EFFECTS OF AGROECOSYSTEM LAND USE ON THE DIVERSITY, ABUNDANCE, AND ECOSYSTEM FUNCTIONS OF INSECT POLLINATORS OF PASSION *(Passiflora edulis)* CROP.

Emily Nduku Kitivo

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A Thesis Submitted in Partial Fulfillment of the Requirements for the award of the Degree of Doctor of Philosophy in Environmental Management in the School of Environment, Water and Natural Resources of South Eastern Kenya University.

June, 2019

DECLARATION

I understand that plagiarism is an offence and I therefore declare that this thesis is my original work and has not been presented to any other institution for any other award.

Signature………………………. Date……………………

Emily Nduku Kitivo
Reg No. 1701/MAC/30037/2014
Department of Environmental Science and Land Resources Management

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as supervisors.

Signature……………………. Date…………………

Professor Gideon H. Nyamasyo
School of Biological Sciences
University of Nairobi

Signature…………………… Date………………….

Dr. Jacinta M. Kimiti
Department of Environmental Science and Land Resources Management
South Eastern Kenya University

Signature…………………. Date…………………

Dr. Josphert N. Kimatu
Department of Biological Sciences
South Eastern Kenya University

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ABBREVIATIONS AND ACRONYMS

AEZ	Agro Ecological Zones
ANOVA	Analysis Of Variance
API	African Pollinator Initiative
ASDS	Kenya's Agricultural Sector Development Strategy
CAN	Ammonium Calcium Nitrogen,
DAP	Di-ammonium Phosphate
FAO	Food and Agriculture Organization
PF	Passion Fruit
GEF	Global Environmental Facility
GoK	Government of Kenya
HCDA	Horticultural Crop Development Authority
IPM	Integrated Pest Management
ISDR	United Nations International Strategy for Disaster Management
KALRO	Kenya Agricultural Livestock and Organization
KPF	Kenya Passion Fruit
MAP	Mono-ammonium Phosphate
MOA	Ministry of Agriculture
NaHMIS	National Horticulture Market Information System
NMKS	National Museums of Kenya
PCPB	Pest Control Products Board

SPSS	Statistical Package for Social Sciences
STEP	Study, Training, Evaluation and Promotion
UN	United Nations
WHO	World Health Organization

DEFINITION OF TERMS

A sustainable agroecosystem refers to an ecosystem that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society.

Agro-ecological Zoning (AEZ) refers to the division of an area of land into small units, which have similar characteristics related to land suitability, potential production, and environmental impact.

Agroecosystems refers to land used for crops, pasture, and livestock, the adjacent uncultivated land that supports other vegetation (hedgerows, woodlots, etc.) and wildlife; the underlying soils and groundwater and associated drainage networks.

Agro-chemicals are chemicals used in agriculture such as a pesticide or a fertilizer.

An environmental niche is the response of an organism to components of its physical environment.

Diversity is the total number of different species, the variability within species, between species and of ecosystems.

Ecosystem function refers the capacity of natural processes and components to provide goods and services that satisfy human needs, either directly or indirectly.

Ecosystem is defined as an area that includes all organisms therein and their physical environment.

Environmental degradation refers to the reduction of the capacity of the environment to meet social and ecological objectives and needs.

Land use type is defined as how land is utilized on the basis of food crops.

Pesticides are substances or mixtures of substances intended for preventing, destroying, repelling or mitigating any pest.

Pollination is a supporting ecosystem function; it is the interaction between biotic vectors (for example, insects, birds, and mammals) and abiotic vectors (such as wind and water) in the movement of male gametes for plant production.

ABSTRACT

Worldwide, crops that require wild pollinators are showing a deficiency of pollination and genetic variation. In the recent past, studies show that there has been a steady decline in production of passion fruits in Kenya. In this study, the major objective was to investigate factors causing the decline of passion fruit production using ecosystem concepts, agricultural practices and social-ecological factors using the case scenario of Mua hills in Machakos County.

The study was carried out during the wet season December, 2015 and the dry season early March, 2016. The farms sampled in each Agro-ecological zone were categorized according to three land use types; horticulture, mixed cropping, and natural patches near each farm which served as the control sites. During sampling on average 1415 insects were collected belonging to 30 species, 10 families and 8 orders. The results indicated that diversity and evenness of bees, which are the main pollinator of passion fruit was much higher in Zone V than in Zone IV and Zone III. There was seasonal variation in abundance although this did not affect the diversity of the insect pollinators. Results of Pearson's correlation analysis between number of fruits and insect abundance per AEZ revealed that there was a positive and significant association between the abundance of the insects and the number of fruits ($r = 0.504$, $p = 0.002$). The study findings revealed that 76.7% of the farmers use the DAM, CAN, DAP type of agrochemicals while 23.3% of the respondents use other types of agrochemicals. For plant richness, a total of fifteen (15) higher plant species, three (3) shrubs and sixteen herbs (16) were recorded. This study revealed that land use type and agro-chemicals could be key factors in determining insect pollinator diversity and abundance in different agro-ecological zones. The findings from this research echo the need for environmental management of agro-ecosystems to support ecosystem services in particular pollination which improves passion fruit production.

1.0 CHAPTER ONE: INTRODUCTION

1.1 Background information

A functional ecosystem is made up of a dynamic sustainable interaction between biotic and abiotic components. Each component in an ecosystem has definite functions and services which are crucial for the wholeness of the ecosystem. Ecosystem functions have been defined as “the capacity of natural processes and components to provide goods and services that can satisfy human needs, either directly or indirectly” (de Groot *et al*., 2002). Hence, recent definitions indicate that the human component in an ecosystem cannot be ignored as it can rapidly destabilize ecosystems. Based on the idea of a human component in an ecosystem, there are four categories of ecosystem services (M.E.A 2005). These four categories have been widely adopted in subsequent studies of the ecosystem services and they include; 1) Provisioning services which are basically the products of ecosystems that provide timber, medicine, and other useful products, 2) regulating services are the processes that control and maintain vital ecosystem resources. Examples include flood control, control of crop pollination and climate regulation, 3) supporting services such as photosynthesis, pollination, soil formation, and water purification; and 4) cultural services which are non-material benefits such as aesthetic appeal, spiritual or recreational assets (Kremen *et al*., 2005).

Pollination is mediated by biotic vectors such as insects and abiotic factors such as wind and water. It increases genetic variations and stabilizes yields of vegetable, oil, seeds and nut crops (Klein *et al*., 2007; Free, 1993). Blesmeijer (2006) asserts that “there is a large-scale parallel decline of plants and pollinators worldwide which reinforce the concern that pollination as an important ecosystem service is at risk’’ (Blesmeijer *et al*., 2006).

Pollinator decline will have consequences on agricultural production since approximately one-third of agricultural production majorly relies on animal pollination (Kremen *et al.*, 2007; Garibaldi *et al*., 2011).To understand the reduction in the pollinator species richness and population, baseline data of the current status of pollinators of certain crops at a regional level has to be established. This was the main objective of the African Pollinator Initiative (API, 2003). Research shows that the abundance and diversity of insect pollinators have significantly reduced globally which raises much concern for functioning of the ecosystem (Cameron *et al*., 2011). Therefore, the current research aimed at solving the environmental problems of pollination limitation of passion fruit crop by using ecological principles to establish the effect of land use and agrochemicals on the ecology of the crop and that of the carpenter bee.

Several types of research have established that , "habitat destruction, degradation, and fragmentation – resulting in a loss of foraging, mating and nesting sites, particularly driven by changes in agricultural management practices" are some of the factors that cause pollinator decline (Brown *et al*., 2009, Kearns *et al*., 1998; Taki *et al*., 2008;). Pollution, in particular by agro-chemicals including neonicotinoids (Kevan, 1999; Brittain *et al*., 2010) and invasive alien species- including introduced plants, pollinators, pests and diseases (Stout *et al*., 2009; Dafni *et al*., 2010). Hegland (2009) asserts that "climate change- which affects the spatial-temporal dynamics of plant-pollinator interactions" is also a major cause of the decline (Memmott *et al*., 2007; Hegland *et al*., 2009).

Nderitu (2008) detailed the detrimental effects of insecticides applied to sunflowers in Kenya, on the diversity of bees and consequent seed yield. Most of these human activities that threaten the richness and abundance of pollinator species have emerged from the increase in population increase which has led to agricultural intensification.

There has been a constant human population increase in both the arid and semi-arid regions which has fostered the rapid expansion of agriculture to help meet the population needs. However, this has, in turn, caused an increase in demand for agrochemicals in the Kenyan agricultural sector and pesticides have now become the main method of crop and plant protection (NES, 2006). While they may seem to be the best option, the main challenge is in the use, safe storage and disposal of these pesticides and fertilizers used in agricultural production. Gemmil et al (2014) recommend research in Africa on assessment of effects of pesticide use on crop pollinators because most African farmers rely on natural pollination services (Styger *et al*., 2006) and wild insect pollinators are of paramount importance for fruit set. Research indicates that the pollinator population is integral to plant production (Kevan *et al*., 1986). Farmers need to have a sustainable agro-ecosystem in terms of pollinator species richness and abundance to be able to meet human needs both now and into the indefinite future. Patricia in collaboration with Gliessman and others argue that much discussion on sustainable agro-ecosystem has been inclined to farm-level production and profitability. She defines a sustainable agro-ecosystem as “one that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society” (Allen *et al*., 2008).

