisturbed where underground nesting bees can construct nests. A closely related strategy is the use of trap nests for the cavity nesting solitary bees. Bees differ in their body sizes. As such, the trap nests should be made of different sizes. Use of local materials, e.g., bamboo reeds should be emphasized to reduce the costs. It is also possible to drill holes of varying sizes in a block of wood.

4. Another important strategy for the conservation of bees is the management of farmer cropping practices. Attention needs to be paid to tillage practices and time of irrigation. Minimum tillage favors ground-nesting bees, as it has minimum disturbance of soil. Soil scientists and agronomists should suggest minimum tillage in the area and advice farmers accordingly. Crop irrigation should be done the time bees are not foraging as noise from the sprinklers and wetness of the foliage of the crop chase away bees.

5. Misuse of pesticides in agriculture has played a key role in the decimation of bees and other pollinating insects. The effect of insecticides on bees is usually high when applied in the blooming period. If it is absolutely necessary, then farmers should time the application to coincide with the period when bees are not foraging. They should use those insecticides that have a low toxic effect on bees. Farmers should also read and follow the instructions written on the pesticide labels. If possible they should use selective pesticides which are effective enough to eliminate the harmful pests without causing damage to bees. On addition, the use of cultural, physical and mechanical methods within
an integrated pest management system may be the most appropriate strategy of controlling pests while conserving bees.

5.4 Suggestions for further research

(1) The experiments should be carried out on pollination biology of French beans to determine if bees of *Xylocopa* spp indeed pollinate them

(2) This study should be carried out in other parts of the Country for better comparisons.
REFERENCES


David-Inouye (1998). Climate change impacts on pollination ecology in mountain environments. Earth Watch Institute


Steffan-Dewenter, I. and Teja Tscharntke (2000). Resource overlap and possible competition between honey bees and wild bees in Central Europe


