AGRONOMIC ACTIVITIES AND SEASONAL VARIATIONS ON ABUNDANCE AND DIVERSITY OF BEE SPECIES AND THE STATE OF KNOWLEDGE OF POLLINATOR IMPORTANCE IN LOITOKITOK SUB-COUNTY, KENYA

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Agronomic activities and Seasonal Variations on Abundance and Diversity of bee Species and the state of knowledge of pollinator importance in Loitokitok Sub-County, Kenya

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A Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Master of Science in Zoology (Conservation Biology) of the Jomo Kenyatta University of Agriculture and Technology

2026

DECLARATION

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

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DEDICATION

I dedicate this work to my caring brothers, sisters and my beloved wife for their untiring support and encouragement in writing this thesis.

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ACRONYMS AND ABBREVIATIONS

FAO	Food and Agriculture Organisation
GPS	Geographical Positioning Satellite
IPCC	Intergovernmental Panel on Climate Change
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KNBS	Kenya National Bureau of Statistics
MEA	Millennium Ecosystem Assessment
NRC	National Research Council
UNEP	United Nations Environment Programme
USA	United States of America

ABSTRACT

Honey bees are prone to agronomic activities such as misuse of agrochemicals, land fragmentation, alteration of natural habitats and change in land use patterns. Understanding how bee species respond to habitat destruction is significant towards development of effective measures to ensure that the environment is protected and conserved. The study sought to assess the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and the state of knowledge of pollinator importance in Loitokitok sub-county, Kenya. Experimental research design comprising of three different habitats was conducted in order to establish effects of agronomic activities on bee abundance and diversity and state of knowledge of pollinator importance in Loitokitok Sub-County, Kenya. The study aimed at evaluating the effect of agronomic practices on the diversity and abundance of bee species, determining the impact of seasonal weather variations on abundance and diversity of bee species and assessing the state of knowledge of pollinator importance among small-holder farmers in Loitokitok sub county, Kenya. The study area was stratified into three habitats (1) cultivated farm, (2) rangeland (3) natural forest. A survey of the study area was done and the habitats identified. A sample area of 1 × 1 km square was picked at random from each of the three study areas. The selected areas were further sub-divided into 0.5 × 0.5 km smaller study areas and a total of 3 belts were laid down randomly within the small study areas. Sampling of the bees was done for 3 months using a sweep net and pan traps to collect the bee species. Shannon Weiner diversity index was used to compute diversity and richness of honey bee species. One way ANOVA was used to compute the statistical significance of bee species abundance across the three habitats. A total of 1,106 bee specimens from 2 families and 7 species were collected from the three study habitats. *Apis mellifera,* was the most abundant bee species followed by *Pseudapis spp.*, *Lasioglossum spp.*, *Xylocopa spp.*, *Braunsapis spp.*, *Ceratina spp.* while *Heriades spp.* was the least abundant bee species. Natural edge habitat had the highest bee species abundance followed by rangeland while cultivated habitat had the least bee species abundance. Cultivated habitat recorded highest diversity index, $H^{/}= 1.511$ followed by rangeland with $H^{/}= 1.424$ while the natural habitat had the least at $H^{/}= 1.351$. However, the overall diversity index was $H^{/}= 1.43$. There was a statistical significance ($p<0.05$) between cultivated habitat & rangeland, cultivated habitat & natural forest edge and also between rangeland & natural forest edge respectively. Seasonal weather changes influenced bee species abundance and diversity in the study area. The bee species abundance and diversity were greater during the rainy season as compared to the dry season. This study reveals that agronomic activities had an influence on bee species abundance and diversity. Farmers demonstrated substantial knowledge of bees, with about 90% identifying different species and recognizing nest sites and food resources. More than 86% had experience in honey harvesting, while most understood the importance of bee visits to crops and live fence flowers. Notably, 90.9% expressed willingness to promote bee populations on their farmlands. Therefore, the local community, farmers and other stakeholders should be sensitized on the importance of bee conservation and its contribution to their welfare and on utilization of cost-effective approaches towards bee management and conservation.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Bees are recognized as a critical component of ecosystems around the world, providing vital biological services such as reproduction in a variety of blooming plants (Kioko *et al.,* 2017). Furthermore, bees contribute to food security and human survival by pollinating nearly a third of plant-based food crops (Klein *et al.*, 2007). Various studies on bee population show that bee populations are rapidly deteriorating (Bartomeus *et al.,* 2013; Koh *et al.*, 2016). Agronomic destruction of bee habitats has been identified as a primary causal factor, despite the fact that these tendencies may not be linked to a specific cause (Goulson *et al.,* 2008; Potts *et al*., 2010).

The *Apis spp*., are the primary pollinators and hence appear to be effective in this important environmental role (Winfree, 2010).

Despite the fact that honeybees (*Apis mellifera*) pollinate a significant portion of Kenya's food crops, the African continent is home to over 4,000 species of natural bees (Gikungu *et al.,* 2018). These native species also play an important role in crop pollination (Kiatoko *et al*., 2018). Various studies have noted that decline in wild bee populations pose a serious threat to environmental services, which both biodiversity (Ollerton *et al.*, 2011) and humans largely rely on (Winfree *et al*., 2008; Winfree *et al.,* 2009).

Human have a significant detrimental impact on bee abundance and thus, the effect of disturbance on bees varies depending on disruption type, grazing activity, fire, farming and tree cutting, essentially having a beneficial impact on bee abundance (Nayak *et al.*, 2015). The recognized abundance and diversity, together with local ecological knowledge can enhance the conservation of local bee populations and provide guidance for restoring pollination services in landscapes where they are deficient, thereby mitigating the decline of certain habitat plant species (Karanja, 2013).

Logging was found to be a common example of a human activity that had been proven to be negatively connected with bee abundance, according to Winfree *et al.,* (2009). Notably, logging was also found to be a common form of anthropogenic disturbance in the northeastern United States, with logging accounting for around 78 percent of early-successional habitats in the region (King and Schlossberg, 2012).

According to Michener, (2007) and Winfree et al., (2011), bees are thought to prefer open, early-successional habitats, however logging activities may have an impact on the bee community. In comparison to late-successional environments, studies of bee populations in even-aged silvicultural treatments, such as clear-cuts, reveal a high richness and diversity of natural bees (Taki *et al.,* 2013, Wilson *et al.,* 2014, Hanula *et al.*, 2015). According to a related study by Nol *et al.,* (2006) and Romey *et al.*, (2007), uneven-aged single-tree management supported more bees than unmanaged stands, but fewer bees and lower diversity compared to even-aged systems. Additionally, Nayak *et al*., (2015) found that mixed-species harvesting systems supported a greater abundance of bees compared to managed forests, suggesting that such practices were more effective than single-tree selection in enhancing bee populations.

In Africa, most countries have a weak understanding of bee community conformation (Gikungu *et al.,* 2018). For instance, in Kenya, existing data revealed that bee numbers and their management status appear to be inadequate (Kioko *et al.,* 2017). It has been established that when factors such as fertilizer, water, and pest control are in place, bees play a critical role in agricultural efficiency (Kiatoko *et al.,* 2014). Bees are important pollination agents in agricultural activities, and their vitality is critical for crop pollination. This can be determined by examining characteristics of an efficient pollinator, such as abundance, pollen loads, visitation periods, and floral consistency (Kasina *et al.,* 2009). There is scanty knowledge on the ecological importance of wild bees or their susceptibility to environmental changes such as habitat degradation and loss (Kioko *et al.,* 2017). Related studies have shown that unlike any other crop input such as fertilizer labor or pesticides, bees play a crucial role in an ecosystem, particularly in crop development (Kasina *et al*., 2009). Studies concerning bee abundance, diversity and bee conservation status may aid towards policy formulation and decision making in regard to management of bee community for agricultural purposes, which is inadequate in Kenya. Consequently, in Kenya, there is need to document and conserve honey bee community as instrumental strategies in their conservation (Kiatoko *et al*., 2014; Macharia *et al*., 2010). In a normal ecosystem, great species diversity can be enhanced even though there occurs some level of agronomic disturbance constituting of farming as long as the disturbance is limited. Therefore, the task is to attain steadiness whereby disturbance may not lead to a substantial deterioration in species abundance and diversity (Marzinzig, 2018).

1.2 Statement of the Problem

Bees are susceptible to great threats majorly from agronomic undertakings and climate transformations. These agronomic activities include human practices such as use of agrochemicals, land degradation, habitat destruction and variations in land use patterns. Kenyan beekeepers experienced a colony decrease of 36.6% between 2021 and 2022, with higher losses during hot, dry periods (Sibaja *et al*., 2025). Despite a 14% increase in beehives from 2019 to 2023, honey production has declined, indicating a significant drop in individual colony health and overall bee abundance. This decline is attributed to environmental degradation, climate change, deforestation, and the use of agrochemicals like pesticides, which disrupt flowering cycles and habitats (Sibaja *et al*., 2025). However, in Loitokitok sub-county, Kenya, related studies have not been undertaken on the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and the state of knowledge of pollinator importance among small–holder farmers. Intensification of agricultural activities, changing land use in Loitokitok and growth in human population has resulted to deforestation and land fragmentation negatively affect the abundance and diversity of bee community. To evaluate decline in bee community negatively influences their environmental role majorly pollination thus threatening food security which in turn upholds the rationale towards bee conservation. Notably, reduction in abundance and diversity of bees more particularly pollinators can compromise crop produce in terms of quality and quantity. Therefore, the main objective of this study was to assess the effects of agronomic activities on abundance and diversity of honey bee community and state of knowledge among the farmers in Loitokitok Sub-County, Kenya.

1.3 Justification of the Study

Food security is a priority in many countries around the world, including Kenya. Other than the pollination function which plays a crucial role in crop productivity, significant effort and resources have been directed toward other production inputs to improve yields. For the majority of cultivated crops, bees are the primary pollination agents. However, a decrease in bee number and variety as a result of agronomic practices such as habitat amendment and fragmentation has a negative impact on crop pollination. Considering the decline in bee community, conserving these pollination agents is essential. Nonetheless, certain data allied to richness, taxonomy, abundance, diversity and conservation level of honey bee (*Apis mellifera* L.) populations need to be studied. Therefore, this study sought to bridge the gap on the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and also provide insights on the state of indigenous knowledge of pollinator importance among small–holder farmers in Loitokitok Sub-County, Kenya. The findings from this study can be used to devise policies for adoption in sensitization of the public and relevant stakeholders on the importance of bees and their contribution to livelihood and their role in enhancing food security and maintenance of the forest cover.

1.4 Hypotheses

H_{01} Agronomic practices do not affect diversity and abundance of bee species in Loitokitok sub-county

H_{02} Seasonal weather variations have no impact on abundance and diversity of bee species in Loitokitok sub county, Kenya.

H_{03} Small-holder farmers in Loitokitok sub-county do not have knowledge on pollinator importance

1.5 Objectives

1.5.1 General Objective

To assess the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and the state of knowledge of pollinator importance among small–holder farmers in Loitokitok sub-county, Kenya.

1.5.2 Specific Objectives

1) To evaluate the effect of agronomic practices on the diversity and abundance of bee species in Loitokitok sub county, Kenya.
2) To determine the impact of seasonal weather variations on abundance and diversity of bee species in Loitokitok sub county, Kenya.
3) To assess the state of knowledge of pollinator importance among small-holder farmers in Loitokitok sub county, Kenya.

1.6 Scope of the Study

This study concentrated on the fragmented habitats of Loitokitok county Kenya with an intent of discovering the effects of agronomic activities, seasonal variations and their possible effects on the existing bee abundance and diversity and the state of knowledge of pollinator importance among small-holder farmers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Diversity of Bee Community

Bees are classified under the Order Hymenoptera, Sub-order Apocrita, Super-family Apoidae, Clade Anthophila and fall under the monophyletic pedigree. There are nearly 20,900 identified bee species from eleven documented biological families, however, most of them are yet to be described and the actual number is probably higher. Out of eleven bee families identified, six of them occur in Africa and they include; Apidae, Megachilidae, Melitidae, Andrenidae, Colletidae and Halicatidae (Michener, 2007).

Globally, bees are quite spread in each continent with an exception of Antarctica, in every habitat on earth comprising of insect-pollinated flowering plants. Bees have excellent adaptive features for feeding on nectar and pollen grains, however, the first predominantly serves as an energy source while the second one largely provides proteins and additional nutrients. Most pollen grains are utilized as food for the developing larvae (Ascher *et al*., 2008). Bees exhibit a wide range in size from minute stingless bee species (*Trigona minima*) (Hymenoptera, Stenotritidae), comprising of workers of less than 2 millimeters in length, to large species of leafcutter bee (*Megachile Pluto*) (Hymenoptera, Melitidae), whose females exhibit a length of 39 millimeters (Michener, 2007; Ascher *et al*., 2008).

Environmental alterations enhance the diversity of bee community in ecosystems and in farming lands, where most farmers embrace farming methods geared towards generating minimal influence to the surroundings (Paula *et al*., 2015). Bees are involved in provision of a vital role in the environment since they contribute in the pollination activity and production of most vegetable crops and fruits (Saeed, 2012). Bees appear to be a varied constituent of wildlife in un-disturbed habitats which comprises of butterflies and moths (Lepidoptera) and wasps (Hymenoptera), beetles (Coleoptera) and flies (Diptera) (Black *et al*., 2007).

According to Goulson (2008), bee species diversity effects have utilized natural gradients of diversity, leaving species richness confounded with other variables such as environment, because they vary in plant species they visit and the place and time of visitation is equally different. There is need to conserve and maintain knowledge and practises of local communities that are in favour of conservation and sustainable use of biological diversity (Njoroge, 2005).

Notably, a few studies have been undertaken to describe the role of bees in enhancement of crop production and quality in an ecosystem such as that of Gikungu *et al*., (2018) who investigated on the effect of distance on diversity and abundance of bees on *Ocimum kilimandscharicum* found in Kakamega Forest habitat. Kasina, (2018) conducted an assessment on sunflower pollinators in Kenya to determine whether bee diversity had a role on seed yield. Similarly, Kioko *et al.*, (2017) conducted an investigation on bee diversity cum floral possessions alongside a disrupted gradient in Kaya Muhaka Forest and immediate farmlands of coastal Kenya.

2.2 Role of Bees in Crop Production

Diversity and the community-level maintenance role of bees are being threatened by environmental disturbance and population declines of plants. Through enhancement of food security bees as pollinators contribute by provision of honey and bees wax that support African economies (Potts, 2010).

The role of bees as pollinators enhances food security which in turn serves to improve the lives of most people in developing countries (Munyuli, 2010). According to (Winfree, 2010), though it has been found that bees carry out pollination on most the plant species while offering sparingly treasured pollination facilities to crops, awareness of approaches for bee management drags with an exception of the valuable taxa; parasitoids and predators (Kioko *et al*., 2017). Nevertheless, the bee community is one of the biotas which is susceptible to disruption mainly due to farming activities including use of agro-chemicals, environment devastation and grazing magnitude besides escalation in land utilization arrangements and adjustment in farming methods (Kasina, 2018).

Bee diversity is significant in an ecosystem since they complement each other in their ecological role of pollination (Njoroge *et al.*, 2006). A highly varied bee community offers an effective pollination role particularly on farms embracing mixed cropping since various pollinators aim at diverse flowers. Bee diversity aid in limiting the risk emanating from inadequacy of pollinators mostly during crop flowering (Kasina, 2007). There is variation in the social behavior of bees which ranges from solitary to eusocial forms. In solitary types, making of nest and search of food for off- springs is carried out at individual level (Kiatoko *et al.*, 2014). On the other hand, in eusocial bees, there is specialization among the colony such as foragers and egg layers and also the females (mothers and daughters) who cooperate in performing hive chores as seen in the *A. mellifera* (honeybees) (Michener, 2009). In a related study carried out by Gikungu, (2006) states that solitary bees are localized in open habitat since they nest in soils and pithy stems or herbs and shrubs. However, solitary bees are known to pollinate plants more efficiently than honey bees and are also provide an essential service of pollinating crops and ensuring that plant communities are healthy and productive (Gikungu *et al.*, 2018).

2.1.1 Bee Species Richness

Species richness is a relatively easy variable to study as it only involves the collection of data on which species occurs in a study area, so it is often used as an indicator of the diversity of a community (Thomson *et al.,* 2007). Species richness data can indicate whether the species are distributed equitably or whether there are a small number of common species and the rest are rare (Hopton and Mayer 2006). However, with the higher species richness observed in tropical agricultural land (Bishop *et al.,* 2016), it is likely that many species are at risk from agricultural expansion in Africa and that focused management may have a large role to play in reducing these potential losses (Gikungu *et al.*, 2018).