According to Taiti (1996), land use is defined as the purpose and the way in which land is conquered and exploited. Land use in agro-ecosystems can affect the plant diversity and density in terms of monoculture or mixed cropping. Plant diversity determines arthropod diversity and abundance since insects’ forage on the plant, use the plants as breeding sites and shelter (Basset *et al*., 2012).According to Vaughan (2008), “the presence of shelterbelts in farms provide good sites for nesting structures for bees and can help to reduce the drift of insecticides” (Vaughan *et al*., 2008). The Kenyan agricultural sector has predominantly been practicing mixed cropping which has not been impacting pollinators negatively. This is because most of the farms have been characterized by the frequent growth of shrubs and low utilization of pesticides. These farm practices have sustained insect pollinator overtime. However, reports on a decline of the abundance and diversity of the pollinator species have been published in the recent past (Kasina *et al*., 2009a, b, c: Mwangi *et al*., 2010).

This decline has been noted on some crops that require wild pollinators such as passion fruits which are already showing a deficiency of pollination (Kasina *et al*., 2010). The reduction in the pollinator species could be as a result of the shift in common farm practices such as monocropping, increased use of crop pesticides, continuous tilling of land and the absence of shrubs in the farms (Kasina, *et al*., 2012). This has placed pollinator conservation at considerable current interest worldwide, and significant concerns have been raised in many countries about the long-term viability of insect pollinators in both agricultural settings and conservation areas (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2016). The conservation community now aims at adopting an ecosystem approach that will protect the diversity in both the protected area and agro-ecosystem. This is because at least half of surviving species do not exist within protected areas (Blann, 2006).

The passion crop is one of the climbing plants that last longer and it has been a common fruit in Kenya since it was first introduced in the 1920's. The purple passion fruit (*Passiflora edulis*) is native to the tropical regions of southern Brazil (Oliveira, 2008) and is the number one worldwide passion fruit producer. According to IBGE (2011), Brazil produced approximately one million tons of passion fruit in 2010 (IBGE, 2011). While most of the crops have flowers that provide both pollen and nectar, for passion fruit flowers, they only provide nectar when their blossoming phase occurs (Camillo, 2003). According to Yamamoto *et al* (2012) and Camillo (2003), it is proven that the pollinator species richness, abundance and how often visitation occurs certainly with evidence increased the fruit set in passion fruit orchards in Brazil (Benevides *et al*., 2009). Farmers in Brazil have used hedgerows in the farms to hinder winds from destroying the passion fruit crops and against the loss of soil humidity (Vaughan *et al*., 2008) while offering sites to nest bees in the farms (Hannon *et al*., 2009).

It has been reported that the presence of standing dead trees and artificial nests that are well-placed in either natural or managed habitats increases the population of carpenter bees (*Xylocopa spp*) that happen to be the key pollinators of passion plant (Vaughan *et al*, 2008). A research byFreitas and Oliveira (2003) on the use of a nesting box in a passion fruit crop increased the frequency of *X. frontalis* flower visitation. Passion fruit farming in Kenya does well in the upper midland to upper highland zones. The most suitable altitude for its production ranges from 1200-2000 meters above sea level and it requires an optimum temperature between 18^0C to 25^0C and well-distributed annual rainfall of 900mm to 2000mm. It grows on a variety of soil with a pH range of 5.5-6.5 and should be reasonably deep and fertile. Passion fruit plant is grown in Thika, Kisii, Nyeri, Kiambu, Nakuru, Machakos, Uasin Gishu and Trans-Nzoia Counties in Kenya (www.nafis.go.ke/fruits/passion-fruit).

1.2 Statement of the problem

In the tropics,there is need to have plans on how to increase crop production so as to have adequate food as well as nutritional security for the growing populations. African countries have responded to this challenge through the modernization of agriculture. With the modernization of agriculture, most of the regions with huge natural vegetation have been prepared for farming and in most cases, a single type of crop is planted in such regions. In the recent past, intensive agriculture has heavily depended on the application of agrochemicals with the use of chemical fertilizers and pesticides being commonly practiced. Such agrochemicals kill beneficial insects, and this has resulted in pollinator decline. Wild insect pollinators including moths (Fox, 2012), butterflies (Maes *et al*., 2001) and bees (Biesmeijer *et al*., 2006; Koisior *et al*., 2007; Cameron *et al*., 2011) have declined in both abundance and diversity, while, at least in some parts of the world, managed populations of honey bees *Apis Mellifera* have experienced large-scale, sudden colony losses (Van Engelsdorp *et al*., 2008). Understanding the causes of these declines is an absolute priority in ecological research, and an increase in the number of studies on pollinators and pollination is one response to widespread pollinator losses (Viana *et al*., 2012).

Studies conducted in some parts of Africa during the independence days and the colonial periods regarding pollination were majorly inclined on commercial cash crops (Dale *et al*., 1961; Mwangi, 1990; Lind and Tallantire, 1962). There were no researchers who narrowed down to the details of the necessities of pollination for a particular crop. In some African countries, plant and insect collections for pre-independence and colonial days are lacking because they no longer exist in this continent. There is need to identify the different crop species, particularly for the native pollinators. Agroecosystems attract numerous insect species for nesting, breeding and especially for pollination function. The study on the status of insect diversity and abundance in the agricultural farms which are subjected to different land use and agrochemicals use is still in its infancy in Kenya. While studies have been done in other nations about the ecological factors that determine fruit set in passion crop, there is little work so far carried out in Kenya over the same. Apparently, in Kenya, no effort has been made to study the ecology of carpenter bee and its effectiveness in passion fruit set. There has been a significant decline in the production of passion fruit over the years. In 2007 about 5193 ha were under passion fruit cultivation yielding 71000 tons worth Kshs.2.1billion. In 2008 less than 2800 ha were farmed yielding an estimated 33800 tons worth about Kshs 1.05billion.These data suggest a massive 50% decrease across all parameters within a single year. The decline of passion fruit production has negatively impacted the living standards of the farmers. Moreover, the low production has greatly affected the industrial processors, with most of the operations being below-installed capacity. For example, Delmonte was importing pulp from South Africa and Brazil (Otipa, 2009). This has caused most farmers to shift from passion fruit farming which is likely to affect the revenue for the families, the production of adequate food and the nutritional value in the area. Inadequate knowledge about the ecology of pollinators of passion fruit could be one of the major challenges in maintaining the pollinator species in the farms for fruit production.

1.3 Objectives of the study

1.3.1General Objective

To determine the impact of land use and agrochemicals on the diversity and abundance of insect pollinators in three different agro-ecological zones and their impact on passion fruit production in Mua hills Location.

1.3.2 Specific Objectives

1. To determine the effect of land use on the diversity and abundance of insect pollinators in different agro-ecological Zones.
2. To determine the influence of insect diversity and abundance on purple passion fruits set in order to identify pollination limitation to the fruit production.
3. To examine the use of agrochemicals and their impact on the insect pollinators in the agro-ecosystems.
4. To determine the association between plant diversity and insect species richness.

1.4 Hypotheses

1. Due to the inherent ecological differences among the three land use types in each agro-ecological zone, there wouldn’t be variation in insect pollinator diversity and abundance.
2. Passion fruitset is not positively correlated with insect diversity and abundance.
3. There is no correlation between the use of agrochemicals and the insect species diversity and abundance in the agro-ecosystem.
4. There exists a negative association between the diversity of plant species and insect pollinator species richness and abundance.

1.5 Significance of the study

The world is becoming more crowded, more consuming, and growing populations are putting increasing pressure on the environment. The rising demand for food by an increasing population combined with environmental degradation means that there are significant pressures on biodiversity and the environment. Such ecological demands call for attention regarding the interaction between the environment, land use together with biodiversity in order to understand limitations on ecosystem functions. This knowledge can be used to create win-win situations for agriculture, biodiversity, and the environment. Furthermore, environmental problems such as pollination limitation as a result of human activity can have unexpected consequences that are hard to reverse. Research indicates that pollination and pollinators are vital for the proper functioning of nearly all productive terrestrial ecosystems together with those for agricultural production. Peter (1999) argues that “insect pollinators can be used to monitor environmental stress brought about by introduced competitors, diseases, parasites, predators as well as by chemical and physical factors, particularly pesticides and habitat modification” (Peter, 1999).

Intensification of agriculture aimed at achieving food security has led to the loss of biodiversity. There is need to increase agricultural production using intensification methods that will not have any further effect on the environment while undoing any possible past damages and losses in the environment (Firbank, 2009; Royal society, 2009). To understand the contribution of agricultural intensification to losses in the pollinator species, these changes should be measured and recorded. Currently, direct evidence for loss of pollinator diversity is patchy (or non-exist) in many geographical regions of Kenya because there little data about the occurrence of the pollinator species. This research documented insect pollinator diversity and abundance in different agricultural land use type. One of the objectives of this research was to provide viable solutions that can be used in mitigating pollinator losses.

According to the Global Hunger Index, at least a billion people worldwide are still malnourished although there's use of latest technological and intensification methods in the production of food (Global Hunger Index, 2010). The rapid population growth requires adequate food that has proper nutrient content. Conserving pollinators provides a great way to increase nutritional security because most fruits, as well as vegetables, depend on insects for pollination. In most cases, insect-pollinated crops have great vitamin content and micro-nutrients and therefore, loss of insect pollinator will affect human nutrition. The people in developing countries who are poor may have to face serious health consequences because they majorly depend on crops that are insect-pollinated for nutrients. Pollinator loss should be given much concern because it can reduce human nutrition and cause people to depend on synthetic micronutrients. People who have poor nutrition will be compelled to use vitamin supplements. This study is relevant to the human goal of nutritional security.

In Africa and particularly in Kenya there is much work to be done about pollination to help us view it the way developed countries. So far, there is little work that has been handled about pollination in Kenya, with less research on population relationships. The less research on pollination in different communities creates gaps in the Kenyan agriculture that should be evaluated. There are gaps for research in pollination biology in taxonomic and geographic coverage, conservation relevance and economic valuation. The study was aimed at determining the effects of land use type, agro chemicals and habitat fragmentation on insect pollinators which are important for pollination. This research provides information on the trade-offs of environmental protection and exploitation which will enhance our knowledge to manage the environment sustainably.

1.6 Scope of the study

The study involved small-scale purple passion fruit farmers in Mua hills in Machakos county Kenya who were in production. According to Kenya's Agricultural Sector Development Strategy (ASDS), small-scale farmers carry out production on farms measuring 0.20ha to 3.00ha (the Republic of Kenya, 2010). However, due to high returns of purple passion fruit farming, farms with an average size of 0.10acres (0.04ha)were considered. Therefore, the study covered farmers with 0.04to 1.00ha of their farm under purple passion fruit.

2.0 CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter provides an overview of ecosystem functions, biodiversity and environmental niche concepts used in this research, importance of pollination as an ecosystem service, Insect pollinator diversity, the effect of land use types and agro-chemicals on diversity and the abundance of insect pollinators, ecology of carpenter bee in relation to passion fruit set, use and storage of agrochemicals and, the correlation between plant diversity and insect pollinator community composition.

2.1 Ecosystem functions, biodiversity, and environmental niche concepts

Ecosystem function is defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, either directly or indirectly" (de Groot *et al*., 2002). According to Noss (1994), ecological functions can be defined as "involving ecological and evolutionary processes, including gene flow, disturbance, and nutrient cycling" (Noss *et al*., 1994). This research shows how different entities in an ecosystem change over time. Ecosystem functions relate to the structural components of an ecosystem (for example vegetation, biota, water, and atmosphere) and how they interact with each other, within ecosystems and across ecosystems. Sometimes ecosystem functions are called ecological processes. Ecosystem functions occur at a range of scales, temporal (for example minutes, years, decades) and geographic (for example patch scale, within a catchment, an airshed, globally). The rate and scale that ecosystem functions operate at must be considered when assessing the potential to provide ecosystem services into the future.

Ecosystem functions are an integral part of biodiversity since they take place within an ecosystem. When ecosystems become degraded by pollution or over-exploitation it results in losses of biodiversity and declines in ecosystem function (Smith, 1968; Lecren *et al*., 1972; Pearson *et al*., 1976; Vitousek *et al*., 1979). There are three levels of biodiversity which include: genetic diversity, species diversity, and ecosystem diversity. Genetic diversity is the variety present at the level of genes whereas ecosystem diversity deals with species distributions and community patterns, the role and function of key species and combines species functions and interactions. This study focused on species because species diversity is easier to work with. Species are relatively easy to identify by eye in the field, whereas genetic diversity requires laboratories, time and resources to identify and ecosystem diversity needs many complex measurements to be taken over a long period of time. Species are also easier to conceptualize and have been the basis of much of the evolutionary and ecological research that biodiversity draws on. Species are well known and are distinct units of diversity. Each species can be considered to have a particular role in the ecosystem, so the addition or loss of single species may have consequences for the system as a whole. Conservation efforts often begin with the recognition that a species is endangered in some way, and a change in the number of species in an ecosystem is a readily obtainable and easily comprehensible measure of how healthy the ecosystem is. Biodiversity experiments have revealed that communities with fewer species generally function less efficiently (Loreau, 2010; Cardinale *et al*., 2012; Naeem *et al*., 2012; Tilma *et al*., 2014; Naeem *et al*., 2009).

Loss of species decrease ecosystem function; hence any loss of biodiversity is predicted to have increasingly negative impacts on ecosystem functioning. There are many theories about how the number of species affects ecosystem functions. One of these is the redundancy hypothesis, which assumes that the rate of ecosystem functions increases as more species are present, but only up to a point. Another theory, the rivet hypothesis, claims that each species added to an ecosystem increases ecosystem functions, although the increase in function may increase more slowly as more species are included. This research adopts the redundancy theory that greater diversity does lead to greater stability. Losing species means loss of ecosystem functions which have important negative ecological and economic impacts that could significantly affect the crop production, plant diversity, wider ecosystem stability, nutrition security, and the general human welfare.

Among the first people to use the term niche was Grinnell (1928). He viewed the niche as the functional role and position of an organism in its community. Grinnell considered the niche essentially a behavioral unit, although he also emphasized it as the ultimate distributional unit (thereby including spatial features of the physical environment). Niche theory states that guilds of competing species will diverge, leading to reduced niche overlap otherwise all but one of them will be driven extinct (the competitive exclusion principle (Raj, 2010). This theory predicts that higher levels of heterogeneity make it harder for one species to cover the niche space, and therefore, we expect that more species are required to support ecosystem functioning when the environmental heterogeneity is high.

An environmental niche is the response of an organism to components of its physical environment (Chesson *et al*., 2001). The response of an organism to components of its physical environment, as distinct from the availability of resources, is an important component of its niche. Differences between species in their environmental niches may promote their coexistence. Environmental niches are temporal niches if they refer to temporally varying aspects of the physical environment, or spatial niches if they refer to spatially varying aspects of the physical environment, or spatiotemporal niches if they refer simultaneously to variation in both space and time. This research adopted the species spatial niche concept because understanding the response of a species' to a spatial structure provides useful information in regards to biodiversity conservation and habitat restoration (Collinge, 2001).

2.2 Importance of pollination as an ecosystem function.

Pollination is a supporting ecosystem function; it is the interaction between plants and (1) biotic vectors (for example, insects, birds, and mammals) and (2) abiotic vectors (such as wind and water) in the movement of male gametes for plant production. Insect pollination is a vital ecosystem service and a large proportion of human diet either directly or indirectly depends on animal-based pollination. It is also essential for the conservation of wild plants. Pollination contributes to the provision of many ecosystem services, especially to provisioning services such as food products, genetic resources for cultivated products, potential biochemical, medicinal and pharmaceutical and ornamental resources. The pollination of agricultural crops is also vitally important to crop production (and therefore food products) when successful pollen transfer allows for seed germination and the growth of new plants which may be fed upon by herbivores (for example, cows and sheep); or through seed germination which produces plants and fruit for consumption by humans.

Natural pollination is related to an increase in production yields in crops such as sunflower (*Helianthus annuus*) and coffee (*Coffea arabica*), (Ricketts, 2004; Greenleaf andKremen 2006). Pollination of *Capsicum annum* flowers by some specific insects has been shown to have a positive effect by enhancing fruit quality and seed set (Pesson and Louveaux 1984). A study carried out in Kakamega forest, in the western region of Kenya, to evaluate the effectiveness of the stingless bee *Hypotrigona gribodoi* on the pollination of green pepper showed an improvement in fruit quality (Kiatoko *et al*., 2014). Studies on bottle-gourd (*Lagenaria siceraria*) in Kenya have shown how important a diverse pollinator community is, to maintaining the extraordinarily diverse forms of gourds (Gikungu *et al*., 2004).

Reduced agricultural yields and deformed fruit often result from insufficient pollination. Fruit set is the proportion of a plant’s flowers that develop into mature fruits or seeds and is a key component of crop yield. The richness of pollinator species increases fruit set (Winfree *et al*., 2009) because of complementary pollination among species (Hoehn *et al*., 2008; Blüthgen *et al*., 2011). Differences in seeds per fruit due to floral visits by a specific pollinator are a direct consequence of the quantity of pollen grain deposited on stigmas of flowers visited by the pollinator (Serrano and Guerra-Sanz 2006). In a well-pollinated flower, a rapid development of ovary occurs, and the fecundated seeds produce plant growth hormones, leading to a good fruit development (Cruz *et al*., 2005).

The status of research on African pollination biology was reviewed in 2004 (Rodgers and Balkwill 2004) at which point it was noted that relatively little work had been done on pollination biology in Africa. Over the last ten years, since the African Pollinator Initiative was established (API, 2003), an expanding focus on the role of pollination in natural and agricultural systems has been seen. A document taking stock of the state of knowledge of pollinators in agricultural production in Africa was produced in 2005 (API, 2005). Progress has been made on making taxonomic information on African bees accessible to end-users, with a key to the African genera of bees (Eardley *et al*., 2010).