2.2 Bee Species Abundance

The most abundant bees in the tropical-agricultural landscapes are from the order Hymenoptera and also from the family Apidae, including subfamilies Apinae (honeybees, bumblebees and stingless bees), Nomadinae (kleptoparasitic cuckoo bees) and Xylocopinae (carpenter bees) (Benjamin *et al*., 2014). From these taxa, the most common one is *Solanum lycopersicum* in Europe and have been reported to be restricted to foraging just a few plant species. There are tens of thousands of insect species worldwide representing these different taxonomist groups and bees alone account for 20,000 of these species worldwide (Wanga *et al.,* 2013). In France, the United Kingdom and Germany, the most common bee species recorded are *Apis mellifera* and *Bombus* spp as observed in the UK and Germany by Nayak *et al*., (2015) and Marzinzing *et al.,* (2018) respectively. In Spain and Algeria bees from the genus *Eucera* can be even more numerous and more efficient in pollination than other species (Suso and Del Rio, 2015).

In African countries, the defined bee community can nevertheless, be termed to be reasonably diverse. Notably, only six from the seven bee families documented by Kioko, (2017) can be traced in the Sub-Saharan African countries. Additionally, nearly 21% of the World's bee genera can be also traced in the Sub-Saharan African countries (102 from an aggregate of approximately 476; Wanga *et al.*, 2013) while almost half of these appear diverse or ancient global endemics. Consequently, at generic level, it proposes rationally great diversity. Nonetheless, at species level, diversity appear compromised. In the developing countries especially in Sub-Saharan Africa, there are 2600 described bee species constituting of only around 13% of the international fauna of about 19400 species. However, a few studies have been documented on how bee diversity in natural habitats (Gikungu, 2018) and on the same cultivated crops and wild crops (Karanja *et al*., (2013).

In Kenya, a few studies have documented bee abundance and diversity though they only looked at their role on pollination on cultivated crops (Karanja, 2009; Gikungu, 2018; Soli *et al*., 2020) and on the same cultivated crops and wild crops (Kasina, 2018).

2.3 Bee Habitats

Bees require both nesting and foraging habitats (Black *et al*., 2007). Crops may provide abundant floral resources while in bloom, but plants bloom in synchronous periods lasting only few weeks and therefore, bees may visit the other plants in the wild habitats near agricultural lands (Morandin *et al*., 2007). A variety of flowering plants around crop stands serve to sustain the pollinators outside the flowering period of the crop stand. However, most of these pollinator groups of these floral resources are not documented (Schaab and Lung, 2006).

However, most wild bee species are observed visiting flowering plants in search of floral resources when the environment is conducive especially when there are enough rains or blossoming of more natural floral resources in surrounding habitats as compared to the short rain season as observed by Soli *et al*., (2020)

Studies carried out by Karanja *et al*., (2013) observed that insect pollinators have diverse habitats. For instance, for moths and butterflies, their habitats must have larval food plants as well as adult food resources, nectar, dung, tree sap and rotting fruit. Management of the different habitats in agronomic landscapes so as to improve and safeguard insect resources is important in order to enhance bee community while land utilization approaches can influence herbivorous and predatory or parasitic insect populations in farmlands (Bianchi *et al*., 2006).

Flowering plants offer crucial resources such as pollen and nectar for pollinators (insects) especially the wild bees, honeybees, hoverflies, butterflies moths and some beetles (Karanja, 2013). Planting ought not to act as a substitute for sustaining present flower rich surroundings nor for re-establishing species variety through modifications in management (Marzinzig, 2018). Habitat enhancement for native pollinators on farms, especially with native plants, provides multiple benefits. More so supporting the bee community, the native plant habitat will attract beneficial insects that are predators or parasitoids of crop pests and lessen the need for pesticide on farms (O'Connor, 2017). Protecting, enhancing or providing habitat is the best way to conserve bees and consequently, provide floral resources that supports local honey bees, on farms with sufficient natural habitat, bees can play the pollination role for most crops (Kasina, 2018).

2.3.1 Agronomic Activities on Bee abundance and Diversity

Human activities in the ecosystem that can result into habitat modifications will disturb bee life which will decrease their abundance (Beyene and Verschuur, 2014). Bee resources such as nesting, sites, mating and food will also diminish. Large scale livestock rearing can end up into overstocking hence overgrazing, deforestation for crop production, monoculture and establishment of irrigation schemes of some crop routine management practices such as smoking and pesticide sprays which will kill or repel foraging bees during visitation on flowering periods (Ali *et al*., 2014). Any agronomic practise which can decrease bee population, leads into inadequate pollination in crops since their population size is much affected (Karanja *et al*., 2013). Nevertheless, some plants may not be at a losing end and produce optimally since the dominant bee may not be their pollinator (Kasina, 2018).

However, bee community destruction can also be enhanced by natural calamities such as fire, floods, drought, pests and diseases, which also lower their population size. Thus, humans should manage the effects of such calamities by provision of survival options to the insects and protecting them against pests and diseases (Kasina, 2007). The cultivated area of bee dependent crops has increased worldwide, raising demand for insect pollination three-fold since 1961(Aizen and Harder, 2009). This demand is unlikely to be met by managed honey bees alone, given that their activity is often insufficient to deliver adequate quantity and quality pollen at the appropriate time and place (Garibaldi *et al*., 2011).

2.3.2 Use of Agro-Chemicals

Habitat loss and pesticide application can contribute to the decline of bee community (Tuell and Isaacs 2010). Pesticide risk assessment carried out has generated information related to only on some few bee species such as *A. mellifera*. Usually, pesticides are used injudiciously without clear direction hence impacting negatively on non-target organisms such as honeybees; hence cross pollination. This in turn lowers crop yields threatening livelihoods (Magembe *et al*., 2014). The use of pesticides is the common practice in farming with detrimental effects of mortality or transformed foraging capabilities for bees as observed by Mutuku *et al*., (2013).

The definite role of pesticides in bees' health is further complicated because where pesticide use is intense often also correspond with places with low availability of both flower resources and nesting sites (Kremen *et al*., 2007). Insecticides have an impact that reduces bees foraging efficiency and also may affect the health of the bees in case they are exposed at a time when their food resources have been contaminated by the application of such herbicides (Brittain and Potts, 2010). Intensive herbicide utilization severely lowers non-crop plant diversity and abundance, compromising food accessibility for bees. Chemical devastation of environments through substantial use of herbicides generates long term concerns, more especially on the occurrence of pollinators in agro-habitats (UNEP, 2010).

Several studies have revealed that excessive use of chemicals lower the immune system of insects rendering them susceptible to diseases, parasites and pathogens. Alaux *et al*., (2010) showed that the combined effects of imidacloprid and parasite infestation significantly, weakened honeybees, causing high mortality and high levels of stress, blocking the ability of bees to sterilize the colony and their food and thus weakening the colony as a whole.

Loitokitok Sub-County is an agro-pastoral area with intensive agronomic practices including farming activities (Magembe *et al*., 2014). Further it has a varied edaphic and climatic conditions ideal for a range of plant vegetation with nectar and pollen for sustaining a large number of honeybee colonies (Muli *et al*., 2014).

2.3.3 Monoculture Farming Systems

Continuous use of mono-cropping systems leads into decline of biodiversity particularly the genomic diversity besides plant diversity and farmlands surrounded by croplands restricting the quantity of food to be accessed by pollinators at a given space and also period (Oliver *et al.*, 2010). Additionally, Biesmeijer *et al*., (2006) conducted an investigation on the degeneration of plant diversity parallel with the drop in bees besides other insect pollinators.

2.3.4 Industrialization

The emergence of industries coupled with numerous industrial operations such as cultivation, irrigation and deforestation, damages nesting locations of pollinators (Kremen *et al*., 2007). Variations in industrial practises can impact bee abundance and diversity and thus lower their ecological role efficiency. Intensive farming usually results into increased use of agrochemicals such as pesticides which has negative impacts on the bee community (Nayak *et al*., 2015). Furthermore, organic farming which is least embraced than usage of agrochemicals has proven to be of great significance for bee population as observed by Power *et al.,* (2012). Intensive agricultural activities compounded with irrigation systems, deforestation for farming can result into homogenization of the bee community (Ekroos *et al*., 2010), with a loss of habitat specialists and poor dispersers leaving only common taxa. Thus, any alteration in agricultural areas that lead into change in land use, spatial configuration or intensity of management have the potential to affect abundance and diversity of the bee community (Oliver *et al*., 2010).

2.4 Climatic Changes

Weather changes such as temperature variations, variations in precipitation configurations and highly intermittent or thrilling weather conditions, will impact on bee populations. The changes might affect bees individually and ultimately their communities reflected in higher extinction rates of bee species (UNEP, 2010). Change in temperature when plants are flowering might lead to declining of the bee community (Potts *et al*., 2010). It can also have mismatch between the bee pollinator and plant that have been evolved together, if one adapts to a new climate faster than the other and changes behaviour (Winfree, 2010). Because bees are valuable to agricultural and natural areas, it is valuable to determine whether pollination services are threatened by their declining populations (Kasina, 2018).

2.5 Decline of Bee Community on Farmlands

Progressive decline in bee diversity raises concern about the maintenance of ecological role of bees in an ecosystem (Potts *et al*., 2010). Decline in bee populations and species diversity have raised concerns regarding potential risks to global food security and economic development, particularly in countries where agriculture is large portion of the economy (Kluser and Peduzzi, 2007). Bees are important biotic components in an ecosystem since they provide a variety of benefits such as food and fiber, plant-derived medicines, ornamentals and other aesthetics, genetic diversity, and overall ecosystem resilience (MEA, 2003).

Bee community decline began to receive widespread attention in 2006 when the popular press reported on the mysterious disappearances of managed honey bee, colonies across U.S. VanEngelsdorp *et al.*, (2008) noted that the honeybee colony declines is due to colony collapse disorder (CCD). Studies by Biesmeijer *et al.,* (2006) observes that bees' diversity fall due to decline in wild plant communities. Reduction in bee community poses additional risks to ecosystem stability and loss of biodiversity not only the pollinator species themselves, but also the plants they pollinate (Biesmeijer *et al*., 2006).

Depending on which crops are most affected, bee population decline may significantly impact human nutrition in terms of availability of many micronutrients (Karanja, 2013). Food security is supported by pollinators, which make a contribution estimated at US dollar 220 billion each year, representing 9.5 percent of the world's agricultural food production (Gallai *et al*., 2009). In particular, many fruits, vegetables, oil crops, stimulant crops (tea, coffee and other beverages) along with nuts and seeds depend on animal pollination (Winfree *et al*., 2007b).

According to LeFeon *et al*., (2010), decline in bee abundance and diversity are particularly strong under intensive agricultural managements. Agricultural intensification and habitat loss and pesticide application also contribute to the loss of insects including bees (Brittain *et al.*, 2010). Studies by Garibaldi *et al*., (2011) showed that bee species decline could pose various risks and threats to world agricultural production. Wild bees are sufficient to pollinate agricultural crops when their needs are met (Kasina, 2018).

2.6 Seasonal Weather Variability on Bee Species Abundance and Diversity

Seasonal weather variability has a potential of threatening bee species abundance and diversity in our ecosystems (González-Varo *et al.,* 2013; McLaughlin *et al.*, 2002). The fourth evaluation report formulated by the Intergovernmental Panel on Climate Change (IPCC) lists a number of observed global variations, most particularly, global temperatures increase, variations in rainfall patterns, frequency and intensity of precipitation have a potential of reducing bee species abundance and diversity (Baede *et al.,* 2007). These consequences of seas variability have negatively influenced the livelihoods of the Loitokitok community. In a related study conducted by Scaven &

Rafferty, (2013) their findings established that the timing of both flower bloom and pollinator activity seemed to be affected by temperature increases thus creating space and time mismatches with severe demographic consequences for the species involved. These mismatches can affect the plants by reduced pollen deposition and bee visitation, whereas the bee species experience shortage in the availability of food. Creation of time and space mismatches between wild plants and their pollinators was reported by Steffan-Dewenter & Westphal, (2008) who investigated the nature of responses of both bee pollinators and plants to increasing temperatures and found that disparities in the slopes of the responses and season in a year indicated a potential mismatch between plants and bee pollinators.

Since Loitokitok sub county lies in ASAR of Kenya, bee species abundance and diversity are therefore susceptible to impacts of seasonal weather variability. Colwell *et al.*, (2008) established that any future temperature increases in the tropics, even relatively small in magnitude, was likely to have consequences that are more deleterious in ASAR areas than changes at higher latitudes. He attributed this to the fact that tropical insects are relatively sensitive to temperature changes (with a narrow span of suitable temperature) and that they were currently living in environments very close to their optimal temperature. Sunday *et al.*, (2011) pointed out that in contrast, insect species found at higher latitudes where the temperature increase was expected to have broader thermal tolerance and higher chance of survival since they are living in climates cooler than their physiological optima. The authors noted that warming would actually enhance the performance of insects living at these latitudes. It is therefore likely that tropical ecosystems such as Loitokitok will suffer from greater extinction of bee species and population decrease than those ecosystems at higher latitudes.

2.7 Ecological and Economic Role of Bees

Globally, decline in bee community negatively affects their ecological role especially pollination which can threaten food security and this appreciates the importance of conserving bees (Hein, 2009). Bees are extremely significant in agricultural crops since they are accountable for almost 1/3 of food utilized by human beings worldwide (Ollerton *et al.*, 2011). According to Marzinzig, (2018), abundance and also diversity of the bee pollinators can influence crop yields in terms of quality and quantity. The occurrence of remains of natural foliage near crops are known to boost the generative accomplishment of domesticated species since these remains offer resources and nesting sites for bees (Holzschuh *et al.,* 2012). Without the assistance of bee pollinators, most plants cannot breed and most farmers face a great yield loss. In actual fact about 90% of all the flowering plants depend on animal pollination as observed by Ali *et al*., (2014).

Bee pollinators form one of the natural resources since pollination is the most important ecosystem service performed by these insects and plays a vital role in the socio-economic status of human being (Saeed, 2012). Saeed, (2012) further observed that, because of its yield enhancing benefits, bee pollination can play a significant role in keeping a defensible and sustainable agriculture with minimized disturbance to environment. The financial importance of bee pollination goes beyond production agriculture because they pollinate more than one crop plant (Sajjad, 2012). *A. mellifera* provide vital ecology facilities to horticulture crops, besides pest control in most crops (Losey & Vaughan, 2006). Additionally, bee pollinated faba bean pods have been linked to resilience against environmental stresses, better fertilization and a higher yield, as well as greater vigor in the next generation (Bishop *et al.*, 2016).

2.8 Bee Conservation Status

Local people are known to have evolved ecologically sound technologies to deal with issues related to agro-ecosystem management. The knowledge that local people have regarding ecology, biodiversity and land use is important in agro-biodiversity management in agro-ecosystems (Gikungu *et al*., 2018). The customary conservation knowledge is regarded to be a social responsibility and it is the way in which traditional societies manipulate biodiversity both in space and time in order to ensure stability of agro-ecosystem management (Njoroge *et al.*, 2008). Conservation and sustainable use of bees for economic and agricultural purposes require cooperation and participation of the local community which is the end user or consumer of bee products (Winfree *et al*., 2007a). The local community in conjunction with scientists' expertise should work together in order to advance native practices in incorporated farm organization systems besides developing appropriate guidelines for bees' management (Kasina, 2007).

However, very little is known about bee biology, ecology as well as economic value in most parts of Africa (Gikungu *et al.*, 2018). A few other insects have been managed in African countries, partly because of general lack of knowledge concerning potential of wild insects as pollinators (Klein *et al*., 2006). Efforts have been made to improve this conservation status but there is still a lot that needs to be undertaken (Klein *et al.*, 2006; Kasina, 2007).

2.9 Knowledge Gap

In America, studies emphasize the decline of pollinators due to pesticide use, habitat fragmentation, and monocropping, but they often neglect the role of knowledge in shaping sustainable pollination practices among smallholder farmers (Kleijn et al., 2019). In Britain, have noted the impacts of land-use changes and agricultural intensification on wild bee diversity, but there is limited integration of local farmers' perceptions and cultural knowledge in pollinator conservation strategies (Powney et al., 2019). In India, while findings indicated that seasonal crop cycles and pesticide reliance significantly affect bee populations, few studies systematically document ecological knowledge of pollinators among small-scale farmers who rely heavily on natural pollination for crop yield (Baek et al., 2020). Similarly, in Nigeria, although evidence suggested that deforestation, pesticide misuse reduce pollinator diversity, there is inadequate research linking smallholder knowledge systems with agronomic practices and seasonal patterns (Tolera & Ballantyne, 2021). In Tanzania, studies show that agronomic practices, seasonal changes, and management systems strongly affect bee abundance and diversity, with honeybees dominating but varying in visitation depending on season and farming methods. While agroecological practices enhance pollinator activity, farmer awareness of pollinators' importance remains low, creating a gap between crop dependence on animal pollination and conservation efforts (Tibesigwa et al., 2019; Sawe et al., 2020; Rweyemamu et al., 2024). In Uganda, research indicates that bee diversity benefits from semi-natural habitats, whereas land-use intensification reduces pollinator richness and favors common species. Although pollination services are vital, farmer recognition of their role is limited, revealing a knowledge gap that threatens sustainability of pollination-dependent crops unless conservation and awareness strategies are strengthened (Munyuli, 2011; Munyuli, 2012). In Loitokitok sub- County, Kenya, studies on the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and the state of knowledge of pollinator importance among small-holder farmers have not been established yet. However, a few studies on bees particularly on pollination have been carried out on some crops such as pollination of *C. arabica* (coffee) in Kiambu county carried out by Karanja *et al*., (2013), bee abundance, diversity and pollination by Gikungu, (2002, 2006), pollination of indigenous crops in Mwingi by Njoroge *et al*., (2008), pollination of *C. lanatus* (water melon) at Yatta (Njoroge, 2005) and bottle guard (*Lagenaria sicerana*) (Morimoto *et al*., 2004), Studies done in Kakamega on economic value of pollinators for crop pollination (Kasina, 2007). Kiatoko *et al*., (2014) have done a study on enhancement of fruit quality in *Capsicum annum* through pollination by *Hypotrigona gribodoi*, in Kakamega, Western Kenya and also Kioko *et al*., (2017) have carried out a study on bee diversity and floral resources along a disturbance gradient in Kaya Muhaka Forest and surrounding farmlands of coastal Kenya. All these studies did not look at the effects of anthropogenic activities on abundance, diversity and the state of knowledge of bee community. Therefore, the rationale of this study was to assess the effects of agronomic activities and seasonal variations on abundance and diversity of bee species and the state of knowledge of pollinator importance among small–holder farmers in Loitokitok Sub-county, Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

Loitokitok sub-county is found in Kajiado County, Kenya. It is situated in the Rift Valley and borders Narok and Kiambu counties to the west, Nairobi and Machakos counties to the north, Makueni and Taita/Taveta counties to the east and Tanzania to the south (Fig. 3.1). The sub county lies between latitude 10° 10´ and 30° 10´ South and longitude 2° 36´ and 37° 53´ East.

The Sub County covers an area of 6300 km^2 and comprises of six group ranges namely: Rombo, Kuku A and B, Kimana, Olgulului, Imbirikani, Ensenkei alongside some privately owned ranges. The area is mainly composed of *Themeda* grassland, dwarf shrub and *Acacia drapanolopium* grassland and *Croton* bushes and other woody species interspersed with grassland (Okello *et al.*, 2011a).

There are several types of soils in the Loitokitok ecosystem, including luvisols, cambisols, volcanic soils, saline and sodic lacustrine deposits, and Pleistocene volcanics. The Pleistocene volcanic soils, in particular, favor agricultural production, especially maize farming at the foot of Mt. Kilimanjaro (Burnsilver et al., 2008). These soils not only sustain crop growth but also enhance floral diversity, providing critical nectar and pollen sources for bee populations. Additionally, alluvial clays accumulate in seasonal runoff zones, creating nutrient-rich patches that support flushes of grasses and herbaceous plants after rains (Kimana Integrated Wetland Management Plans, 2008-2013). Such short-lived flowering cycles are essential for wild bees that rely on ephemeral floral resources.

The Loitokitok ecosystem has experienced notable vegetation changes, with dense woodlands and thickets increasingly dominating the plains. These shifts, driven by agronomic activities, climate change, reduced fire frequency from recurrent droughts, and declining wildlife populations, have altered the availability of nesting and foraging habitats for bees (Okello et al., 2011b). For example, increasing thickets provide nesting opportunities for cavity-nesting bees, while reduced open grasslands limit ground-nesting habitats. Annual temperatures range between 18.4°C and 22.3°C, with a bimodal rainfall pattern short rains from October to December and long rains from March to May. Rainfall ranges from 500 mm around Lake Amboseli and Magadi to 1250 mm on the slopes of Mt. Kilimanjaro. This climatic variability drives seasonal flowering cycles, influencing bee foraging activity and colony survival.

Naturally, Loitokitok supports a mosaic of forests, woodlands, scattered bushes, and open grasslands, but it is rapidly being transformed into cultivated land. Each landscape feature holds ecological significance for bees: forested zones provide diverse floral resources and cavity-nesting sites in tree trunks, grasslands favor ground-nesting bees, and wetlands with alluvial soils promote flowering herbaceous plants that act as seasonal foraging hotspots. The main land uses like pastoralism, tourism, and agriculture further influence bee populations by either enhancing floral diversity through crop plants and rangeland pastures or reducing habitat quality through monoculture and land conversion. The study area was therefore selected because its wide range of soil types and land-use practices provide a natural laboratory for understanding how agronomic activities influence the nesting and foraging ecology of bee populations. The map (Figure 3.1) illustrates a section of Loitokitok Sub-County.

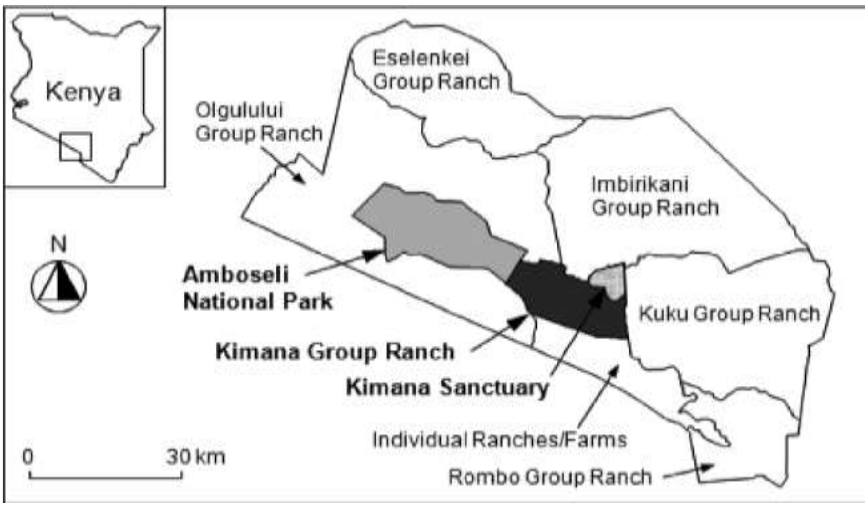

Figure 3.1: Map of Oloitokitok Sub-County

Source: Adopted from Google Maps, (2021).

3.2 Research Design

The study adopted an experimental research design with three different habitats; stratified sample design. The study area was stratified into habitats 1) Cultivated farm 2) Range land 3) Natural-forest edge. A sample area of 1 × 1 km square was picked at random from each of the three study areas. Those selected areas were further sub-divided into 0.5 × 0.5 km smaller study areas and a total of 3 belts were laid down randomly per habitat in order to establish effects of agronomic activities on honey bee species abundance and diversity and conservation status in Loitokitok Sub County. The study design was based on a protocol developed and agreed upon by global partners for bee visitation in crops (Vaissière *et al*., 2011) (Fig. 3.2). The overall layout of the study followed a standardized protocol developed by global partners for bee visitation in crops (Vaissière et al., 2011). Specifically, a 3 km transect was established in each habitat, stretching from the forest edge to habitats away from the forest (Fig. 3.2). The figure illustrates the spatial arrangement of the survey design, showing how transects were positioned to capture variations in bee diversity and abundance across cultivated farms, rangelands, and natural forest edge habitats.

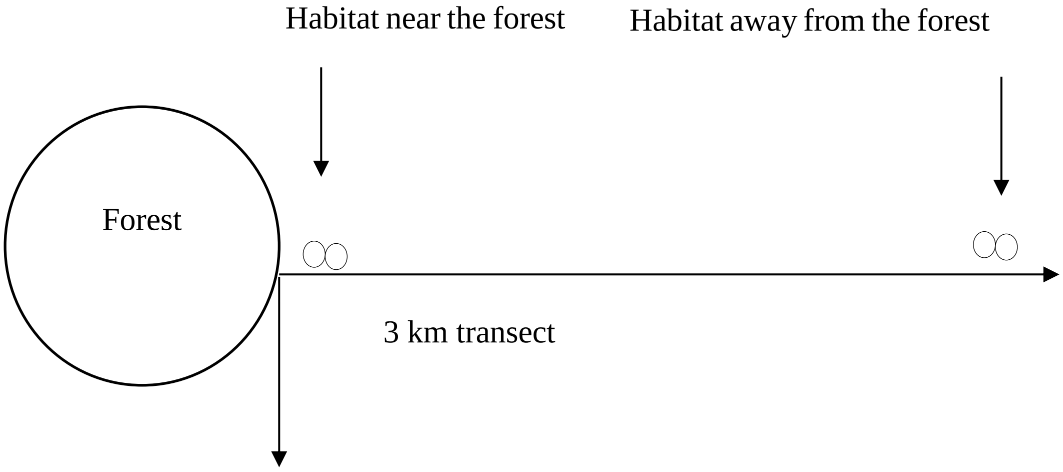

Figure 3.2: A Survey Design for Assessing Abundance and Diversity of Bees in Different Habitats

3.3 Site Selection

Sites were chosen based on the intensity of agriculture and the extent of scrubland and farmed land in order to cover as wide a range of agricultural intensities as possible, as well as naturally forested areas. Initially some areas in the sub-county under agricultural practices were once a naturally forested area and currently have been cleared for the aforementioned agricultural activities. The area covering individual ranges and farms has undergone agronomic activities while Loitokitok community forest area was the main forested area.

3.4 Sample Size and Sampling Procedures

Among the seven ranches namely; Kuku, Eselenkei, Olgului, Imbirikani, Rombo, Kimana, individual farms and Amboseli national park; stratified random sampling was used to divide the study area into mutually exclusive groups based on the relevant characteristics. Thus, the strata boundaries were defined based on land-use types, namely cultivated farms and settlements, rangeland, and natural forest edge. Therefore, the study area was stratified into three habitats; 1) Cultivated farm and human settlements 2) rangeland and 3) natural forest edge.

Cultivated farm and areas under human settlement are more disturbed by agronomic activities, rangelands represented areas with moderate level of agronomic disturbances, while the natural forest habitat is prone to minimal agronomic disturbances and therefore chosen based on visual determination of the intensity of various land use practices like agriculture and forested land in order to cover a wider range of agronomic affected areas.

Ten farms were selected using simple randomization along transect of 3 km, extending from the forest edge to the arable land. A sample area of 1 × 1 km square was picked at random from each of the three study areas. Those selected areas were further sub-divided into 0.5 × 0.5 km smaller study areas and a total of 3 belts were laid down randomly within the habitats. A belt in this context refers to a linear sampling unit (transect strip) measuring 500 m in length and 20 m in width**.** The belts were randomly located within each selected 0.5 × 0.5 km study area by using random points to determine their placement. They were randomly oriented (not fixed to a single compass direction) to reduce bias in habitat coverage. The belts were laid out so that each was spatially independent, typically separated by at least 50–100 m apart (or more, depending on habitat extent) to avoid overlap and ensure representative sampling across the mosaic of land-use types. The areas consisted of a mosaic of many different habitats and field types. In order to limit the habitats surveyed per transect, transects were restricted to 500 m by 20 m in size.

For the area under Agriculture and human settlements, they were selected by simple randomization along a transect of 3 km, extending from the edge of the forest towards farmland. This also involved moving along a pre-determined route along the transect for almost one hour and all bees seen captured using sweep net. The program GPS Utility was used to place transects within each site. Geographic positioning system (GPS) coordinates were used to mark the study habitats. Sampling was conducted twice per habitat over a period of 16 day; once during the rainy season (January to April) and once during the dry season (May to October). Sampling was spread over the three months (January, February and March) in the rainy season and (May, June and July) for the dry season, so that the habitats were visited at different times during each season. In the forest habitat, a 1.5 km long study transect was established along a path through the forest with a minimum distance to the forest border of 150 m to avoid edge effects. Each transect was sampled repeatedly over 13 days between 7:00 am and 16:30 pm. On the remaining three days, 350 m long section of the forest border was visited because some bee species normally live in the tree crowns and only come down to lower vegetation levels along forest edges. The 350 m forest border section was randomly selected along an accessible edge, then sampled on three separate days using the same sweep netting method as in the main transect. Data from this edge section were combined with the main transect data to account for edge-associated bee species.

The sample for questionnaire administration was determined using Kathuri and Pals (1993);

$S = X^2NP\ (1-P) \div d^2\ (N-1) + X^2\ P\ (1-P)$ where;
S = required Sample Size

N = the given population

P = Population proportion that for this study was taken to be 0.50; this is the degree that generates the optimal sample size needed.

d = the degree of exactness as indicated by the error that can be accommodated in the reduction of a sample proportion p about the proportion P-the value of d being 0.05 in the calculations for entries in a table, a quantity equivalent to plus or minus 1.96σ.p

X^2 =table value of chi square for a degree of freedom in relation to desired level of confidence, which is 3.84 for the 0.95 confidence level signified by items in the table.

Thus, the sample size of the respondents was calculated as shown:

$S = X^2NP(1-P) \div d^2(N-1) + X^2P(1-P)$

$S = 3.84 \times 228(0.5)^2 \div (0.05)^2(227) + 3.84(0.5)^2$

$S = 218.88 \div 1.5275$

$S = 143.29$

$S = 143$

The sample size was determined from the infinite population of two hundred and twenty-eight (228) households living near the forest as shown so that there was a 95% level of confidence. The sample proportion P was within plus or minus 0.05 of the population value of 0.05 for P for which a minimum of hundred cases is acceptable for research. A sample of 143 local residents was employed as an appropriate sample because, according to Kathuri and Pals (1993), a minimum of 100 respondents should be used during survey research.

Thus, a random sample of 143 households was selected from a total of 228 households living near the forest for questionnaire administration. Simple randomization was used where each household was assigned a number and a computer was used to generate the samples. Two enumerators were trained about the issues of agronomic activities and bee abundance and diversity and shown all the steps of the enumeration procedure. They were picked from the local community and therefore easier for them to source information from the local respondents.

3.5 Data Collection Procedure

The researcher obtained a letter of introduction from the School of Graduate Studies, Jomo Kenyatta University of Agriculture and Technology. Permission was obtained from the County Director, Ministry of Agriculture, Kajiado County and then the Sub-County Director of Agriculture, Loitokitok sub-county in order to conduct this research in the Sub-County.

3.5.1 Effect of Agronomic Practices on Diversity and Abundance of Bee Species in Loitokitok Sub County

Nesting and visiting bees were observed using a pair of binoculars in each sampled habitat. Bees in the sampled habitats were noted and captured by use of a sweep net over a 1km belt transect. After each collection, the bees were killed using ethanol, sun dried for three days, preserved in storage containers using naphthalene to guard them from pest attack and damage. This was followed by pinning, labeling and archiving in National Museum of Kenya laboratory.

Bees that were not be captured from the flowering plants, there were laying of three pan traps of different conspicuous colours, blue, white and yellow colours (Morandin *et al.*, 2007; Campbell and Hanula, 2007) at random points per habitat in order to trap any bee that were not collected by sweep nets. There was a 200ml of rainwater and 4ml of unscented cleansing agent placed in each laid trap. The collected bees were put in vials, sun dried for three days and then pinned and transported to the laboratory at Zoology Department in the National Museums of Kenya, Nairobi for identification. The collected bees were distinguished by use of colour, body size and then classified to genus level. All the honey bees identified were used for the determination of abundance and diversity. In the course of the observation time, bees were differentiated by colour and body size. This was simultaneously done in the three habitats at an interval of 15 minutes in each habitat to avoid variations (Gikungu, 2002).

3.5.2 Impact of Seasonal Weather Variations on Abundance and Diversity of Bee Species in Loitokitok Sub County, Kenya

In in each habitat for both the rainy and dry seasons, the nesting and visiting bees were observed and captured along 1km belt transect using a sweep net. Two pan traps (Yellow and blue) were also laid at random points per habitat in order to trap any bee that may not be collected by sweep nets. The collected bees were placed in vials and euthanized using aerosols labeled for bee control. They were then sun-dried for three days, pinned, and transported to the Zoology Department at the National Museums of Kenya, Nairobi, for identification. All the bees identified were used for the determination of abundance and diversity.

3.5.3 State of Knowledge of Pollinator Importance among Small-holder Farmers in Loitokitok Sub County

Questionnaires were administered on the 143 households. The questionnaires contained questions on the respondents' socio-demographic features that can assist in explaining variances of the farmers' knowledge on pollinator importance, knowledge of different bee species, knowledge on bee history, their nesting requirements, food resources, how the farmers utilized bees and possible methods of increasing bee pollination. Other questions on whether they kept honeybees and the number of hives they had. The respondents were required to indicate on whether they domesticated stingless bees for honey production. Respondents were asked on whether they were familiar with pollination and its significance towards crop farming, as a means of embracing the bee community (Appendix 1).

3.5.4 Agronomic Practices in Loitokitok Sub County

Data collection on agronomic practices was carried out using both field observations and household surveys. Field observations involved documenting farming activities such as land clearing, use of agrochemicals, burning of vegetation, overgrazing, and continuous tillage, which are known to negatively affect bee habitats and foraging behavior. Observations were made along the established transects in cultivated farms, rangelands, and forest edge habitats to in order to document the agronomic practices. Structured questionnaires were also administered to the 143 randomly selected households living near the forest. These questionnaires were designed to capture community perspectives on common farming practices, the frequency of agrochemical use, and perceptions of their impact on pollinators and the environment. These data were discussed and recommendations made.