The role of native bees and natural habitats to the pollination of eggplant has been documented (Gemmil-Herren and Ochieng 2008). The contributions of a diversity of pollinators to smallholder agriculture in western Kenya and their economic benefits have been recorded by Kasina *et al* (2009). The role of hawk moths in papaya pollination has been shown to be of great significance (Martins *et al*., 2009), and by Martins *et al* (2013) study hawk moths were found to also visit numerous indigenous plant species. An important study on cowpea pollination has documented gene-flow dynamics between cultivated and wild species (Pasquet *et al*., 2008).

Nderitu *et al* (2008) detailed the detrimental effects of insecticides applied to sunflowers in Kenya on the diversity of bees and consequent seed yield. As one-third of agricultural production depends on animal pollination (Kremen *et al*., 2007), the consequences of pollinator decline for agriculture need to be evaluated (Garibaldi *et al*., 2011). Understanding the causes of these declines is an absolute priority in ecological research, and an increase in the number of studies on pollinators and pollination is one response to widespread pollinator losses (Viana *et al*., 2012). Pollination limitation due to the reduced species richness of pollinators on islands like New Zealand and Madagascar significantly reduced fruit sets and decreased the reproductive success of dioecious plant species (Farwig *et al*., 2004).

2.3 Insect pollinator diversity

Fossilized insects of enormous size were found from the Paleozoic Era, including giant dragonflies (Engel *et al*., 2004).The most diverse insect groups appear to have coevolved with flowering plants (Grimaldi *et al*., 2005).The earliest angiosperms evolved in the mid-Jurassic era (approximately 170 million years ago) and though initially some were wind pollinated this was later replaced by insect pollination (Gang *et al*., 2016). The evidence for biotic pollination of early gymnosperms has been discussed since at least the 1970s (Crepet, 1979), but only in recent times has the true diversity and importance of insect pollination in pre-angiosperm floras become apparent.

Fossil insects from China, Spain, and Russia have revealed ancient groups of insects that appear, on the basis of interpretations of their mouthparts and associated pollen grains, to have been pollinators; examples include mid-Mesozoic thrips (Thysanoptera), flies (Diptera), lacewings (Neuroptera), scorpion flies (Mecoptera), and beetles - Coleoptera (Labandeira, 2010; Labandeira et al., 2007, 2016; Peñalver *et al*., 2012, 2015; Peris *et al*., 2017; Ren, 1998; Ren *et al*., 2009). Cardinal and

Danforth (2013) estimated that the main extant clades of bees originated during the mid- to late Cretaceous. Insects belong to the class Insecta, phylum Arthropoda, which are animals with jointed appendages (Linnaeus, 1758).

Insects may be found in nearly all environments, although only a small number of species reside in the inter-tidal zone of the oceans, a habitat dominated by another arthropod group, crustaceans. The class Insecta comprises about 27 orders, of which 25 occur in southern Africa and are classified into two main subclasses, Apterygota (wingless) and Pterygota (winged) (Lloyd *et al*., 2003).

Insects can be categorized by their feeding guilds which include: herbivorous, decomposers, predators, parasites, disease vectors and pollinators. These guilds describe where they must go to find, eat and process food and they also set the stage for understanding ecological relationships. Individual orders can have insects in one or many feeding guilds. Pollinators are insects that move pollen between plants (for example wasps, bees and flies). Insect pollinators are essential to the life cycle of many flowering plant species on which most organisms, including humans, are at least dependent, without them, the terrestrial portion of the biosphere (including humans) would be devastated (Grimaldi *et al*., 2005).

There are many important pollinating insect species in the orders, Hymenoptera (bees, wasps, and ants), Lepidoptera (butterflies and moths), Diptera (flies), and Coleoptera (beetles). These are, in order of increasing specialization and importance as pollinators, the Orthoptera (cockroaches, grasshoppers, crickets, walking sticks, praying mantis), Hemiptera (true bugs, cicadas, leafhoppers, scale insects, aphids), Thysanoptera (thrips), Coleoptera-beetles(Speight, 1978; Allen-Wardell *et al*., 1998; Jennersten,1988; Frankie *et al*., 1990; Irvine *et al*., 1990; Kevan 1999; Westerkamp *etal*., 2000; Kearns, 2001; Larson *et al*., 2001).

The most diverse group of pollinators is the Lepidoptera (and in particular the moths), with more than 140,000 species that are expected to visit flowers, based on 90% of species with functional mouthparts as adults, following Wardhaugh (2015), though some butterflies feed on plant and animal exudates rather than flowers. This is more than twice as many as the next most diverse groups, the Coleoptera and the Hymenoptera.

Diptera is the least diverse of these four main orders of pollinating insects, though that may change in the future as more work is done and the true diversity of flies as pollinators is revealed (Larson *et al*., 2001; Ollerton *et al*., 2009, 2017; Orford *et al*., 2015). The remaining groups are all rather low in diversity in overall terms, although they are no doubt ecologically important in certain regions and for particular plants.

2.3.1Order Lepidoptera (butterflies and moths)

Lepidoptera (plate 2.1) also pollinate plants to various degrees (Bascompte *et al*., 2003). They are not major pollinators of food crops, but various moths are important pollinators of other commercial crops such as tobacco (MacGregor *et al*., 2015).The insects in this order have the following identifying characteristics- scaly wings, adults have siphonous mouth parts and are adapted to feed on pollen and nectar, caterpillar immatures (have chewing mouthparts feeding on plant tissue (mostly), have up to 5 pairs of prolegs which are stubs emerging from abdomen that function as legs (Capinera, 2008). Moths and Butterflies (an artificial classification) may be separated as follows: moths- have feathery antennae and are night flyers (can be dull or bright colored) whereas butterflies have hooked or nobbed antennae, day flyers and can be bright colored (Scoble, 1995).

2.3.2 Order Coleoptera (beetles and weevils)

Coleoptera's forewing hardened into sheath called elytra and, the adults and larvae have chewing mouthparts although weevils have elongated mouth or rostrum, giving them the appearance of having long snouts (Plate 2.4). Larvae can be "C" shaped grub (scarabs), Slender long-legged active crawlers (ground, leaf, and lady beetles), or slender short-legged and sclerotized as in wireworms (Ross *et al*., 1980).

2.3.3Order Hymenoptera (ants, bees, wasps)

The insects belonging to the order of Hymenoptera (Plate 2.2), in particular, the super familyApoidea which encompass all species of bees, are important pollinators which are increasingly threatened with multiple stressors (Kremmel, 2002). Bee pollination is a virtually irreplaceable ecosystem service to human agricultural endeavors (Klein, *et al*., 2007). In recent times there has been a decline in bee communities in both wild and managed communities resulting in significant losses of pollination services (Delaplane *et al*., 2000; Klein *et al*., 2007; Gallai *et al*., 2007). This decline has been linked to habitat destruction and fragmentation (Kremen *et al*., 2002; Rathcke *et al*., 1994; National Research Council, 2007). Studies have shown local fauna and landscape can play a role in determining pollinator visits (Klein, 2005) and evidence exists suggesting the decline of pollinators is associated with a decline of insect-pollinated plants (Biesmeijer *et al*., 2006).

Honeybees have been investigated as bioindicators to monitor pollutants. The release of arsenic and cadmium may cause mass killings of honeybees and contaminate pollen, but not nectar (Krunic' *et al*.,1989). They also sample fluorides (Dewey, 1973), heavy metals (Stein, *et al*., 1987) and organic compounds, for example, PCBs and pesticides (Anderson *et al*., 1986; Morse *et al*., 1987) through floral nectar, pollen, and their own bodies. They have been advocated as bio-indicators in natural, agricultural, industrial and urban milieus (Rousseau, 1972; Drescher, 1982; Celliet *etal*., 1989; Bromenshenk *et al*., 1985; Stein *et al*., 1987) yet, despite their proven worth, programs for their use as bio-monitors do not seem to have been instituted. The Hymenoptera identifying characteristics include chewing mouthparts, 2 pairs of membranous wings, have junction between thorax and abdomen constricted (Apocrita), Sawflies and horntails have a broad junction between the thorax and abdomen (Symphyta), Larvae can be legless as in bees, and social wasps, or legged, as in sawflies, Sawfly larvae have 6 or more pairs of prolegs (Goulet *et al*., 1993).

Social behavior is often highly developed in this order (Peters *et al*., 2017). Larvae usually lack legs and develop in nests or as parasites of other insects. A few Hymenoptera are pests and others are also beneficial insects. Many species are parasitic on other insects and important bio-control agents, while bees produce honey and pollinate crop (Peters *et al*., 2017)

2.3.4 Order Diptera (flies, mosquitoes, midges)

The identifying characteristics of Diptera include- mouthparts are variable, adapted for piercing-sucking, cutting sponging and sponging. Examples of insects in this order are mosquitoes, horse flies and house flies (Plate 2.3). Larvae chew in many ways; one pair of membranous wings on mesothorax (forewing); the hind wings are reduced to nubs, called halters; antennae can be long and body slender in the gnat-type flies or antennae can be a bristle, and the body stout in the housefly type flies (Gibb *et al*., 2006). Flies are highly adaptable and have evolved a great variety of lifestyles, often bringing them into direct conflict with man. Many are important agricultural pests, some parasitize other insects and many families are vectors of diseases in animals and humans (Lawrence, 1992).