3.6 Data Analysis

3.6.1 Effect of Agronomic Practices on Diversity and Abundance of Bee Species in Loitokitok Sub County

Descriptive statistics such as frequencies and percentages were used to describe the data. Data on honey bee species diversity in the three habitats was calculated using the Shannon diversity (H) index (Shannon and Weiner, 1949). Species richness is a biologically appropriate measure of alpha (α) diversity and is usually expressed as number of species per sample unit (Whittaker, 1972). The Shannon diversity index (H) was computed using the following equation;

Shannon Index ($H^{/}$) $=\sum p_i (\ln p_i)$ (Shannon & Weaver, 1949).

Where, $H^{/}$= diversity, $\sum$= Summation, $p_i = n_{i/}N_{total,}$ ln = natural logarithim, Ni= number of individuals of species $i_,$ Ntotal = Total number of individuals on all species.

Relative abundance of a species is the abundance of a species divided by total abundance of all species. It is based on the assumption that the more frequently a species is seen the more abundant it is (Bibby *et al.*, 2002). Then for every habitat, absolute abundance and relative abundance of each species was calculated as follows;

Absolute abundance = Aggregate number of entities in a species/aggregate number of sampling units comprising that species (Whittaker, 1972; Magurran, 1988).

Relative abundance = Absolute abundance of a species/Sum of all absolute abundance x 100. (Bibby *et al.*, 2002).

In order to determine the similarity of bee species abundance between different habitats**,** one way analysis of variance (ANOVA) was used to compute the statistical significance of bee species abundance across the three habitats.

3.6.2 Impact of Seasonal Weather Variations on Abundance and Diversity of Bee Species in Loitokitok Sub County, Kenya

Descriptive statistics such as frequencies and percentages were used to describe the data. Sorenson diversity index was used to determine how the various habitats compared in terms of abundance and diversity in reference to the rainy and dry seasons.

Sorenson, similarity index; Cs=2J/a+b (Sørensen, 1948). Where; a= number of species found in site A, b= number of species in site B and J= number of species shared by the two sites.

Paired sample t-test was used to make a **c**omparison between percentage abundance of the study habitats during the rainy season and dry season**.**

3.6.3 State of Knowledge of Pollinator Importance among Small-Holder Farmers in Loitokitok Sub County

Data on the knowledge of pollinator and pollination, pollinator history among small-holder farmers; one sample t-test. The analysis was conducted using IBM SPSS Statistics version 28.0 (IBM Corp., 2021). This test is used to determine whether the mean score of a sample significantly differs from a known or hypothesized population mean (Snedecor & Cochran, 1989). In this study, smallholder farmers' responses on indigenous knowledge indicators (e.g., awareness of pollinator species, understanding of pollination roles and traditional practices supporting pollinators) were collected using questionnaires. Each farmer's score on knowledge was computed and the sample mean was compared against a test value (μ_0). The one-sample t-test statistic was computed as:

$$t = \frac{\bar{X}}{s/\sqrt{n}}$$

Where:

$\bar{x}$ = sample mean score of knowledge
$\mu 0$ = hypothesized population mean (test value)
s = standard deviation of the sample
n = sample size

The null hypothesis (H_0) stated that there is no significant difference between farmers' indigenous knowledge and the hypothesized test value, while the alternative hypothesis (H_1) stated that a significant difference exists. The test was carried out at a 5% significance level ($\alpha = 0.05$). If the computed *p*-value was less than 0.05, the null hypothesis was rejected, indicating that farmers' knowledge significantly differed from the expected level. The analysis was conducted using IBM SPSS Statistics version 28.0 (IBM Corp., 2021).

3.7 Ethical Considerations

This study adhered to ethical research principles to ensure respect, integrity, and protection of all participants and the environment. Approval to conduct the research was obtained from relevant institutional review boards and research authorization bodies, including the National Commission for Science, Technology and Innovation (NACOSTI), and local county authorities. Prior to data collection, community leaders and agricultural extension officers were consulted to obtain gatekeeper consent and to foster trust between the researcher and the participants.

Participation in the study was voluntary, and informed consent was obtained from each respondent before administering questionnaires. Farmers were clearly informed about the purpose of the study, the expected duration of their participation, and their right to withdraw at any point without facing any negative consequences. Confidentiality was guaranteed by assigning codes instead of names on data collection tools, and all information gathered was treated strictly for academic purposes only.

Special care was taken to avoid any form of coercion, and questions were designed in a culturally sensitive manner to respect local traditions and indigenous knowledge systems.

In addition, the study ensured that findings related to pollinators and farming practices would not expose participants to risks such as stigmatization or misuse of their knowledge. Where knowledge of pollinator management was shared, it was acknowledged respectfully, recognizing the intellectual contributions of local farmers.

Environmental ethics were also considered, especially during bee sampling. Non-destructive sampling techniques were used to minimize harm to bee populations and their habitats. The study avoided over-collection of specimens to preserve biodiversity and ensured that all activities were conducted in compliance with conservation guidelines. The results of the study will be shared with the local community and relevant stakeholders to promote sustainable pollinator conservation and farming practices.

CHAPTER FOUR

RESULTS

4.1 Abundance of Bees

A total of 1,106 bees from 2 families and 7 species were collected from the three study habitats. *Apidae* was the most abundant family with four bee species. The distribution of total bee specimens collected comprised of; 600 *Apis mellifera,* 200 *Pseudapis spp.,* 90 from *Lasioglossum spp.,* 70 from *Xylocopa spp., Braunsapis spp.* had 60, *Ceratina spp.* with 50 while *Heriades spp.* had 36 individuals (Table 4.1).

Table 4.1: Bee Family, Genera and Species Names

	Family	**Genus**	**Species**	**No. of individuals**	**Abundance (%)**
1	Apidae	Apis	Mellifera	600	54.3
		Xylocopa	Sp.	70	6.3
		Ceratina	Sp.	50	4.5
		Braunsapis	Sp.	60	5.4
2	Halictidae	Pseudapis	Sp.	200	18.1
		Lasioglossum	Sp.	90	8.1
		Heriades	Sp.	36	3.3
Total				**1,106**	**100**

In terms of percentage abundance, out of the aggregate number of honey bee species collected, 54.3% were *A.* mellifera followed by 18.1% *Pseudapis spp.*, 8.1% *Lasioglossum spp.*, 6.3% *Xylocopa spp.*, 5.4% *Braunsapis spp.*, 4.5% *Ceratina sp.* while *Heriades spp.* had the least, 3.3% of the total bee specimens collected as shown in Figure 4.1.

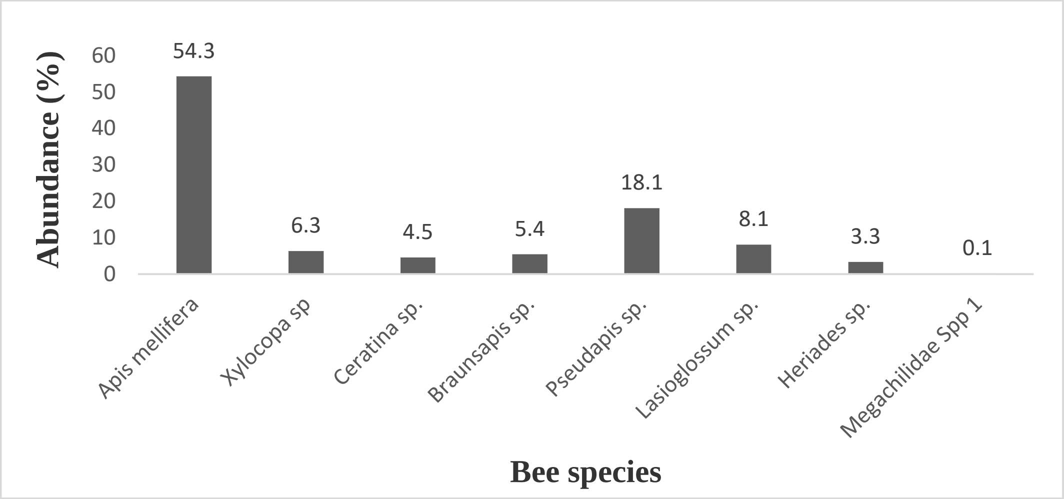

Figure 4.1: Bee Species Abundance

4.1.1 Abundance of Bees in Each Habitat

The natural forest habitat recorded the highest bee species abundance of 594 individuals followed by rangeland and the cultivated land had the least bee species abundance of 218 as illustrated in Table 4.2. The key for bee species identification with individual bee species score is as illustrated in Appendix 3.

Table 4.2: Bees Species Abundance in Each Habitat

Bee species	Cultivated farm		Rangeland		Natural Forest Edge	
	No. of individual	**Percentage**	**No. of individuals**	**Percentage**	**No. of individuals**	**Percentage**
Apis mellifera	110	50.5	150	51.0	340	57.2
Xylocopa sp.	13	6.0	20	6.8	37	6.2
Ceratina sp.	16	7.3	15	5.1	19	3.2
Braunsapis sp.	12	5.5	20	6.8	28	4.7
Pseudapis sp.	39	17.9	51	17.3	110	18.5
Lasioglossum sp.	20	9.2	28	9.5	42	7.1
Heriades sp.	8	3.7	10	3.4	18	3.0
Totals	**218**	**100**	**294**	**100**	**594**	**100**

There was no statistical significance ($p>0.05$) on bee species abundance on cultivated habitat as shown in Table 4.3.

Table 4.3: Statistical Analysis of Bee Species Abundance on Cultivated Land Habitat

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
C	2.277	6	.063	14.30000	-1.0698	29.6698

There was no statistical significance (p>0.05) on bee species abundance on rangeland habitat as shown in Table 4.4.

Table 4.4: Statistical Analysis of Bee Species Abundance on Rangeland Habitat

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R	2.247	6	.066	14.27143	-1.2726	29.8154

There was no statistical significance (p>0.05) on bee species abundance on natural forest habitat as shown in Table 4.5.

Table 4.5: Statistical Analysis of Bee Species Abundance on Natural Forest Habitat

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
N	1.921	6	.103	14.27143	-3.9089	32.4518

Bee species distribution in each habitat was computed and the natural habitat recorded the highest bee species abundance of 594 individuals followed by rangeland and the cultivated habitat had the least bee species abundance of 218 as illustrated in Table 4.6.

Table 4.6: Bee Species Abundance in Each Habitat

Habitat	No. of individuals	Abundance (%)
Cultivated land	218	19.7
Rangeland	294	26.6
Natural forest edge	594	53.7
Total	**1,106**	**100**

The percentage abundance of the bee species collected in each habitat was computed with the natural forest edge recording the highest percentage abundance of 53.7% followed by rangeland at 26.6% and the cultivated habitat had the least percentage bee species abundance of 19.7% as presented in Fig. 4.3.

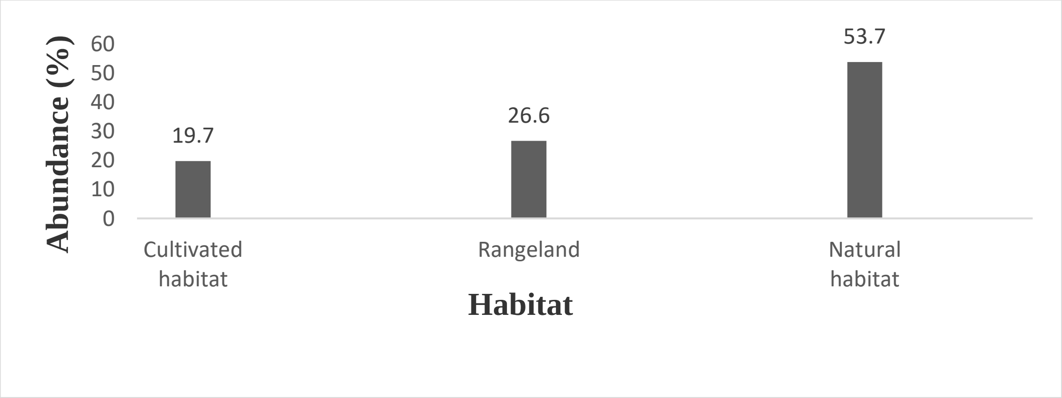

Figure 4.2: Bee Species Abundance in Each Habitat

4.1.2 Similarity of Bee Species Abundance between Different Habitats

There was a statistical significance ($p<0.05$) between the cultivated habitat & rangeland as presented in Table 4.7.

Table 4.7: Statistical Analysis on Bee Species Abundance between Cultivated Habitat and Rangeland

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	7864.357	5	1572.871	3145.743	.014
Within Groups	.500	1	.500		
Total	**7864.857**	**6**			

There was a statistical significance ($p<0.05$) between the cultivated habitat & natural forest edge as shown in Table 4.8.

Table 4.8: Statistical Analysis on Bee species Abundance between Cultivated Habitat and Forest Edge

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	7864.357	5	1572.871	3145.743	.014
Within Groups	.500	1	.500		
Total	**7864.857**	**6**			

There was a statistical significance ($p<0.05$) between rangeland & natural forest edge as presented in Table 4.9.

Table 4.9: Statistical Analysis on Bee Species Abundance between Rangeland and Forest Edge

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	81856.357	5	16371.271	404.229	.038
Within Groups	40.500	1	40.500		
Total	**81896.857**	**6**			

4.1.3 Commonest Bee Species Based on Number of Encounters on Each Habitat

A. mellifera was the most common bee species in the three study habitats followed by *Pseudapis sp.* while *Heriades spp* was the least common bee species in the study habitats as shown in Fig. 4.4.

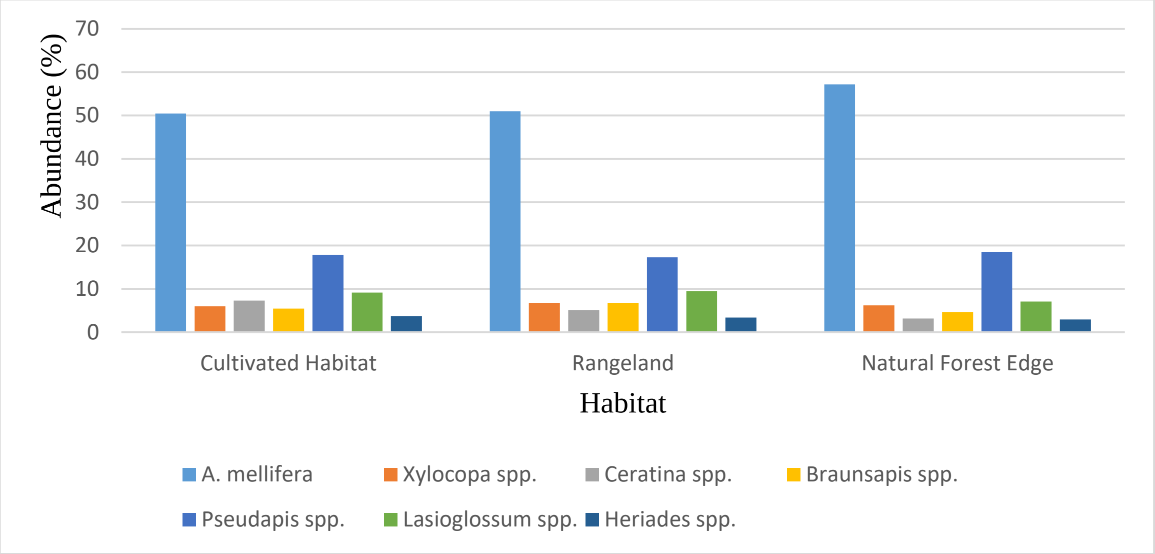

Figure 4.3: Commonest Bee Species Based on Number of Encounters on Each Habitat

4.2 Diversity of the Bee Species

4.2.1 Diversity of the Bees in the Cultivated Habitat

Bee species diversity in the cultivated habitat was computed based on individual bee species abundance. A diversity index, *H*/= 1.511 was obtained as illustrated in Table 4.10.

Table 4.10: Diversity Index of Bee Species in the Cultivated Habitat

Bee species	**No. of individuals**	**p*i*= Sample/sum**	**ln(p*i*)**	**P*i* *ln(p*i*)**
Apis mellifera	110	0.505	-0.683	-0.345
Xylocopa sp.	13	0.059	-2.830	-0.167
Ceratina sp.	16	0.073	-2.617	-0.191
Braunsapis sp.	12	0.055	-2.900	0.159
Pseudapis sp.	39	0.179	-1.720	-0.308
Lasioglossum sp.	20	0.092	-2.386	-0.219
Heriades sp.	8	0.037	-3.297	-0.122
Sum	**218**		**Total**	**1.511**

Diversity index *H*/; summation of p*i**ln (p*i*) of each bee species and therefore;

H/= 1.511.

4.2.2 Diversity of Bees in Rangeland Habitat

Bee species diversity in the rangeland habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.424 was obtained as illustrated in Table 4.11.

Table 4.11: Diversity Index of Bee Species in the Rangeland Habitat

Bee species	**No. of individuals**	**pi= Sample/sum**	**ln(pi)**	**Pi *ln(pi)**
Apis mellifera	150	0.510	-0.673	-0.343
Xylocopa sp.	20	0.068	-2.688	-0.182
Ceratina sp.	15	0.051	-2.976	-0.152
Braunsapis sp.	20	0.068	-2.688	-0.183
Pseudapis sp.	51	0.173	-1.754	-0.303
Lasioglossum sp.	28	0.095	-2.354	-0.224
Heriades sp.	10	0.034	-1.079	-0.037
Sum	**294**		**Total**	**1.424**

Diversity index $H^{/}$; summation of pi*ln (pi) of each bee species and therefore;

$H^{/}$= 1.424.

4.2.3 Diversity Index of Bees in the Natural Forest Habitat

Bee species diversity in the natural habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.351 was obtained as illustrated in Table 4.12.

Table 4.12: Diversity Index of Bee Species in Natural Habitat

Bee species	**No. of individuals**	**pi= Sample/sum**	**ln(pi)**	**Pi *ln(pi)**
Apis mellifera	340	0.572	-0.559	-0.320
Xylocopa sp.	37	0.062	-2.781	-0.172
Ceratina sp.	19	0.032	-3.442	0.110
Braunsapis sp.	28	0.047	-3.058	-0.144
Pseudapis sp.	110	0.185	-1.687	-0.312
Lasioglossum sp.	42	0.071	-2.645	-0.188
Heriades sp.	18	0.030	-3.507	-0.105
Sum	**594**		**Totals**	**1.351**

Diversity index $H^{/}$; summation of pi*ln (pi) of each bee species and therefore;

$H^{/}= 1.351$

Comparison of the diversity indices of the three habitats was done. Cultivated habitat had the highest diversity index $H^{/}= 1.511$ followed by rangeland with $H^{/}= 1.424$ while the natural habitat had the least at $H^{/}= 1.351$ as shown in Fig. 4.4.

Figure 4.4: Comparison of the Diversity Indices of the Three Study Habitats

4.2.4 Overall Diversity Index

The overall bee species diversity was computed based on individual bee species abundance. A diversity index, $H^{/}= 1.430$ was obtained as illustrated in Table 4.13.

Table 4.13: Overall Diversity Index

Bee species	**No. of individuals**	**p*i*= Sample/sum**	**ln(p*i*)**	**P*i* *ln(p*i*)**
1 Apis mellifera	600	0.542	-0.612	-0.332
2 Xylocopa spp.	70	0.063	-2.765	-0.174
3 Ceratina spp.	50	0.045	-3.101	-0.140
4 Braunsapis spp.	60	0.054	-2.919	-0.158
5 Pseudapis spp.	200	0.181	-1.709	-0.309
6 Lasioglossum spp.	90	0.081	-2.513	-0.204
7 Heriades spp.	36	0.033	-3.411	-0.113
Sum	**1,106**		**Total**	**1.430**

4.3 Impact of Seasonal Weather Variations on Abundance and Diversity of Bee Species in Loitokitok Sub County, Kenya

4.3.1 Bee Species Abundance in Each Season per Habitat

Bee species distribution in each habitat during a dry spell and a rainy season was computed. The rain season recorded the highest bee species abundance of 818 while the dry season recorded a lower bee species abundance of 288 as shown in Table 4.14. The number and type of species however did not vary between the two seasons.

Table 4.14: Bee Species Abundance in Each Season per Habitat

Habitat	Rainy season		Dry spell	
	No. of individuals	Abundance (%)	No. of individuals	Abundance (%)
Cultivated land	133	16.3	85	29.5
Rangeland	197	24.1	97	33.7
Natural forest edge	488	59.6	106	36.8
TOTAL	**818**	**100**	**288**	**100**

Comparison of the percentage abundance between the study habitats during the rainy season and dry season was done as shown in Fig. 4.5.

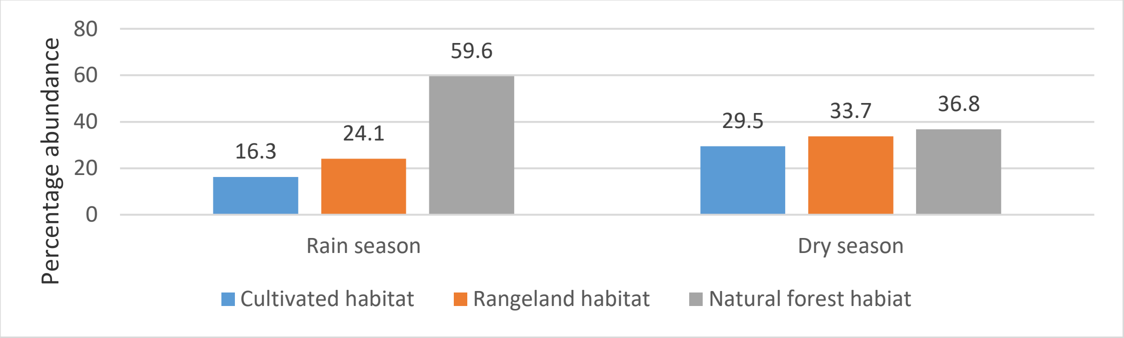

Figure 4.5: Comparison between Percentage Abundance of the Study Habitats during the Rainy Season and Dry Season

However, there was no statistical significance (p>0.05) between percentage abundance of the study habitats during the rainy season and dry season as indicated in Table 4.15.

Table 4.15: Statistical Analysis between Percentage Abundance of the Study Habitats during the Rainy Season and Dry Season

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	R – D	.00000	19.82725	11.44727	-49.25363	49.25363	.000	2	1.000

4.3.2 Diversity of the Bee Species during Rainy Season

4.3.2.1 Diversity of the Bees in the Cultivated Habitat

Bee species diversity in the cultivated habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.344 was obtained as illustrated in Table 4.16.

Table 4.16: Diversity Index of Bee Species in Cultivated Habitat

Bee species	No. of individuals	p*i*= Sample/sum	ln(p*i*)	P*i* *ln(p*i*)
Apis mellifera	80	0.602	-0.508	-0.3058
Xylocopa sp.	11	0.083	-2.4889	-0.2066
Ceratina sp.	8	0.060	-2.8134	-0.1688
Braunsapis sp.	6	0.045	-3.1011	-0.1396
Pseudapis sp.	9	0.068	-2-6882	-0.1828
Lasioglossum sp.	16	0.120	-2.1203	-0.2544
Heriades sp.	3	0.023	-3.7723	-0.0868
Sum	**133**		**Total**	**1.3438**

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore;

$H^{/}$= 1.344.

4.3.2.2 Diversity of Bees in the Range Habitat

Bee species diversity in the range habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.311 was obtained as illustrated in Table 4.17.

Table 4.17: Diversity Index of Honey Bees in Range Habitat

Bee species	**No. of individuals**	**pi= Sample/sum**	**ln(pi)**	**Pi *ln(pi)**
Apis mellifera	112	0.568	-0.566	-0.3213
Xylocopa sp.	11	0.056	-2.882	-0.1614
Ceratina sp.	9	0.046	-3.079	-0.1416
Braunsapis sp.	14	0.071	-2.645	-0.1878
Pseudapis sp.	32	0.162	-1.820	-0.2947
Lasioglossum sp.	16	0.081	-2.513	-0.2036
Heriades sp.	3	0.176	-1.737	-0.3058
Sum	**197**		**Total**	**1.3114**

Diversity index $H^{/}$; summation of pi*ln (pi) of each bee species and therefore;

$H^{/}$= 1.311.

4.3.2.2 Diversity of the Bees in the Natural forest Habitat

Bee species diversity in the natural forest habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.117 was obtained as illustrated in Table 4.18.

Table 4.18: Diversity Index of Bee Species in Natural Forest Habitat

Bee species	**No. of individuals**	**pi= Sample/sum**	**ln(pi)**	**Pi *ln(pi)**
Apis mellifera	304	0.623	-0.473	-0.2948
Xylocopa sp.	21	0.043	-3.147	-0.1353
Ceratina sp.	7	0.014	-4.269	-0.0598
Braunsapis sp.	19	0.039	-3.244	-0.1265
Pseudapis sp.	98	0.200	-1.609	-0.3219
Lasioglossum sp.	32	0.066	-2.718	-0.1794
Heriades sp.	7	0.014	-4.269	-0.0598
Sum	**488**		**Total**	**1.1177**

Diversity index $H^{/}$; summation of pi*ln (pi) of each bee species and therefore;

$H^{/}$= 1.117.

Comparison of the diversity indices of the three habitats was done. Cultivated habitat had the highest diversity index $H^{/}$= 1.344 followed by rangeland with $H^{/}$= 1.311 while the natural habitat had the least at $H^{/}$= 1.117 as shown in Fig. 4.6.

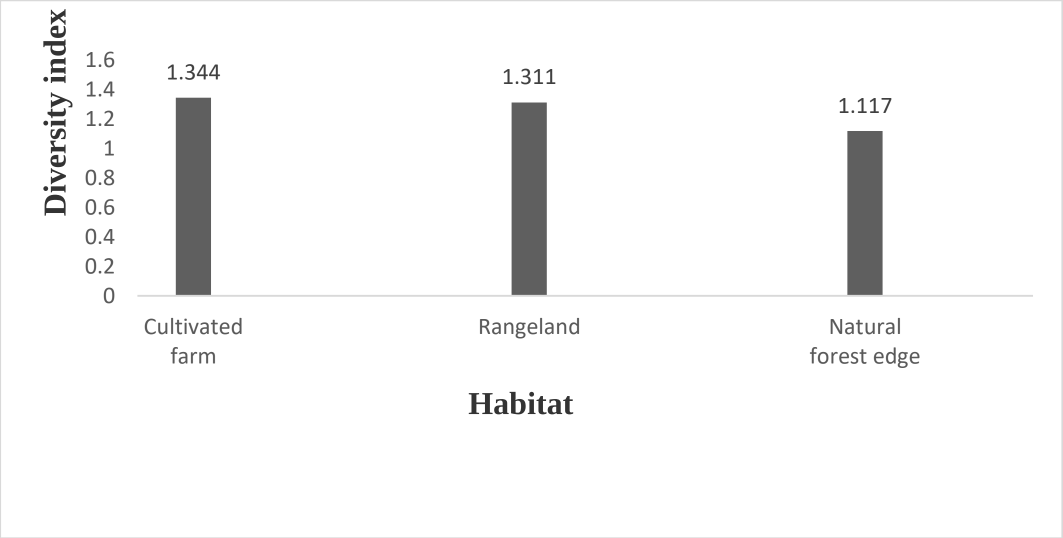

Figure 4.6: Comparison of the Diversity Indices of the Three Study Habitats during Rainy Season

4.3.3 Diversity of the Bee Species during Dry Season

4.3.3.1 Diversity of the Bees in the Cultivated Habitat

Bee species diversity in the cultivated habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.546 was obtained as illustrated in Table 4.19.

Table 4.19: Diversity Index of Bee Species in Cultivated Habitat

Bee species	No. of individuals	p*i*= Sample/sum	ln(p*i*)	P*i* *ln(p*i*)
Apis mellifera	30	0.353	-1.041	-0.3676
Xylocopa sp.	2	0.024	-3.730	-0.0895
Ceratina sp.	8	0.094	-2.365	-0.2223
Braunsapis sp.	6	0.071	-2.645	-0.1878
Pseudapis sp.	30	0.353	-1.041	-0.3676
Lasioglossum sp.	4	0.047	-3.058	-0.1437
Heriades sp.	5	0.059	-2.830	-0.1670
Sum	**85**		**Total**	**1.5455**

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore;

$H^{/}$= 1.546.

4.3.3.2 Diversity of the Bees in the Range Habitat

Bee species diversity in the range habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.701 was obtained as shown in Table 4.20.

Table 4.20: Diversity Index of Bee Species in Range Habitat

Bee species	**No. of individuals**	**p*i*= Sample/sum**	**ln(p*i*)**	**P*i* *ln(p*i*)**
Apis mellifera	38	0.392	-0.936	-0.3671
Xylocopa sp.	9	0.093	-2.375	-0.2209
Ceratina sp.	6	0.062	-2.781	-0.1724
Braunsapis sp.	6	0.062	-2.781	-0.1724
Pseudapis sp.	19	0.196	-1.630	-0.3194
Lasioglossum sp.	12	0.124	-2.087	-0.2589
Heriades sp.	7	0.072	-2.631	-0.1894
Sum	**97**		**Total**	**1.7005**

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore;

$H^{/}$= 1.701.

4.3.3.3 Diversity of the Bees in the Natural-forest Habitat

Bee species diversity in the natural forest habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.812 was obtained as illustrated in Table 4.21.

Table 4.21: Diversity Index of Bee Species in Natural Forest Habitat

Bee species	**No. of individuals**	**p*i*= Sample/sum**	**ln(p*i*)**	**P*i* *ln(p*i*)**
Apis mellifera	36	0.340	-1.079	-0.3668
Xylocopa sp.	16	0.151	-1.891	-0.2855
Ceratina sp.	12	0.113	-2.180	-0.2464
Braunsapis sp.	9	0.085	-2.465	-0.2095
Pseudapis sp.	12	0.113	-2.180	-0.2464
Lasioglossum sp.	10	0.094	-2.364	-0.2223
Heriades sp.	11	0.104	-2.263	-0.2354
Sum	**106**		**Total**	**1.8123**

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore;

$H^{/}$= 1.812.

Comparison of the diversity indices between the three study habitats was done. Natural forest habitat had the highest diversity index $H' = 1.812$ followed by rangeland with $H' = 1.701$ while the cultivated habitat had the least at $H' = 1.546$ as shown in Fig. 4.7.

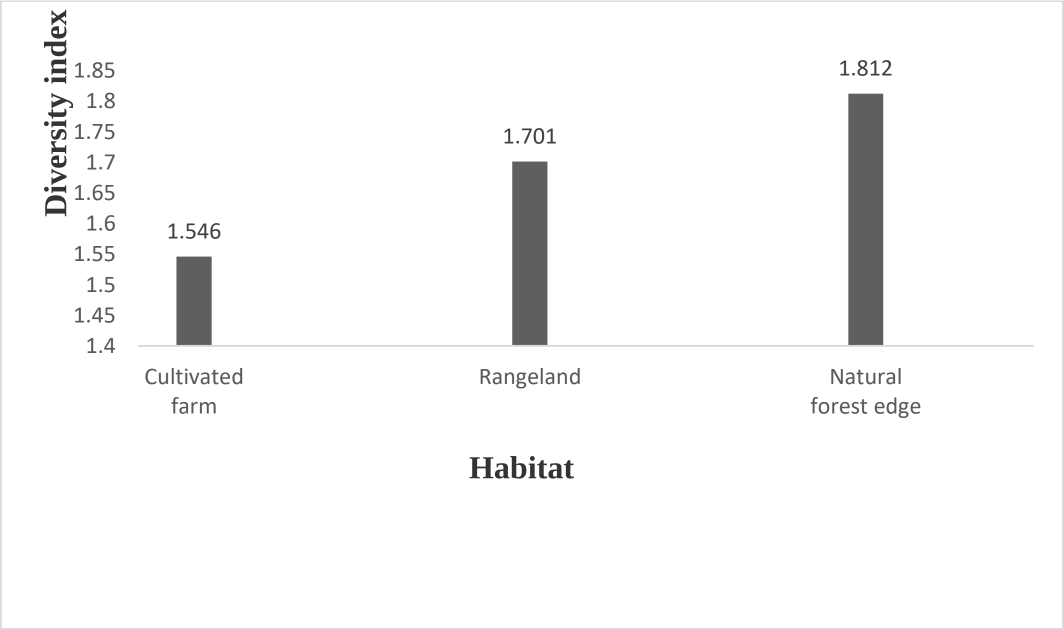

Figure 4.7: Comparison of the Diversity Indices of the Three Study Habitats during Dry Season

Comparison of the diversity indices between the study habitats during the rainy season and dry season was done as shown in Fig. 4.8

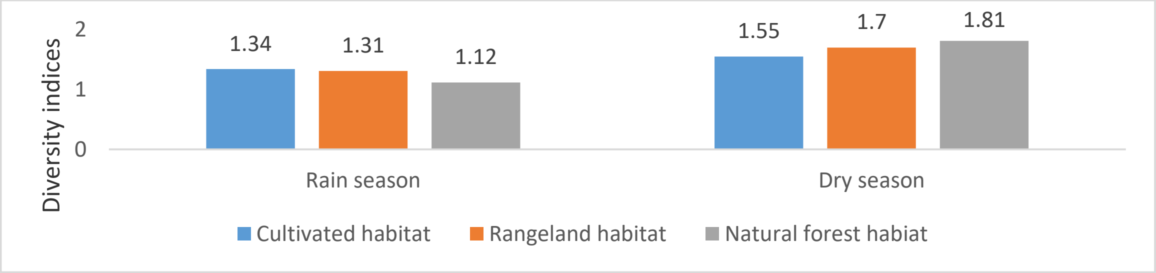

Figure 4.8: Comparison of the Diversity Indices between the Study Habitats during the Rainy Season and Dry Season

4.3.3.4 Similarity of Bee species Abundance between study Habitats in the two Seasons using Sorenson's Similarity Index

Sorenson's similarity index Cs was used to compare similarity of bee species abundance across the three habitats between the two seasons. During the rainy season, cultivated habitat had the highest similarity association with rangeland at 80.6% although the Cs was quite low between cultivated habitat and natural forest habitat at 42.8%. Similarly, during the dry season, cultivated habitat had the highest similarity association with rangeland at 93.4% and again, the Cs was relatively low between rangeland habitat and natural forest habitat at 75.2%.