2.3.5 Order Orthoptera (crickets, grasshoppers, locusts).

Insects in this order have leathery forewings with parallel veins which appear in straight lines and an elongate body (Plate 2.5). Many possess stridulatory organs that make sounds used in courtship and they have chewing mouthparts (Rentz, 1996). They are found in vegetation, and leaf litter. Grasshoppers occasionally are found feeding on leaves of perennials, flowers, and grass (Lomer *et al*., 2001).

2.3.6 Order Araneae (spiders)

Spiders vary considerably in shape and colour (Plate 2.6). The cephalothorax is connected to the unsegmented abdomen by a thin pedicel. They usually have 8 eyes but the number varies from none to six. The chelicerae are strong and bear fangs with a venom gland opening at each tip. The pedipalpi are leg-like, tactile and are used by males as secondary sexual organs. Spinnerets are present on the posterior end of the abdomen. Spiders are a large, diverse group of predators occurring in many habitats (Dunlop, 2011).

2.3.7 Order Blattodea (cockroaches)

Insects in order Blattodea have leathery forewings with parallel veins (Plate 2.7) that appear in straight lines, elongate flattened body, legs built to run, have chewing mouthparts and lay several eggs in a large, often bean-shaped case (Bell *et al*., 2007).

2.3.8 Order Hemiptera

Hemiptera consists of the suborder Heteroptera made of the true bugs such as lace bugs, Wheel bugs Assassin bugs (Plate 2.8). Their identifying characteristics include part of forewing thickened or leathery with tips which are membranous, wings held flat over the body, piercing-sucking mouthparts, the antenna is slender with visible segments and triangular scutellum (dorsal plate) located behind prothorax (Linnaeus, 1758).

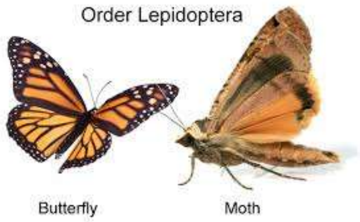

Plate2.1: Members of Order Lepidoptera. **Plate 2.2**: Members of the Order Hymenoptera

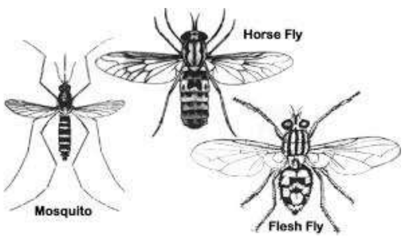

Plate 2.3: Members of the Order Diptera **Plate 2.4**: Member of Order Coleoptera

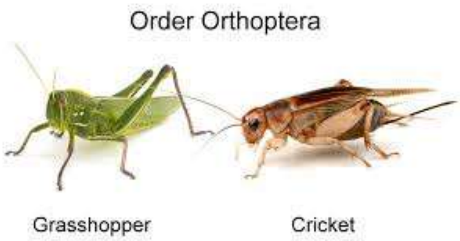

Plate 2.5: Members of Order Orthoptera **Plate 2.6**: Member of Order Aranea

Plate 2.7: Member of Order Blattodea **Plate 2.8**: Member of the Order Hemiptera

2.4 Effects of land use type on insect diversity and abundance

Land use is the purpose and the way in which land is conquered and exploited (Taiti, 1996). Land use has generally been considered a local environmental issue, but it is becoming a force of global importance. Land use change mostly includes the conversion of forests to farms or pastures and involves a change of environmental conditions which influences species richness (Laurance *et al.*, 1997). There is an increasing trend of land use changes in the tropics due to the increase in human population and a basic understanding of the impacts of this change is important in order to understand biodiversity sustainability (Daily *et al.*, 2001). In tropics, that is where a lot of biodiversities occur and it is predicted that clearing and fragmentation of forested land will increase because there is greater demand for agricultural land (Jackson *et al.*, 2005). Forest conversion causes biodiversity loss and is a threat to ecosystem function and sustainable land use (Hoekstra *et al*. 2005; Cardillo, 2006). As such, there is a growing interest to conserve biodiversity in agricultural lands (Ricketts, 2004).

Agroecosystems include land used for crops, pasture, and livestock, the adjacent uncultivated land that supports other vegetation (hedgerows, woodlots) and wildlife; the underlying soils and groundwater and associated drainage networks. An agroecosystem is not restricted to the immediate set of agricultural activity but rather includes the region that is impacted by this activity, usually by changes to the complexity of species assemblages, energy flow, and net nutrient balance. Agro-ecosystems often produce food at the expense of biodiversity, water quality and soil conservation (Bennet *et al*., 2007; Kareiva *et al*., 2007). The presence of shade-providing trees in coffee plantations have served as habitat remnants for higher species diversity (Greenberg *et al*., 1997) and a decline in shading vegetation is correlated with a decrease in species diversity (Ngai *et al*., 2006).

The use of land is one of the most significant driving forces in human impact on the agro-ecosystem. Land use can cause soil erosion, alter the hydrological balance, pollute surface and groundwater, destroy wildlife habitats, increase energy use and air pollution, habitat fragmentation and loss of biodiversity. Agricultural intensification reduces both species richness of pollinator assemblages and wild insect visitation (Potts *et al*., 2010; Garibaldi *et al*, 2011; Winfree *et al*., 2009; Klein *et al*., 2009).

Pollinating insects may also be destroyed by increased inputs of agrochemicals, decreased crop diversity, and reduction of adjacent natural semi-natural habitats (Garibaldi *et al*., 2005; Deguines *et al*., 2014). According to Thompson (2001) intensive land management often reduces plant species richness via changes in plant community composition, while fertilization and irrigation may increase flower size, leading to a higher nectar and pollen availability, which affects pollinators (Cartar, 2004). This study determined the difference in passion fruit mean fruit set at the three agro-ecological zones at Mua hills Location to understand the threat to its production at the farm level. The decline of pollinator diversity and abundance resulting from poor agricultural practices is a major concern in the environmental management of agro-ecosystems**.**

2.5 Ecology of Carpenter bee

Large carpenter bees (Plate 2.9) belong to the Order Hymenoptera, family Apidae. They are currently grouped into a single genus, Xylocopa (Minckley, 1998). The genus comprises at least three clades (Leys *et al*., 2002) and ca. 470 species (Michener, 2007). Carpenter bees occur in tropical and subtropical habitats around the world, and occasionally in temperate areas (Hurd *et al*., 1963). Biogeographical analyses suggest that the genus probably has an Oriental-Palaearctic origin and that its present world distribution results mainly from independent dispersal events (Leys *et al*., 2002).

As implied by their name, carpenter bees dig their nests in dead or decaying wood, except for the subgenus Proxylocopa that nests in the soil (Gottlieb *et al*., 2005).The wood-nesting carpenter bees construct two main types of nests: (i) unbranched (also called linear), with tunnels extending in either one or both directions from the nest entrance. Linear nests are usually constructed in hollow or soft-centered plant material, such as reeds; (ii) branched nests (> 2 tunnels), usually constructed in tree trunks or timber (Gerling *et al*., 1989). The type of nest constructed usually varies with species, but some species show plasticity in nest architecture, depending on the nesting substrate available to them (Steen *et al*., 2000). The nesting female lays one or a few eggs along a tunnel during a brood cycle, provisions them, and constructs partitions of masticated wood to separate the offspring from one another. Maternal care in carpenter bees also involves guarding of the immature offspring and feeding of the newly matured ones by trophallaxis (Gerling *et al*., 1981, 1983; Steen, 2000). Some species are univoltine, whereas others produce more than one brood per year (Steen *et al*., 2000). The activity season of carpenter bees spans 8-12 months, depending on species (Camillo *et al*., 1986; Camillo *et al*., 1982; Ben Mordechai *et al*., 1978).

Carpenter bees in natural habitats are generalist nectar and pollen foragers. For example, foraging *X. cearensis* were recorded from 43 plant species in Bahia, Brazil (Viana *et al*., 2002), while *X. latipes* and *X. pubescens* foraged on 30 species in India (Dedej *et al*., 2004); In Israel, *X. pubescens* and *X. sulcatipes* used 61 species as forage plants (Gerling *et al*., 1983); X. darwini in the Pacific is known to visit the flowers of 79 plant species (Sugiura, 2008); 28 plant species provide nectar and pollen for *X. ordinaria* in Brazil (Bernardino *et al*., 2008).

Carpenter bees pollinate passionflower (*Passiflora spp*.) in their native habitats (Mcguire, 1999) and in commercial agricultural settings (Corbett *et al*., 1980; Roubik, 1995; Freitas *et al*., 2003; de Siqueira *et al*., 2009). They provide better pollination service than honey bees for this crop (Roubik, 1995). *Xylocopa* subgenus *Lestis* has been successfully reared in greenhouses for tomato pollination in Australia. Their foraging activity led to an increase in tomato weight by 10% relative to a combination of wind and insect pollination. The efficiency of carpenter bees in pollinating tomatoes is increased by their ability to buzz the anthers (Hogendoorn *et al*., 2000).