4.4 State of Indigenous Knowledge of Pollinator Importance among Small-holder Farmers in Loitokitok Sub County, Kenya

4.4.1 Demographic Characteristics of the Respondents

The respondents for the study were 143 households. These categories were characterized by gender, age, marital status and farm size.

4.4.1.1 Distribution of Respondents by Gender

Most respondents were female 87 (60.8%) while male respondents were 56 (39.2%) as illustrated in Table 4.22.

Table 4.22: Gender of the Respondents

Gender	Frequency (f)	Percentage (%)
Male	56	39.2
Female	87	60.8
Total	**143**	**100**

4.4.1.2 Age of the Respondents

Table 4.9 reveals that some of the respondents 46 (32.20%) were aged 41-50 years, 41 (28.7%) were aged 31-40 years, 29 (20.3%) were aged 19-30 years. The table further reveals that 10 (6.9%) respondents were below 18 years old while 17 (11.9%) were more than 51 years (Table 4.23).

Table 4.23: Distribution of Respondents by Age

Age (years)	Frequency (f)	Percentage (%)
<18	10	6.9
19 -30	29	20.3
31 - 40	41	28.7
41-50	46	32.2
>51	17	11.9
Total	**143**	**100**

4.4.1.3 Marital Status of the Respondents

It was established that majority of the respondents 89 (62.2%) were married, 27 (18.9%) were widowed while 19 (133%) were single. The Table further reveals that 5 (3.5%) of the respondents were separated while 3 (3.1%) were divorced (Table 4.24).

Table 4.24: Distribution of Respondents by Marital Status

Marital Status	Frequency (f)	Percentage (%)
Single	19	13.3
Married	89	62.2
Separated	5	3.5
Divorced	3	2.1
Widowed	27	18.9
Total	**143**	**100**

4.4.1.4 Distribution of Respondents by Farm Size

Most of the respondents 45 (31.5%) had 2-3 acres of land followed by 30 (21.0%) with >5 acres, 26 (18.2%) with 4-5 acres while 20 (13.9%) had 1 acre size of land. Fourteen (9.8%) respondents had ¼ acre of land while 8 (5.6%) had $^{1}/_{8}$ acre of land as illustrated in Table 4.25.

Table 4.25: Distribution of Respondents by Farm Size

Acreage	**Frequency (f)**	**Percentage (%)**
$^1/_8$ Acre	8	5.6
$^1/_4$ Acre	14	9.8
1 Acre	20	13.9
2-3 Acres	45	31.5
4-5 Acres	26	18.2
>5 Acres	30	21.0
Total	**143**	**100**

4.4.2 Knowledge on Bee Pollinators and Pollination

Questionnaire administration was done to 143 households. The administered questionnaires had questions on pollination aspects such as awareness of bees, their domestication, number of hives and number of hives colonized and un-colonized, location of hives in farms and honey harvesting.

4.4.2.1 Farmers' Awareness of Bees involvement in pollination

Majority, 141 (98.6%) of the farmers out of the total sample of 143 respondents revealed that they were aware of bees' involvement in pollination while 2 (1.4%) indicated that they were not aware as illustrated in Table 4.26.

Table 4.26: Farmers' Awareness of Bees' Involvement in Pollination

Response	**Frequency (f)**	**Percentage (%)**
Yes	141	98.6
No	2	1.4
Total	**143**	**100**

4.4.2.2 Domestication of Bees

Majority, 109 (76.2%) of the farmers proved that they were aware of bees while 34 (23.8%) demonstrated that they were not aware of bees as illustrated in Table 4.27.

Table 4.27: Farmers' Responses on Domestication of Bees

Response	Frequency (f)	Percentage (%)
Yes	11	7.3
No	132	92.3
Total	**143**	**100**

4.4.2.3 Number of Bee hives

Four (36.4%) of the respondents showed that they had established 4 bee hives followed by 3 (27.2%) with >10 bee hives while with <4 and 7-10 bee hives, each had 2 (18.2%) of the respondents respectively as illustrated in Table 4.28.

Table 4.28: Farmers' Responses on Number of Bee Hives Established

Response	Frequency (f)	Percentage (%)
<4	2	18.2
4-6	4	36.4
7-10	2	18.2
>10	3	27.2
Total	**11**	**100**

4.4.2.4 Colonization of the Bee Hives

Seven (63.6%) farmers proved that not all the bee hives were colonized while 4 (36.4%) indicated that all the bee hives were colonized as illustrated in Table 4.29.

Table 4.29: Farmers' Responses on Colonization of the Bee Hives

Response	Frequency (f)	Percentage (%)
Yes	4	36.4
No	7	63.6
Total	**11**	**100**

4.4.2.5 Number of Un-Colonized Bee Hives

Only one (9.1%) of the respondents expressed that 1-2 beehives were not colonized followed by 2 (18.1%) with >7 with un-colonized bee hives while with 3-4 and 5-6 un-colonized bee hives were 3 (27.3%) and 5 (45.5%) of the respondents respectively as illustrated in Table 4.30.

Table 4.30: Farmers' Responses on Number of Un-Colonized Bee Hives

Response	Frequency (f)	Percentage (%)
1-2	1	9.1
3-4	3	27.3
5-6	5	45.5
>7	2	18.1
Total	**11**	**100**

4.4.2.6 Position of Bee Hives on Farms

Six (54.6%) of the respondents showed that they positioned their beehives under trees followed by 3 (27.2%) on farmland while 2 (18.2%) of the respondents placed their bee hives on fence edge as illustrated in Table 4.31.

Table 4.31: Farmers' Responses on Position of Bee Hives on Farms

Response	Frequency (f)	Percentage (%)
Farmland	3	27.2
Under Trees	6	54.6
Fence edge	2	18.2
Total	**11**	**100**

4.4.2.7 Farmers' Knowledge on Different Types of Bees

Both genders had some information concerning different types of bees. However, male respondents demonstrated a higher level knowledge of *Xylocopa spp*. than other bee species bees as compared to the female respondents. It was established that among the bee species, majority, 53.6% of the respondents had more information on *Xylocopa* spp. than other bee species. Similarly, some, 20 (22.9%) of the female respondents had more knowledge on *Lasioglossum spp.* than their male counterparts. However, some, 16.1% of the males had more knowledge on *Pseudapis spp.* than the females 7 (8.1%) as illustrated in Table 4.32.

Table 4.32: Percentage of Respondents who were Familiar with Different Types of Bees

Bee species	Male		Female		Totals	
	Freq	Perc	Freq	Perc	Freq	Perc
Xylocopa spp.	**21**	**37.5**	**14**	**16.1**	**35**	**53.6**
Ceratina spp.	13	23.2	16	18.4	29	41.6
Braunsapis spp.	4	7.1	13	14.9	17	22.0
Pseudapis spp.	9	16.1	7	8.1	16	24.2
Lasioglossum spp.	6	10.7	20	22.9	26	23.6
Heriades spp.	3	5.4	17	19.5	20	24.9
Totals	**56**	**100**	**87**	100	**143**	

However, there were no statistical significance (p>0.05) among male and females who were familiar with different types of bees as shown in Table 4.33.

Table 4.33: Statistical Analysis on Percentage of Respondents Who Were Familiar with Different Types of Bees

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	M - F	.01667	13.80933	5.63764	-14.47534	14.50867	.003	5	.998

4.4.2.8 Nesting Site of Bees

Fifty-six (39.2%) of the respondents specified that tree branches were the nesting sites for the bees followed by 35 (24.4%) of the respondents who indicated that fence edges were bee nesting sites. Nineteen (13.3%) of the farmers showed that house parts were bee nesting sites while house structures, dead wood and ground had 12 (8.4%), 9 (6.3%) and 12 (8.4%) of the respondents respectively as shown in Table 4.34.

Table 4.34: Farmers' Responses on Nesting Site of Bees

Response	Frequency (f)	Percentage (%)
Tree branches	56	39.2
House structures	12	8.4
Fence edge	35	24.4
Dead wood	9	6.3
House parts	19	13.3
Ground	12	8.4
Total	**143**	**100**

However, there was a statistical significance ($p<0.05$) farmers' responses on nesting site of bees as shown in Table 4.35.

Table 4.35: Statistical Analysis on Farmers' Responses on Nesting Site of Bees

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
P	3.182	5	.024	16.66667	3.2025	30.1308

4.4.2.9 Farmers' Ability to Harvest Honey

Majority 123 (86.01%) of the farmers showed that they were able to harvest honey from the bees while 20 (13.99%) expressed that they were not able to harvest honey as illustrated in Table 4.36.

Table 4.36: Farmers' Responses on Ability to Harvest Honey

Response	Frequency (f)	Percentage (%)
Yes	123	86.01
No	20	13.99
Total	**143**	**100**

4.4.2.10 Resources Bees obtain from Flowers

Majority 112 (78.3%) of the farmers pointed out that bees collected pollen from flowers while 31 (21.7%) hinted that bees collected nectar from flowers as illustrated in Table 4.37.

Table 4.37: Farmers' Responses on What Bees Obtain from Flowers

Resource	Frequency (f)	Percentage (%)
Pollen	112	78.3
Nectar	31	21.7
Total	**143**	**100**

4.4.2.11 Benefits of Bee Visitations on Flowers

Eighty-eight (61.5%) of the farmers revealed that bee visitations on plants aids in pollination while 41 (28.7%) and 14 (9.8%) showed that they improved produce quality and increased crop yields respectively as shown in Table 4.38.

Table 4.38: Farmers' Responses on Benefits of Bee Visitation on Flowers

Resource	Frequency (f)	Percentage (%)
Aids crop pollination	88	61.5
Improved produce quality	41	28.7
Increased crop yields	14	9.8
Total	**143**	**100**

However, there was no statistical significance (p>0.05) farmers' responses on benefits of bee visitation on flowers as shown in Table 4.39.

Table 4.39: Statistical Analysis on Farmers' Responses on Benefits of Bee Visitation on Flowers

<table>
<tr><th rowspan="3"></th><th colspan="6">Test Value = 0</th></tr>
<tr><th rowspan="2">t</th><th rowspan="2">Df</th><th rowspan="2">Sig. (2-tailed)</th><th rowspan="2">Mean Difference</th><th colspan="2">95% Confidence Interval of the Difference</th></tr>
<tr><th>Lower</th><th>Upper</th></tr>
<tr><td>P</td><td>2.207</td><td>2</td><td>.158</td><td>33.33333</td><td>-31.6507</td><td>98.3173</td></tr>
</table>

4.4.3 Pollinator Natural History

The study aimed to establish the type and usage of pesticides in control of crop pests, type of live fences and also inputs used by farmers to boost bee pollination.

4.4.3.1 Farmers’ Responses on Pesticide Use on their Farms

Majority 113 (79.02%) of the farmers indicated that they used pesticides to control pests in their farms while 20 (20.98%) specified that they were not able to harvest honey as illustrated in Table 4.40.

Table 4.40: Farmers’ Responses on Pesticide Use on Their Farms

Response	Frequency (f)	Percentage (%)
Yes	113	79.02
No	30	20.98
Total	**143**	**100**

4.4.3.2 Farmers’ Responses on time of Pesticide Use on their Farms

Thirty six (31.9%) of the farmers pin pointed that they used pesticides during flowering time to control pests in their farms, 31 (27.4%) during fruiting time, 25 (22.1%) during planting time while 21 (18.6%) proved that they used pesticides to control pests during weeding time as illustrated in Table 4.41.

Table 4.41: Farmers’ Responses on Time of Pesticide Use on Their Farms

Time of application	Frequency (f)	Percentage (%)
During planting	25	22.1
Weeding time	21	18.6
Flowering time	36	31.9
Fruiting time	31	27.4
Total	**113**	**100**

There was a statistical significance ($p<0.05$) on farmers’ responses on time of pesticide use on their farms as shown in Table 4.42

Table 4.42: Statistical Analysis on Farmers' Responses on Time of Pesticide Use on their Farms

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
P	8.544	3	.003	25.00000	15.6881	34.3119

4.4.3.3 Other Pest Control Methods

Forty-five (31.4%) of the farmers expressed that they used smoking to control pests in their farms, 37 (25.9%) used ash, 34 (23.8%) hunting while 16 (11.2%) and 11 (7.7%) used weed control and hand picking to control pests respectively as shown in Table 4.43.

Table 4.43: Farmers' Responses on Other Pest Control Measures on their Farms

Method	Frequency (f)	Percentage (%)
Smoking	45	31.4
Use of ash	37	25.9
Weed control	16	11.2
Hunting	34	23.8
Hand picking	11	7.7
Total	**143**	**100**

There was a statistical significance (p<0.05) on farmers' responses on other pest control measures on their farms as shown in Table 4.44.

Table 4.44: Statistical Analysis on Farmers' Responses on Other Pest Control Measures on their Farms

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
P	4.428	4	.011	20.00000	7.4607	32.5393

4.4.3.4 Fencing Type on Farms

Majority, 78 (54.5%) of the farmers revealed that they had live fence on their farms, 34 (23.7%) barbed wire fence, 21 (14.7%) wooden fences while 6 (4.2%) and 4 (2.8%) had perimeter wall and woven fences on their farms respectively as shown in Table 4.45.

Table 4.45: Farmers' Responses on Fencing Type on Farms

Fence Type	Frequency (f)	Percentage (%)
Live fence	78	45.5
Wooden fence	21	14.7
Barbed Wire fence	34	23.7
Woven Wire	4	7.7
Perimeter wall fence	6	8.4
Total	**143**	**100**

There was a statistical significance ($p<0.05$) on farmers' responses on fencing type on farms as shown in Table 4.46.

Table 4.46: Statistical Analysis on Farmers' Responses on Fencing Type on Farms

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R	2.860	4	.046	20.00000	.5859	39.4141

4.4.3.5 Extent of Use of Fencing Type on Farms

Majority, 60 (76.9%) of the farmers demonstrated that they used live fence on their entire farms while 18 (23.1%) showed that they used it on farm sections. Wooden fence was used on the entire farm as indicated by 5 (23.8%) of the farmers while 16 (76.2%) of them used in on farm sections. Barbed wire fence, woven fence and perimeter wall fences were used only on farm sections as indicated by 34 (100%), 4 (100%) and 6 (100%) of the farmers respectively as shown in Table 4.47.

Table 4.47: Farmers' Responses on Extent of Use of Fencing Type on Farms

Fence type	Entire Farm		Farm section		Totals	
	Freq	Perc	Freq	Perc	Freq	Perc
Live fence	60	76.9	18	23.1	78	100
Wooden fence	5	23.8	16	76.2	21	100
Barbed wire fence	0	0	34	100	34	100
Woven Wire	0		4		4	100
Perimeter	0	0	6	100	6	100
Totals	**65**	0	**78**	100	**143**	100

However, there was no statistical significance (p>0.05) on farmers' responses on extent of use of fencing type on farms as shown in Table 4.48.

Table 4.48: Statistical Analysis on Farmers' Responses on Extent of Use of Fencing Type on Farms

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	E - S	-59.72000	66.72295	29.83941	-142.56748	23.12748	-2.001	4	.116

4.4.3.6 Fencing Type on Farms

Thirty, (20.9%) of the farmers indicated that they used *Croton macrostachyus* as a live fence while 28 (19.6%) and 15 (10.5%) used *Lantana camara* and *Markhamia lutea* as live fences respectively. The least plant species used as live fences were *Cypressus lustanica* and *Psidium guajava* at 5 (3.5%) respectively as indicated in Table 4.49.

Table 4.49: Farmers' Responses on Plant Species Used as Live Fences

Botanical Name	English Name	Maasai Name	Frequency	Percentage (%)
Croton macrostachyus (tree)	Croton		30	20.9
Cypressus lustanica (tree)	Cypress		5	3.5
Markhamia lutea (tree)	Markhamia		15	10.5
Dracaena fragrans (shrub)	Dracaena		14	9.8
Caesalpinia decapetala (shrub)	Cat's claw		11	7.7
Tithonia diversifolia (shrub)	Tithonia		12	8.4
Eucalyptus saligna (tree)	Eucalyptus		9	6.3
Lantana camara (shrub)	Lantana		28	19.6
Agave sisalana (shrub)	Sisal		14	9.8
Psidium guajava (tree)	Guava		5	3.5
		Total	**143**	**100**

There was a statistical significance ($p<0.05$) on farmers' responses on plant species used as live fences as shown in Table 4.50.