In a pilot study in Israel, the fruit set of greenhouse-grown honeydew melons was three times higher when pollinated by X. *pubescens* compared to honey bee pollination (Sadeh *et al*., 2007). Social and solitary nesters had similar efficiency in pollinating this crop: they did not differ in the daily activity patterns and flower visitation rates. Pollination by both types of nesters led to similar fruit sets, fruit mass, and fruit seed number (Keasar *et al*., 2007). Carpenter bees are important pollinators of cotton in Pakistan, India, and Egypt (Watmouth, 1974). X. *varipuncta* is compared favorably with honey bees (*Apis mellifera*) as pollinators of male-sterile cotton in field cages in the USA (Waller *et al*., 1985). The night-flowering cactus *Cereus repandus* (syn. *C. peruvianus*) is pollinated by *X. pubescens* in Israel (Weiss *et al*., 1994). Large bodied bees such as the carpenter bee are sensitive to increasing habitat modification and are most likely to go locally extinct with agricultural intensification (Larsen *et al*., 2005).


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A) Plate 2.9 Carpenter Bee (*Xylocopa Spp)* by Emily, 2018

B) Plate 2.10 Passion fruit crop (*Passiflora edulis)* by Emily, 2018

2.6 Ecology of Passion Fruit crop

Although passion fruit crop (Plate 2.10) is cultivated in other parts of the world, such as Columbia, Peru, Ecuador, Venezuela, South Africa, Zimbabwe, Kenya, Angola, Sri Lanka, Taiwan, Malaysia, Papua New Guinea, The US and Australia (Menzel *et al*., 1994), Brazil is the world's largest producer of passion fruit . Due to its self-incompatibility, this crop depends on pollinators for fruit formation (Corbet *et al*., 1980). Cross-pollination is necessary in the passion fruit because of its flower morphology where the anthers are placed below the stigma (Corbet *et al*., 1980), pollen grains are large, heavy and sticky (Akamine *et al*., 1957; Nishida, 1958) and mainly because of the self-incompatibility (Bruckner *et al*., 1995).

Numerous techniques have been developed and are considered effective for maintaining high populations of native bees in agricultural areas, including artificial nests (Freitas *et al*., 2003), alternative sources of food (Pontin *et al*., 2006), and the diversification and habitat conservation of areas in the vicinity of the crop (Freitas *et al*., 2009). Being a mass flowering plant, the passion fruit and other plants (Westphal *et al*., 2003), require pollination when the flower is receptive to receive pollen, usually during hours of high temperature during the day (Cobert *et al*., 1980; Siqueira *et al*., 2009); and indeed larger populations of native bees are observed visiting the plant during this period (Benevides *et al*., 2009; Siqueira *et al*., 2009). Therefore, the pollination efficiency of this species justifies its conservation in agricultural landscapes (Benevides *et al*., 2009).

Purple passion fruit, *Passiflora edulis* is the Order Violales, family Passifloraceae. It was distributed throughout the tropics and subtropics via Europe and Australia during the 19th century. Demand for passion fruit has largely been driven by the fruit juice market with increasing numbers of farmers growing passion fruit in Kenya (MoA, 2006). It is now a popular fruit for both domestic and export markets. From 2001 to

2005 export from Kenya of passion fruit was around 1,000 tons per year, against a total production of around 30,000 tons yearly (MoA, 2006).

Daily data from the Ministry of Agriculture website indicates that the average price of one kilo of passion fruit is 50 shillings. From one hectare, it is possible to earn over 2,000,000 shillings; an earning that exceeds that of maize, beans and many other farming enterprises (www.nafis.go.ke/fruits/passion-fruit). Kenya Livestock and Research Organization (KALRO) has developed three passion fruit varieties (KPF 4, KPF 11, KPF 12) which are best suited to the local climate and are good as the Brazil C5 variety grown in the coastal region. Two companies are collaborating with KALRO to enhance fruit production in Eastern region; Equity Bank provides loans to passion fruit farmers while Sunny Processors extract the fruit concentrate for sale to Coca-Cola (NaHMIS, 2011).

Passiflora edulis flowers can be manually pollinated, but natural pollination is cost-free and increases the quality and quantity of fruits (Roubik, 1995). The fruits are pollinated by large bees, usually species of the genera *Xylocopa*, *Bombus*, *Centris*, *Epicharis* and *Eulaema* (Camillo, 2003; Hoffmann *et al*., 2000; Malerbo-Souza *et al*., 2002; Sazima *et al*., 1989). In Kenya passion fruit plants (Plate 1.2) are dependent on pollinators to set fruit and without them, there would be no passion fruits. It is unfortunate that farmers often mistake the large carpenter bees for beetles, or pests, and kill them because there is little information on the usefulness of these bees to the lives of people in East Africa. In the recent past, passion fruit production in Kenya has been on the decline. In 2007 about 5193 ha were under passion fruit cultivation yielding 71000 tons worth Kshs.2.1billion (MOA, 2010). In 2008 less than 2800 ha were farmed yielding an estimated 33800 tons worth about Kshs. 1.05 billion (MOA, 2010). This data suggest a 50% decrease across all parameters within a single year.

Reduced production has adversely affected the livelihoods of growers and industrial processors with many operations below installed capacity. For example, a company such as Delmonte was importing pulp from South Africa and Brazil (Otipa, 2009). A decline in fruit production in Mua hill Location has led to relocating of Kenya Orchard Limited to Ruiru (MOA, 2009). A survey conducted to determine the major constraints to passion fruit production in eight growing districts (Murang'a North, Muranga South, Kirinyaga East, Kirinyaga West, Embu East, Embu West, Meru Central and Imenti South) within Central and Eastern regions confirmed diseases as a major limiting factor to production (Mbaka *et al*., 2006). The key diseases include Fusarium wilt, Phytophthora canker, brown spots,andwoodiness virus (Mbaka *et al*., 2006) and a more recently emerged one known as die back.

A number of insects are associated with passion fruit plant. Some of these insects such as mealy bugs, passion fruit mite, fruit flies and aphids are troublesome and other insects are beneficial as pollinators. Some of the pests and disease of passion fruit can be controlled by applying fungicides such a mixture of indofil M45 and Dudu accerematine (MOA/HCDA, 2010). The use of agrochemicals could have adverse effects on the insect pollinators. Use of pesticides in agro ecosystems has led to a decline in pollinators (Brittain *et al*., 2010; Henry *et al*., 2012). Most of the studies on the effects of pesticides on pollinators have been done in Europe and North America (Greiger *et al*., 2010). Effects of pesticides on pollinators in Africa has received little attention (Donaldson, 2002) and particularly in Kenya relatively little work has been done (Kasina *et al*., 2012).

2.7 Effect of Agro-chemicals on insect diversity and abundance

Horticultural farming is very important in Kenya and between 40-60% of the horticultural producers are small and medium scale farmers. As many as 60,000 farming families and up to one million Kenyans out of a total population of above 45 million depend directly or indirectly on the export of the vegetables for their living

(World Bank, 2014). The horticultural sub-sector employs approximately 4.5million people countrywide directly in production, processing, and marketing, while another 3.5million people benefit indirectly through trade and other activities (Horticultural Crops Development Authority, 2009). Horticulture is a major source of livelihood to farmers generating in excess of $1.0 billion in foreign earnings annually (HCDA, 2010). Horticulture production, therefore, offers the best alternative for increased food self-sufficiency, improved nutrition and ensuring the generation of increased incomes and employment (Ganry, 2007; 2009).

The Pest Control Products Board (PCPB) is a statuary organization of Kenya government established under the pest control products act, cap 346 laws of Kenya of 1982 to regulate the importation and exportation, manufacture, distribution and use of pest control products in Kenya. Several categories of the products included in this are synthetic chemicals, microbial pesticides, botanical pesticides, biochemical pesticides, and natural enemies. Pesticides are substances or mixtures of substances intended for preventing, destroying, repelling or mitigating any pest (Oudejans, 1991).

Pesticides are divided into organic and inorganic. Inorganic pesticides are naturally occurring non-carbon elements, they are generally stable, nonvolatile and soluble in water. Most inorganic pesticides contain arsenic, cyanide, mercury, and thallium, but the presence of such metals make pesticides persistent and bio-accumulative (Hassall, 1990). Organic pesticides are mainly synthetic compounds containing either aliphatic or aromatic hydrocarbon chains. They are further classified according to their active ingredients (Louis, 1994). They consist of organochlorines, organophosphorus, organosulfur, carbamates and pyrethroids depending on the element bonded to the hydrocarbon system (Waswa, 2008).The World Health Organization (WHO) classifies pesticides in terms of their toxicity; as extremely hazardous (class IA), highly hazardous (class IB), moderately hazardous (class II), slightly hazardous (class III) and unlikely to present an acute hazard (class IV) (WHO, 2008).