Table 4.50: Statistical Analysis on Farmers' Responses on Plant Species Used as Live Fences

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PS	5.313	9	.001	14.30000	8.2108	20.3892

4.4.3.7 Rationale of Using Live Fences on Farms

Twenty six, (18.2%) of the farmers argued that they used live fence on their farms since some were of medicinal value while 22 (15.4%) indicated that live fences were used to mark boundaries. Twenty one, (14.7%) hinted that live fences acted as source of fuel and also animal fodder, 20 (13.9%) indicated that live fences served as windbreakers while 19 (13.3%) and 14 (9.8%) specified that live fences provided shed for animal shelter and also as a source of building materials respectively as illustrated in Table 4.51.

Table 4.51: Rationale of Using Live Fences on Farms

Rationale	Frequency (f)	Percentage (%)
Animal fodder	21	14.7
Medicinal Value	26	18.2
Source of fuel	21	14.7
Source of building materials	14	9.8
Boundary marking	22	15.4
Act as wind breakers	20	13.9
Shed for animal shelter	19	13.3
Total	**143**	**100**

There was a statistical significance ($p<0.05$) on farmers responses on the rationale of using live fences on farms as shown in Table 4.52.

Table 4.52: Statistical Analysis on the Rationale of Using Live Fences on Farms

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R	14.990	6	.000	14.28571	11.9537	16.6177

4.4.3.8 Methods of Maintaining Live Fences

Some, 67 (49.9%) of the respondents demonstrated that they trimmed their live fences, 29 (20.3%) carried out weeding, 27 (18.9%) carried out gapping while 20 (13.9%) applied manures in maintaining live fences on their farms as shown in Table 4.53.

Table 4.53: Farmers' Responses on Methods of Maintaining Live Fences

Method	Frequency (f)	Percentage (%)
Trimming	67	49.9
Weeding	29	20.3
Gapping	27	18.9
Manuring	20	13.9
Total	**143**	**100**

There was no statistical significance ($p>0.05$) on farmers' responses on methods of maintaining live fences as shown in Table 4.54.

Table 4.54: Statistical Analysis on Farmers' Responses on Methods of Maintaining Live Fences

	Test Value = 0					
	t	**Df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	**Upper**
R	3.153	3	.051	25.75000	-.2389	51.7389

4.4.3.9 Flowering Time of Live Fence Plants

The respondents (88.1%) reported that the plants (in the fence) usually flowered at different times of the year, 7 (4.9%) showed that the plants flowered at the same time while 10 (7.0%) indicated that flowering coincided with those of the crops as shown in Table 4.55.

Table 4.55: Farmers' Responses on Flowering Time of Live Fence Plants

Response	Frequency (f)	Percentage (%)
Flowered at different times	126	88.1
Flowered at same time	7	4.9
Flowering coincided with crops	10	7.0
Total	**143**	**100**

4.4.3.10 Bee Visitation Preference on Live Fence and Crop Flowers

More than half of the respondents 86 (60.8%) suggested that bees preferred live fence flowers to crop flowers when flowering coincided as shown in Table 4.56.

Table 4.56: Farmers' Responses on Flowering Time of Live Fence Plants

Response	Frequency (f)	Percentage (%)
Live fence flowers	86	60.8
Crop flowers	56	39.2
Total	**143**	**100**

4.4.3.11 Other Insects Visiting Flowers

Forty seven, (32.9%) of the respondents specified that butterflies visited flowers, flies 25 (17.5%), moths 22 (15.4%), flower beetles 20 (13.9%), wasps 18 (12.6%) while ants had 11 (7.7%) as illustrated in Table 4.57.

Table 4.57: Other Insects Visiting Flowers

Insect	Frequency (f)	Percentage (%)
Butterflies	47	32.9
Moths	22	15.4
Flies	25	17.5
Wasps	18	12.6
Ants	11	7.7
Flower Beetles	20	13.9
Total	**143**	**100**

There was a statistical significance (p<0.05) on other insects visiting flowers as shown in Table 4.58.

Table 4.58: Statistical Analysis on Other Insects Visiting Flowers

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
R	4.743	5	.005	16.66667	7.6340	25.6993

4.4.3.12 Bees Moving in/out of Earth Holes

Majority, 139 (97.2%) of the farmers suggested that they noticed bees moving in/out of earth holes while 4 (2.8%) indicated that they did not notice bees moving in/out of earth holes as illustrated in Table 4.59.

Table 4.59: Farmers' Responses on Bees Moving In/Out of Earth Holes

Response	Frequency (f)	Percentage (%)
Yes	139	97.2
No	4	2.8
Total	**143**	**100**

4.4.3.13 Type of Bees Moving in/out of Earth Holes

Majority, 122 (85.3%) of the farmers revealed that stingless bees dwell mainly in earth holes while 21 (14.7%) indicated that solitary bees nest in earth holes as illustrated in Table 4.60.

Table 4.60: Farmers' Responses on Type of Bees Moving In/Out of Earth Holes

Bee species	**Frequency (f)**	**Percentage (%)**
Stingless bees	122	85.3
Solitary bees	21	14.7
Total	**143**	**100**

4.4.3.14 Enhancement of Pollinators on Farmland

Most of the respondents, 130 (90.9%) suggested that they would prefer enhancement of pollinators on their farmland while 13 (9.1%) indicated the contrary as illustrated in Table 4.61.

Table 4.61: Farmers' Responses on Enhancement of Pollinators on the Farmland

Response	**Frequency (f)**	**Percentage (%)**
Yes	130	90.9
No	13	9.1
Total	**143**	**100**

4.4.3.15 Methods of Enhancement of Pollinators on Farmland

Most of the respondents, 85 (65.4%) pointed out that they would favor constructing honeybee hives and planting more shrubs in their fence 42 (42.3%) in order to enhance bee population in their farmlands. However, relatively fewer respondents, 3 (2.3%) also suggested that trap nests could be an option for improving bee populations as illustrated in Table 4.62.

Table 4.62: Farmers' Responses on Methods of Enhancement of Pollinators on Farmlands

Reason	Frequency (f)	Percentage (%)
Construction of more honey bee hives	85	65.4
Construction of more shrubs in fences	42	42.3
Construction of trap nests	3	2.3
Total	**130**	**100**

4.4.3.16 Rationale for not Enhancing Bee Pollinators on Farmland

Seven, (53.8%) proved that they would not enhance bee pollinators of their farmlands since they can sting humans, 4 (30.8%) can sting livestock while 2 (15.4%) indicated that they feared utilizing bee inhabited farms as shown in Table 4.63.

Table 4.63: Farmers' Responses on Rationale for Not Enhancing Pollinators on Farmlands

Reason	Frequency (f)	Percentage (%)
Sting humans	7	53.8
Sting animal/livestock	4	30.8
Fear to utilize bee inhabited farm (s)	2	15.4
Total	**13**	**100**

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

Bees are important in the provision of vital ecological services especially pollination in most flowering plants. Bee pollination is a significant input in crop production comparable to any other resource in crop production including fertilizers, labor or pesticides (Gikungu, 2018). Agronomic activities such as intensive land clearing and use of agrochemicals in agricultural production have a negative impact on bee community. For instance, *A. mellifera* is highly sensitive to pesticides than other bee species such as bumble bees as observed by Sygolastra, (2014).

Comprehensive studies on assessment of the effects of agronomic activities on abundance and diversity of honey bee community and the state of indigenous knowledge of pollinator importance among small–holder farmers would assist in policy formulation and decision making in regard to management of the bee community for agricultural purposes, which is inadequate in Kenya.

5.2 Abundance and Diversity of the Bee Community

5.2.1 Abundance of the Bees Species

Seven bee species from seven genera belonging to two families were collected from the habitats studied. The abundance of bee species showed an increasing trend across the habitats, with the lowest numbers recorded in the cultivated areas, followed by higher abundance in the rangelands, and the highest abundance observed in the natural forest habitat. *Apis* followed by *Pseudapis spp.* recorded the highest bee abundance. The individuals of *A. mellifera* were great in number compared to other bee species. These results are in tandem with those obtained by Kasina *et al.*, (2007) who established that *A. mellifera* was the most abundant bee species in common bean farms. The number of individuals of *A. mellifera* was higher than those of other bee species and kept dominating in each habitat compared to other bee species. This high abundance of *A. mellifera* can be attributed to its crucial role in offering pollination services to most flowering plants as noted by Potts *et al.*, (2016).

A. mellifera is a social bee and sociality is often central since social bees can converse the availability of resources to their colony and recruit in large numbers to mass flowering crops such as coffee (Kioko *et al.*, 2017). Additionally, *A. mellifera* is aggressive in nature and takes advantage of intense nectar flow associated with coffee flowering (Vergara & Badano, 2008). It has the ability to inhabit and persevere in a variety diverse habitat types, nest under a variety of conditions and also forage on a great variety of both native and alien flowers (Chacoff & Aizen, 2006). In support of these results, Vergara & Badano (2008), conducted a related study in Mexico and established that *A. mellifera* was the most abundant bee species accounting for more than 80% of total bee assemblages. Further, the current results indicate a clear variation in bee distribution across habitats, with natural habitats supporting greater diversity and abundance compared to anthropogenically disturbed habitats (Klein *et al*., 2007; Garibaldi *et al*., 2013).

Statistical analysis revealed no significant differences in bee species abundance within individual habitats ($p > 0.05$) across cultivated land, rangeland and forest edge. However, significant differences ($p < 0.05$) were observed in bee abundance when comparing habitats, specifically between cultivated and rangeland, cultivated and forest edge, and rangeland and forest edge. This suggests that although intra-habitat variation was minimal, inter-habitat differences in bee abundance were evident, reflecting the influence of habitat heterogeneity on pollinator communities (Winfree *et al*., 2009; Potts *et al*., 2010).

Moreover, *A. mellifera* consistently dominated across all three habitats, while *Heriades spp.* were the least encountered. This distribution pattern reflects both ecological adaptability and floral resource preferences, with generalist species thriving across diverse environments while specialist groups remain less abundant (Michener, 2007; Ollerton, 2017). The observed variations highlight the critical role of habitat type in structuring bee populations and affirm the need to conserve natural habitats to sustain pollinator diversity.

5.2.2 Diversity of the Bee Species

Typical diversity index values are generally between 1.5 and 3.5. In most ecological studies, the index is rarely greater than 4. However, higher values indicate lower diversity while lower values indicate high diversity (Shannon and Weiner, 1949). The bee species diversity index was highest on the cultivated habitat with $H^{/}$= 1.55, followed by rangeland with $H^{/}$= 1.42 while the natural forest edge had $H^{/}$= 1.35. This study established that there was variation on bee species diversity on the studied habitats. These differences in diversity indices among the studied habitats can be linked to variations in agronomic activities, light intensity and amount of floral resources as noted by Kioko *et al.,* (2017). These findings are in tandem with those recorded by Shambhu *et al*., (2013) who recorded a diversity index of 1.01 on a cultivated farm. Individuals belonging to seven bee species were collected from Loitoktok Sub County. These findings are in agreement with those obtained by Masiga *et al.,* (2014) on a farmland of French beans at the North-Eastern slopes of Mt Kenya which recorded bees in five families, five genera and eight species. Similarly, Gikungu, (2006) recorded 17 bee species from a farmland of non-crop plants belonging to fabaceae family. Additionally, Gikungu (ibid.) found more than 200 species of bees in the forest and in the more open farmland. According to Greenleaf and Kremen (2006), diversity of wild bee populations influences efficiency of ecological bee services such as the pollination and therefore, agronomic activities in poses dangers to bee species diversity as noted by Lichtenberg *et al*., (2017). Agronomic practices compounded with tropical deforestation have been documented to change bee communities due to foraging characteristics (Compbell *et al.,* 2018; Lichtenberg *et al*., 2017; Gikungu *et al.,* 2018). Nevertheless, fallow farmland can provide resources for pollinators and with greater bee diversity (Chiawo *et al.,* 2017). According to Martins *et al., (*2015) changes in land uses and climate are stressors to species declines such as *Meliponula* (stingless bees).

5.3 Impact of Seasonal Weather Variations on Abundance and Diversity of Bee Species in Loitokitok Sub County, Kenya

Seasonal weather changes have a great influence in determination of bee species abundance and diversity in a given environment as observed by González-Varo *et al.*, *(*2013). The bee species abundance and diversity were relatively higher during the rainy season as compared to the dry spell. These findings are in line with those obtained by the fourth evaluation report formulated by the Intergovernmental Panel on Climate Change (IPCC) which lists a number of observed global variations, most particularly, global temperatures increase, variations in rainfall patterns, frequency and intensity of precipitation have a potential of reducing bee species abundance and diversity (Baede *et al.,* 2007). During a rainy season, there is vast vegetation cover with blossoming flowers for bee visitation as compared to dry spells. These findings are supported by a related study conducted by Scaven & Rafferty, (2013) whose findings established that the timing of both flower bloom and pollinator activity seemed to be affected by seasonal variations especially increase in temperature thus creating space and time mismatches with severe demographic consequences for bee species. These mismatches can affect the plants by reduced pollen deposition and bee visitation, whereas the bee species experience shortage in the availability of food. In support of these findings, Steffan-Dewenter & Westphal, (2008) conducted an investigation on the nature of responses of both bee pollinators and plants to increasing temperatures. The study established that creation of time and space mismatches between vegetation and their pollinators was reported. Additionally, the findings noted that disparities in the slopes of the responses and season in a year indicated a potential mismatch between plants and bee pollinators.

Additionally, Colwell *et al.,* (2008) found out that any temperature variations in the tropics, was likely to have consequences that are more deleterious in ASAR areas than changes at higher latitudes. This was noted to be affecting bee species abundance and diversity. He attributed this to the fact that tropical insects are relatively sensitive to temperature changes (with a narrow span of suitable temperature) and that they were currently living in environments very close to their optimal temperature. Sunday *et al.,* (2011) pointed out that in contrast, insect species found at higher latitudes where the temperature increase was expected to have broader thermal tolerance and higher chance of survival since they are living in climates cooler than their physiological optima.

5.4 State of Indigenous Knowledge of Pollinator Importance among Small-holder Farmers in Loitokitok Sub County, Kenya

5.4.1 Respondents' Demographic Information

5.4.1.1 Distribution of Respondents by Gender

Even though the fact that most of the farming undertakings are viewed as men's job only as observed by Getu and Birhan**, (**2014), these study findings established that most the respondents were female than the males. Consequently, these findings contradict those obtained by Haftu and Gezu, (2014) who found out that there were fewer numbers of female respondents who practised bee farming.

5.4.1.2 Distribution of the Respondents by Age

Age of the individuals influences the magnitude to which a farmer has knowledge in bee pollinators and pollination activities in crop production. However, efficiency and competence of a farmer decrease with age since elderly farmers have decreased vigor and power in farming practices. The study established that most farmers were in their prolific age. In support of these findings, a related study conducted by Beyene and Verschuur, (2014) reported that elderly had vast knowledge on bee pollinators and pollination activities since they are actively engaged in crop farming activities.

5.4.1.3 Distribution of Respondents by Income

Income levels of farmers determine the extent to which they engage in farming activities since it influences acquisition of farming inputs. The study revealed that income levels varied among the respondents with the majority of them earning at lower levels. Depending on the earning level of the farmer, one can decide to engage in farming practices in order to supplement the earnings from crop production. In support of these findings, Munyuli, (2011) established that majority of the farmers acknowledged that their annual incomes were relatively low which affected their crop farming activities.

5.4.1.4 Farm Size Distribution and Its Ecological Implications on Pollinator Habitats

The rapid growth of a population in an area leads into considerable land fragmentations. This land sub division results into possessing small parcels of land. Frank, (2009) observed that land fragmentation is common among farmers as a result of purchasing parcels of land across the region to increase their output. Subsequently, land sub division causes habitat devastation resulting into segregation of pollinators, thus condensed genetic vigour alongside enhanced genetic drift between isolated populations (Zayed *et al.,* 2005).

5.4.2 Farmers' Knowledge on Bee Pollinators and Pollination

5.4.2.1 Awareness and Domestication of Bees

Almost all respondents (98.6 %) reported awareness of bees, which is encouraging and suggests a basic recognition of bees in the local environment. However, only 7.3 % indicated that they practice domestication (i.e., keep managed hives). This disparity between general awareness and actual beekeeping is consistent with findings from Kasina *et al.*, (2009) who observed that many farmers recognize honey bees but rarely maintain them, reflecting limited adoption of beekeeping despite awareness (Kasina *et al*., 2009). Similarly, Osterman *et al.*, (2021) also noted that most farmers perceive bees as beneficial pollinators but do not necessarily domesticate them (i.e., engage in apiculture).

The low rate of domestication may result from multiple constraints (lack of capital, technical knowledge, perceived risks), as documented in other farmer surveys (Tarakini *et al*., 2025). Thus, even though bees are broadly known, translating that into proactive hive establishment appears limited in your population.