Pesticides are known to cause environmental contamination, pollution and also kill non target beneficial organisms such as those useful in plant pollination (Nderitu, *et al*., 2007). In developing countries, unprecedented public and environmental contamination occur due to use of more toxic pesticides, poor pesticides handling practices, inadequate management and regulation of these chemicals (Waichman *et al*., 2007; Gitonga *et al*., 2010 and Ntow, 2008). According to Basel convention of 1989, the pesticide containers are considered to be hazardous waste and should be disposed of in an environmentally sound manner.

The dangers of pesticides, especially insecticides, to pollinators are well documented and understood (Johansen *et al*., 1990; Sihag, 1995). Most studies on pesticide toxicity and hazards to pollinators have dealt with honeybees, but these are poor bio-indicators for effects on other pollinators, even bees (NRCC, 1981; Johansen *et al*., 1990; Kevan *et al*., 1995). Piles of dead honeybees in front of hives and behavioral abnormalities are bio-indicators of serious environmental problems. Although most mass mortalities of honeybees stem from accidents and careless application, occasionally deliberate misuse of pesticides despite label warnings and recommendations have caused major pollinator kills.

Mosquito Control Program has been associated with major losses of honeybees in Canada and the USA. In Manitoba, efforts to combat outbreaks of western *Equine encephalitis* by controlling its mosquito vectors resulted in damage to colonies of honeybees totaling $90,000 in 1981 and $850,000 in 1983 (Dixon *et al*., 1982, 1984). There are records of evaluated losses of alfalfa leafcutting bees caused by pesticides in the western USA (Johansen, 1977). The number of plant species of the forest and forest margins suffered reduced fruit and seed set due to the decline of bees (Kevan *et al*., 1989, 1995).

Approximately 85-90% of the pesticides amounts used in agriculture never reach the pests; much is carried away from agricultural fields by rain run-off (advection) or wind drift, (Moses *et al*., 1993). Effects of the pesticides on non-target organisms can be direct or indirect, long term or short term. An estimation of risks connected to pesticide use is difficult; many factors complicate determining the actual risk. Since Kenya has an active and growing program to help stakeholders build their capacities to manage chemicals safely (NES, 2006), the general approach is to provide awareness, legal and policy framework and training in key chemical safety elements.

Pesticides use should not be the only pest management practice. Farmers should be encouraged to weed instead of using herbicides. Other important preventive strategies are the release of pheromones, crop rotation, resistant host-plants, biological control and use of Genetically Modified Organisms/Crops (GMO/GMC). Integrated Pest Management (IPM) strategies apply a combination of these control tools can be designed for local pest problems. It has been successfully practiced in both perennial and annual crops in temperate and tropical conditions for control of all pests, especially insects and fungi (Oerke and Dehne 2004).

Dewey (1973) showed that the highest levels of fluoride, associated with an aluminium reduction plant, were found in flower-visiting insects (from bumblebees to butterflies and hoverflies). Sulphur dioxide reduces the activity of pollinators including honeybees and male sweat bees (*Lasioglossum zephrum*) but may not kill them (Ginevan *et al*., 1980). Little information is available in Kenya on the effects of agro-chemicals on insect pollinators in different agro-ecological zones. This study was aimed at finding the correlation between agrochemicals use and diversity and abundance of insect pollinators. The researcher hypothesized that the over use of pesticides is poisoning insect pollinators as bio-indicators of the state of the agro-ecosystem health.

The main horticultural crops grown in Kenya can be broadly grouped into fruits, vegetables, and flowers. The major fruits grown include avocados, bananas, citrus, pineapples, mangoes, and papaya, while the vegetables include cabbages, spinach, tomatoes, onions, chilies, pepper, carrots, French beans and Asian vegetables (karella, dhudi, brinjals). Rapid growth in horticultural production has been accompanied by heavy use of pesticides. Heavy pesticide use occurs in part because numerous pests attack horticultural crops reducing market value and yield on high-value crops. Pesticide use raises safety concern about environmental health for insect pollinators in the agroecosystems. Lately, the export segment has been faced with stiff regulations that require monitored pesticide use, including utilization of only specific pesticide molecules (Okello, 2005).

Efforts to control plant pests can have severe unintended consequences for pollination. The impact of insecticide application on pollination services and the resulting crop yields depends on the kind of pesticide, dosage, formulation, and timing of application. Research has shown that one of the probable causes for the population declines of pollinators, including honeybees, is the indiscriminate use of pesticides (Klein *et al*., 2007; Potts *et al*., 2010; Nakasu *et al*., 2014). Insect pollinators of crops and wild plants are threatened worldwide by pesticide use and the spread of disease and parasites (Adam *et al*., 2012; Potts *et al*., 2010). Chemical insecticides targeting pests are often employed as part of intensive crop management strategies but these chemicals can also be harmful to beneficial insects such as pollinators (Creswell, 2011).

There is evidence that wild bee and butterfly species richness tend to be lower where pesticide loads and cumulative exposure risk are higher (Brittan *et al*., 2010). Recent experiments have shown that sub-lethal neonicotinoid (systemic pesticide) exposure impaired the ability of foraging honey bees to relocate the hive (Henry *et al*., 2012). Most of the studies on the effects of pesticides on pollinators have been done in Europe and North America (Greiger *et al*., 2010). Effect of pesticides on pollinators in Africa has received little attention (Donaldson, 2002). In Kenya, there is little research on the effect of agrochemicals on pollinator decline in agro-ecosystem. The current study examined the effect of agrochemicals on the diversity and abundance of insect pollinators in different land use types under contrasting agro-ecological zones.

2.8 The association between plant species and diversity of pollinators

Plants are important to insect pollinators in providing food resources and nesting sites. The availability of food resources is likely to show a strong impact on insect pollinators. Enhanced plant species richness has been hypothesized to promote richness of pollinators because of plant species-specific pollinator preferences and a better pollen and nectar resources availability over space and time (Linsley, 1958; Eickwort *et al*., 1980; Steffan-Dewenter *et al*., 2001; Potts *et al*., 2003; Hegland et al., 2005; Fontaine *et al*., 2006; Ghazoul, 2006; Bluthgen *et al*., 2007; Holzschuh *et al*., 2007; Kwaiser *et al*., 2008).The loss in plant-pollinator interactions can lead to parallel declines of plant species and their associated pollinators(Biesmeijer *et al*., 2006). The size of the pollinator population is generally thought to be the most important to plant reproduction (Kevan *et al*., 1986).

In studies of seasonal fallows (Steffan-Dewenter *et al*., 2001) and wheat fields (Holzschuh *et al*., 2007), bee species richness increased with plant species richness. The competition theory for diversity suggests that consumer (pollinators) diversity is directly correlated to resource (plants) abundance and vice versa (MacArthur, 1972). This could mean that fluctuations in the bee community may impact the abundance and diversity of the corresponding plant community.

Research done by Jordano (1987), Memmot (1999) and Waser *et al* (1996) has shown that floral reproductive success is associated with a greater diversity of pollinator visitors. Furthermore, diverse insect communities occur where pollen and nectar resource diversity is high (Potts *et al*., 2003). This mutualistic relationship suggests a correlation between the diversity of plant and pollinator communities (Ghazoul, 2006).

Bees are highly sensitive to floral resource abundance and diversity and probably also to the presence of nesting sites (Roulston *et al*., 2011). In some parts of the world, the diversity and abundance of wild bees have decreased, leading to concern about habitat degradation and a crisis of pollination services (Potts *et al*., 2010). Habitat fragmentation as a form of habitat degradation is caused by humans who clear native vegetation for agriculture and other development activities. There has been habitat fragmentation at Mua hills Location due to land use changes with impact on the diversity and abundance of insect pollinator diversity (Martins *et al*., 2009). The objective of this study was to answer two questions 1) are the diversity and abundance of flowering plant and pollinator communities correlated with one another? and 2) does the relationship between plant and pollinator diversity differ among these three agro-ecological zones? The researchers hypothesized that differences in plant species richness were mostly the result of differences in the intensity of land use.

An ecosystem can also be defined as the biotic community plus its abiotic environment (Linderman, 1942). An ecosystem is divided into the community; these are the organisms that interact in a given area. The community is formed of several guilds of species; these are groups of species that exploit the same resource in a similar manner (Root, 1967; Jaksic, 1981). Species are reproductively isolated from other such groups (Mayr, 1963), and populations are composed of individual organisms. The highest level of organization is the ecosystem, which may be classified into natural ecosystems, composed of native organisms; semi-natural ecosystems, in which human activity is limited and it is subject to some level of low-intensity human disturbance; and “managed ecosystems”, where human control is fully exercised for example agroecosystem. An agroecosystem is an ecosystem under agricultural management, connected to other ecosystems.

Agroecosystems are inclusive of the land used for crops, pasture, and livestock, the adjacent uncultivated land that supports other vegetation (hedgerows, woodlots) and wildlife; the underlying soils and groundwater and associated drainage networks. An agroecosystem is not restricted to the immediate set of agricultural activity but rather includes the region that is impacted by this activity, usually by changes to the complexity of species assemblages, energy flow, and net nutrient balance. An ecosystem provides services to the organisms found living in it. Agroecosystem biodiversity is threatened by human activities such as different land use type and agro-chemicals.