5.4.2.2 Number of Hives and Colonization Status

Among the minority who maintain hives, the modal number was 4 hives (36.4 %) and a substantial share had more than 10 hives (27.2 %). This variation aligns with other smallholder contexts where beekeepers maintain small apiaries rather than large-scale operations (e.g., Kasina *et al*., 2009). On colonization, only 36.4 % of those with hives reported that all hives were colonized, while 63.6 % had some uncolonized hives. That is, even within the small set of beekeepers, most hives remained empty. The distribution of uncolonized hives (with 45.5 % reporting 5–6 uncolonized, and 18.1 % > 7 uncolonized) affirmed a significant challenge in establishing and maintaining viable colonies. This pattern may reflect difficulties in attracting or retaining colonies (e.g. competition, disease, lack of forage, management skills) and is reminiscent of findings in other tropical and smallholder systems (Kasina *et al*., 2009; Tarakini *et al*., 2025).

5.4.2.3 Hive Placement (Micro-Location)

Farmers' hive placement preferences showed that 54.6 % place hives under trees, 27.2 % on farmland, and 18.2 % on fence edges. The preference for shade (under trees) is sensible, as beehives under tree cover may receive moderated temperature, protection from direct sun, and proximity to floral resources-practices echoed in apiculture extension recommendations. Fence edges are sometimes used but perhaps less optimal. This pattern roughly parallels observations that beekeepers aim to situate hives where they are sheltered and close to forage, but local constraints (farm layout, security, shading) may limit options.

5.4.2.4 Farmers' Knowledge of Bee Taxa and Nesting

When asked about bee species, respondents demonstrated uneven familiarity. Over half (53.6 %) recognized *Xylocopa* spp., while recognition of *Ceratina*, *Braunsapis, Pseudapis, Lasioglossum,* and *Heriades* was lower. The fact that *Xylocopa* (large carpenter bees) was better known it's unsurprising they were more conspicuous and sometimes cause aesthetic or structural damage, making them more noticeable than small solitary bees. This pattern aligns with findings of Kasina *et al*., (2009) who established that farmers commonly recognize honey bees but rarely distinguish among wild pollinators.

In terms of nesting sites, some (39.2 %) reported tree branches, followed by fence edges (24.4 %), parts of houses (13.3 %), ground (8.4 %), dead wood (6.3 %), and house structures (8.4 %). This suggested some awareness of the diversity of nesting substrates used by bees (e.g. cavity nesters, ground nesters). The high proportion of farmers observing bees moving in/out of earth holes (97.2 %) further confirmed that ground-nesting bees (especially stingless bees) are visible to many farmers. Indeed, 85.3 % of respondents identified *stingless bees* nesting in earth holes vs. solitary bees (14.7 %). This is a reasonable perception, as stingless bees are known to nest in cavities and subterranean habitats in many tropical agro-ecosystems. These results illustrated that farmers possess partial knowledge they can identify some conspicuous taxa and nesting habits but lack fine-grained understanding of many bee genera or their ecological roles. This partial awareness is consistent with farmer-pollinator studies in Kenya and Zimbabwe, where knowledge is moderate and often skewed toward familiar species (Tarakini *et al*., 2025).

5.4.2.5 Ability to Harvest Honey and Perceived Bee Resources

A large majority (86.0 %) said they can harvest honey, suggesting that where beekeeping exists, farmers are confident in extraction, or have experience. However, the fact that many beehives remain uncolonized may reduce actual honey yield. Regarding resources bees obtain, 78.3 % cited pollen while 21.7 % cited nectar. In reality, bees collect both pollen and nectar; pollen mainly for protein/offspring provisioning and nectar for energy (carbohydrates) as noted by (Klein *et al.*, 2007). The skew toward pollen in farmer responses may reflect that pollen is more visible (e.g. pollen on bees) or better understood as a bee–flower link, whereas nectar is less visible as observed by Kasina *et al*., (2009). This shows a limited but partial conception of bee foraging ecology. Farmers cited pollination as the main benefit of bee visitation (61.5 %), with others noting improved produce quality (28.7 %) and increased yields (9.8 %). The emphasis on pollination aligns with broader recognition in literature that pollinators contribute to yield, quality, and food security (Klein *et al*., 2007; Gemmill-Herren & Klein, 2014). Nevertheless, the lesser mention of yield or quality suggests that farmers may underappreciate the full suite of pollination benefits.

5.4.2.6 Pesticide Use and Timing

Most farmers (79.0 %) reported pesticide use. Concerningly, 31.9 % apply during flowering time, 27.4 % during fruiting, 22.1 % during planting, and 18.6 % during weeding. The use of pesticides during flowering is particularly risky to pollinators, as bees are actively foraging then. Such practices have been reported in other studies as a key threat to pollinator health (Kasina *et al.*, 2009; Tarakini *et al*., 2025). In addition to chemical control, farmers use alternative pest management methods: smoking (31.4 %), ash (25.9 %), hunting (23.8 %), weed control (11.2 %), and hand picking (7.7 %). The use of cultural and mechanical pest control aligns with integrated pest management (IPM) approaches that can reduce pollinator harm (Muriithi *et al*., 2024).

5.4.2.7 Live Fences, Floral Resources, and Pollinator Enhancement

Fencing in these farms often uses living plants: 54.5 % use live fences, followed by barbed wire, wooden, woven, and perimeter wall fences. Among those using live fences, 76.9 % apply them across the entire farm. In line with these findings, Gemmill-Herren & Klein, (2014) noted that live fences are commonly advocated for promoting biodiversity and pollinators because of their dual roles as structural boundaries and floral habitat. Species used for live fences included *Croton macrostachyus* (20.9 %), *Lantana camara* (19.6 %), *Markhamia lutea, Dracaena fragrans, Caesalpinia decapetala, Tithonia diversifolia, Eucalyptus saligna, Agave sisalana*, and *Psidium guajava*. Some of these (e.g. Croton, Markhamia, Tithonia) are known to have attractive flowers for bees, providing forage near farms. The flowering time of live fence plants was seen by 88.1 % to occur at different times of year, which would help ensure continuous floral resources. Yet only 7.0 % indicated that flowering coincided with crop flowering. Interestingly, 60.8 % believed that bees prefer live fence flowers when they coincide. This suggested that farmers perceive competition between fence and crop blooms for bee attention, which is recognized in the literature as a potential tradeoff (i.e. floral resources can both support pollinators and possibly draw them away) (Gemmill-Herren & Klein, 2014).

Regarding pollinator enhancement, 90.9 % of farmers expressed willingness to enhance pollinators in their farms. Their favored methods were constructing additional beehives

(65.4 %) and planting shrubs in fences (42.3 %). Only 2.3 % suggested trap nests. These preferences echo findings in other farmer surveys: for instance, Kasina *et al*., (2009) found that farmers are more inclined to plant floral resources or create nesting sites than to build nest boxes. That said, a minority (9.1 %) declined enhancing pollinators, citing fear of stings (53.8 %), danger to livestock (30.8 %), or reluctance to use bee-inhabited fields (15.4 %). Fear of bee stings is a recurrent barrier in other related studies (Tarakini *et al*., 2025).

5.5 Conclusion

5.5.1 Effect of Agronomic Practices on the Diversity and Abundance of Bee Species in Loitokitok Sub County, Kenya

Habitat heterogeneity is a significant factor that influences diversity and abundance of bees on habitats. Habitats with high heterogeneity exhibit a great potential to meet diverse ecological needs of the bee community.

In this study, abundance of bee species decreased across the natural forest edge, rangeland to the cultivated habitat. However, bee species diversity increased from natural habitat, rangeland to the cultivated habitat. *A. mellifera* (Honey bees) was the most abundant bee species in the study area.

The study results revealed that agronomic activities influenced abundance and diversity of bee community and therefore, there is a need to conserve the populations of non-Apis bees, especially, *Lasioglossum*, *Xylocopa* and *Pseudapis* so as to enhance provision of ecological bee services.

5.5.2 Impact of Seasonal weather Variations on Abundance and Diversity of Bee Species in Loitokitok Sub County, Kenya

Seasonal weather changes influenced bee species abundance and diversity in the study area.

The bee species abundance and diversity was greater during the rainy season as compared to the dry season. During a rainy season, there are vast vegetation cover with blossoming flowers for bee visitation which enhanced abundance and diversity of the bee species as compared to dry spells. The timing of both flower blooming and bee species activity was influenced by seasonal variations especially during a dry spell thus creating space and time mismatches with severe demographic consequences for bee species. These variations affect the vegetation cover by reduced pollen deposition and bee visitation, whereas the bee species experience shortage in the availability of food.

5.5.3 State of Indigenous Knowledge of Pollinator Importance among Small-holder Farmers in Loitokitok Sub County, Kenya

The farmers had a great knowledge of bees. Approximately 90% were familiar with different bee species. Most farmers were conversant with bee nest sites and their food resources. More than 86% of the farmers knew on how to harvest honey from the bees. Additionally, most farmers were familiar with the importance of bee visitations on crop and live fence flowers. A large percentage of the famers (90.9%) were willing to enhance bee population on farmlands.

5.6 Recommendations

1. Therefore, this study emphasizes on the embracing of bee-friendly farming practices in the study in order to conserve the bee community.
2. *A. mellifera* was the most abundant bee species and thus, environment management practices that improve bee population, such as habitat management and adoption of good agricultural practices should be encouraged in order to ensure maximum conservation of the bee community.
3. The government should emphasize on policies that bring information to the farmers by availing extension services so as to enhance famers' knowledge of bee pollinators and pollination.

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APPENDICES

Appendix I: Farmer's Questionnaire

Questionnaire No…………

Dear Sir/Madam

This questionnaire is designed to assess the level of indigenous knowledge of pollinator importance among small-holder farmers in Loitokitok Sub County. The questionnaire will be filled by the respondent only after prior informed consent willingly and without coercion. The researcher will only proceed with questions if the respondent consents. Therefore, you have been selected to assist in providing information considered essential for the study; Assessment of indigenous knowledge of pollinator importance among small-holder farmers in Loitokitok sub county. Kindly fill the questionnaire which will be used for the purpose of this study.

PART A: Identification

1. Sex: Male [ ] Female [ ] 2. Marital status: Married [ ] single [ ] 3. Age (years) 0- 18 [ ], 19- 30 [ ], 31- 40 [ ], 41- 50 [ ], 51 and above [ ]

4. Farm size; 1/8 Acre [ ] ¼ Acre [ ] 1 Acre [ ] 2-3Acres [ ] 4-5 Acres [ ], 5 Acres and above [ ]

PART B: Pollinators and Pollination

5. Are you aware of honeybees? Yes [ ] No [ ] ***(if no, go to 7)***6. Do you domesticate them? Yes [ ] No [ ] ***(if no, go to question 7)*** i). If yes, how many beehives? ....ii). Are all the bee hives colonized? Yes [ ] no [ ] how many un-colonized? ....

iii) Where have you placed the hives in the farm? ....

7. Are you conversant with bees besides honey bees which produce honey? Yes [ ] No [ ] a. If yes, state them; ....b.

Which place do they inhabit ***(nest)***? ....c. Are you able to harvest the honey they produce? Yes [ ] No [ ] if no, reasons: ....

....

8. Are you familiar with what bees obtain from flowers? Yes [ ] No [ ]

State them: ....

9. In your opinion, are crops ***(or flowers)*** benefiting from bee visitations? Yes [ ] No [ ] identify the possible benefits...

PART C: Pollinator natural history

10. Do you embrace pesticide usage in controlling pests? Yes [ ] No [ ]

a. If **YES**, indicate time of application......................

b. What **OTHER METHODS** do you employ in pest management? ....

11. What kind of fencing have you embraced in your household of farm? ***(If no live fence, go to 15)***

12. If live fence: i). Have you used it in the entire farmland? Yes [ ] No [ ] ii). What plant species does it constitute of? ....

iii). What is the rationale of those species in the fence? ....

iv). what are the ways of maintaining the fence? ....

13. Do the plant species ***(in the fence composition)*** flower? Yes [ ] No [ ] If yes,

i. Are they flowering at the same period? Yes [ ] no [ ] ***(if yes, go to ii)***

a). If no, do you notice a few flowering concurrently with the crops? Yes [ ] no [ ]

ii. Do bees prefer the crops more than the shrubs when they flower same time? Yes [ ] no [ ]

iii. Do you notice other insects apart from bees visiting the flowers this period? Yes [ ] No [ ] list them; ....

14. (a) Do you observe bees moving in/out of earth holes? Yes [ ] No [ ]

b. If yes, what type of bees? Honey making bees [ ] solitary bees [ ]
15. Will you prefer to enhance bee pollinators in your arable land? Yes [ ] no [ ]

A). If yes, through which means? ....

b). If no, what are the reasons? ....

The end

Thank you for your cooperation

Appendix II: Translated Farmer's Questionnaire into Local Language (Maasai)

EMATUA EDIKUYA: EYIELOUNOTO.

1 .Orshamba: Olee (   ) Ekituyo

2. Enkiema (iemishe) (itu iemishe)

3. Ilarini? 0-18 (   ), 19-30 (   ), 31-40 (   ), 41-50 (   ), 51 and above (   )

4. Esapuko o rshamba

Ematua Eare: Lyanout lesong'ouna oo Esong'ounashu.

5 lyiolo ilotorok loo naishi? Ee (   ) aa (   )

6 .Ipik kulo itorok tiang? Eeh (   ) aa (   )

- i. Enaa eeh, ingidong'i adha?
- ii. Kerikoritoi ingidong'I pooki? Eeh (   ) aa (   ) kadha merikotoi?
- iii. Kai etii ingidongi inonok?

7. Iyiolo iloitorok lemee loitorok lenaisho? Eeh ( ) aa (   )

- a. Enaa eeh, tolomu pooki
- b. Kai emanya (engajienye)
- c. Iturru enaisho enye? Eeh (   ) aa (   ) Enaa aa kanyoo

8. Iyiolo adho kanyoo enya/ ewok iloitorok too tampuka ? Eeh (   ) aa (   ) Nkenu

9. Iyiolo arashe etum indaiki (arashe intapuka) ereteto te lotunoto ooh loitorok

Ematua Ee uni: iyaunot lesong'ouna oo ntepen emakewon

10. Iyararie irkiek loon ng'eusi ingeusi? Eeh (   )   aa (   )

- a. Enaa eeh, tolimu impukunot enye……..? Kanu? Esaa oo nging'orunot
- b. Kakwa losekini irkulie libokie inguesi kutitik?

11. Kkaalo paashe ingenorie ewuas ino/engag ino?

12. Eneishu ilo paashe

i. Kemanita orshamba pooki? Eeh ( ) aa ( )
ii. Kibunga oo rpaashe lelatia ? Eeh ( ) aa ( )
iii. Pakwa pukunot loorkiek naatiin orshamba pooki?
iv. Kanyoo pee etii kuna pukunot pooki naaripitoi orpaashe?
v. Kadha inko enirrip orpaashe?

13(.a) Keete imbukunot pooki oo rkiek (Tiatu orpaashe) intapuka? Eeh ( ) aa ( )

  i. Keisho ninje airiamaki ? Eeh ( ) aa ( ) enaa eeh shomoii
  ii. Enaa (Aa) idolita ingutik pukunot airimaki oo daiki inonok?

b) Tenena nairiamaki aisho oo daiki inonok, idolita iloitorok egira aaboki intapuka enye? Eeh ( ) aa ( )

    I. Keikashe iloitorok iidaiki aalangu intapuka
    II. Etadua kulie sampurumpur teneponu atua entapuka nemee iloitorok? Eeh ( ) aa ( )

14. Etadua iloitorok ejing'ita arashe ipango too ululuni enye? Eeh ( ) aa ( )

i. Enaa eeh kakwa oitorok? (iloitorok le naisho) (Iloitorok kulie)
ii. Enia pukunot enkop?
iii. Kanyoo eciaiena enkop?

15. Iny'oro teniau ilkuliek yaunot lesong'ouna to rshamba?

(a) Enaa Eeh, aikunaki adha?

(b) Enaa aa, kanyoo?

Appendix III: Bee Species Identification Key

Individual Scores Summary (Trait Scoring per Species)

Species	**Body Size**	**Colour/Sheen**	**Wing Venation**	**Corbicula**	**Distinct Traits Used**
Apis mellifera	Medium	Brown/yellow bands	3 submarginal cells	Present	Worker caste + bands
Xylocopa spp.	Very large	Black metallic	Clear venation	Absent	Robust + mandibles
Ceratina spp.	Small	Metallic green/blue	Normal	Absent	Slender + metallic
Braunsapis spp.	Very small	Dark, slender	Normal	Absent	Tiny + elongated metasoma
Heriades spp.	Small	Black, punctate	Normal	Absent	Resin-collecting mandibles
Lasioglossum spp.	Small	Metallic green	Basal vein arched	Absent	Ground-nesting indicator
Pseudapis spp.	Medium	Dark/slender	Basal vein arched	Sparse hairs	Slender + long glossa