In this research, land use type is defined as how land is utilized on the basis of food crops. In the Lower Eastern Region of Kenya (Ukambani area) food crops are grown according to rainfall amounts and temporal distribution, which is bimodal in nature. The long rains occur from March to and including May, while the short rains occur from October to and including December. Following these rainfall patterns, annual single-crop systems and double-crop systems can be found. Annual crops include maize, vegetables, peas and beans which are grown as a monoculture or as mixed cropping in small farms. Perennial crops include fruits such as passion fruit, mangoes, guavas, avocados and bananas which are intercropped with the annual crops or grown in monoculture.

The Mua Hills location has three Agro-ecological zones namely; Zone III, Zone IV, and Zone V. It is a good representation of the large Ukambani region which is situated on a predominantly semi-arid, eastward-facing slope, which becomes progressively lower and drier to the east. This part of Kenya forms an environmental gradient of decreasing altitude (2,100m to 440m), increasing temperatures and decreasing moistures. Elevation controls the quantity of rainfall at the regional scale, whereas topography influences rainfall distribution at the local level. The farms sampled in each Agro- ecological zones in this study were categorized according to three land use types; horticulture, mixed cropping, and natural patches near each farm which served as the control sites.

In this location, farmers are caught in a cycle where degrading soils force them to increase applications of agrochemicals often above the recommended levels to correct for the continual decline in soil fertility, and according to Altieri and Anderson (1992) this, in turn, causes further degradation to soil health and affects plant growth. Pesticide misuse and drift from aerial spraying are a major threat to insect pollinators, especially spraying with persistent chemicals that remain in the environment for a long time before degrading. Systemic insecticides applied to seeds can contaminate the pollen grains that are an essential source of food for bees and their young. This study has provided baseline data on insect pollinator species diversity, distribution, and abundance in Mua hill Location. This information is important for agroecosystem function and biodiversity conservation. Reduced abundance and loss of pollinators will affect individual plant species and also the wider community of organisms associated with plant and pollinator, and ultimately ecosystem function.

This study was done in order to understand through field-based research the status of insect pollinators in Mua hills Location. The information provided through this study is needed in order to identify pollination limitation of passion fruit and advocate for agricultural sustainability and environmental conservation.

2.9 Conceptual Framework

The conceptual framework was based on earlier studies done to determine how agricultural intensification affects pollination and the effects of pollinator loss to passion fruit nutritional content. Klein *et al* (2007) did case studies for nine crops on four continents which revealed that agricultural intensification jeopardizes wild bee communities and their stabilizing effect on pollination services at the landscape scale.

Eilers *et al*. (2011) study evaluated the nutritional composition of animal-pollinated world crops and found out that Crop plants that depend fully or partially on animal pollinators contain more than 90% of vitamin C, the whole quantity of Lycopene and almost the full quantity of the antioxidants β-cryptoxanthin and β-tocopherol, the majority of the lipid, vitamin A and related carotenoids, calcium and fluoride, and a large portion of folic acid. The research highlighted the importance of pollinators to global health and stated that ongoing pollinator decline may exacerbate the current difficulties of providing a nutritionally adequate diet for the global human population.

Ellis *et al* (2015) study tested the suggestions that animal pollinators are crucial for human nutritional health. It combined data on crop pollination requirements, food nutrient densities, and actual human diets to predict the effects of pollinator losses on the risk of nutrient deficiency.. The study recommended the potential health effects of ecosystem change that limit pollination. The current study builds on these earlier researches by investigating the link between environmental degradation, diversity, and abundance of insect pollinators and passion fruits (Figure 2.1).

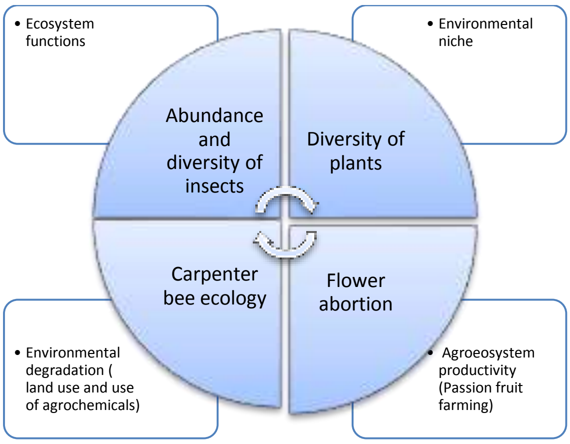

Figure 2.1 Conceptual Frame work

3.0 CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter focuses on the key components of the research methodology used in this study. It covers the study area, sampling design, research instruments, and data analysis. Importantly, the chapter identifies and justifies the study area selected as well as tools used in the research and analysis.

3.2 General Materials and Methods

In sampling insect pollinators, colored pan traps were used because of the visual acuity of insects and the color also mimic a flower. Hand net was used during the day and for short periods. Hand netting is effective in capturing mobile large bodied insect species. Line transect was used to illustrate the gradient pattern along which the insect pollinator communities change. The farms sampled in each Agro-ecological Zone was categorized according to two farming practices; horticulture and mixed cropping. Sampling of insect pollinators was done within the natural patches near each farm to determine the diversity and abundance and they served as control sites.

3.3Study Area

The location of this study was Mua Hills situated in Machakos County in Kenya (Figure 3.1 below). The County is categorized into five agro-ecological zones (AEZs) based on the potential crop production suitability (Jaetzold *et al*., 2010; KNBS, 2015). Zone III is suitable for mangoes, maize, pigeon pea, cow peas, and indigenous poultry and is found in Machakos, Kangundo, Kathiani, Mwala, Yatta, Matungulu, and Masinga. Zone IV has the potential for production of maize, beans, mangoes, cow peas, indigenous chicken, and pigeon peas and Matungulu, Kangundo, Kathiani, Machakos, Mwala, Yatta and Masinga fall under this AEZ. Zone V is suitable for dairy, beans, maize, pigeon peas, cow peas, mangoes, and indigenous chicken and is found in Matungulu, Mwala, Masinga, and Yatta.

Machakos sub-county has several Wards including Mua hills Location and this area is important for horticulture. In Kenya, horticulture comes third in ranking just after tourism and tea in exports and it is the rapidly developing sector in agricultural production (Gioe, 2006). Mua hills Location has experienced habitat fragmentation and coming up human settlements such as Lukenya and Katelembo. Such factors may easily influence biodiversity in this area.

A decline in fruit production in Mua hill Location led to relocating of Kenya Orchards Limited to Ruiru (MOA, 2009). A study done on the pollinators of *Carica papaya* in Katheka-kai location showed a decrease in the density of hawk moth (Martins, *et al* 2009). This region experience long rains between March and May whereas short rains are received between October and December. Due to the rainfall patterns that occur in the area, farmers usually practice annual single-crop and double-crop systems. Annual crops include maize, vegetables, peas and beans which are grown as a monoculture or as mixed cropping in small farms. Perennial crops include fruits such as mangoes, guavas, avocados and bananas which are intercropped with the annual crops or grown in monoculture.

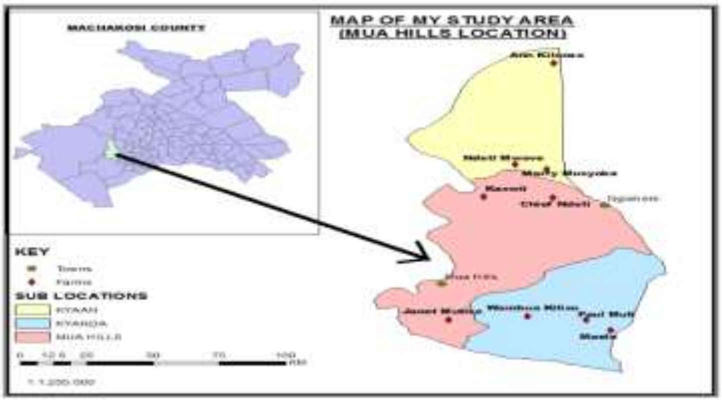

Figure 3.1 Map of Machakos County locating Mua Hills sub-locations and farm owners where sampling was done (Emily, 2018).

According to Alteiri and Anderson (1992), farmers are compelled to use agrochemicals above the manufacturer's suggested amounts because of soil degradation but in turn results in further soil degradation which greatly affects the growth of plants (Altieri and Anderson, 1992). The relationships between the quality of soil in an area and the coexistence of plants with other important pollinator species have not been widely studied. In this study, the impact of land use on the abundance and diversity of the insect are determined.

3.4 Sampling design

3.4.1 Sampling design used to determine the trends of the diversity and abundance of insect pollinators in different land use types and passion fruit set in contrasting AEZ

3.4.1.1 Sweep net

To have a successful insect activity, the temperature must be high enough to allow the easy collection. Once the sites were exposed to the sun, sampling using sweep nets (Plate 3.1) was done at 8:00 a.m. and collecting continued until late afternoon (when the weather is dry). This studyused a sweep net with an eversible stick and a diameter of 38cm to increase the collection radius (Plate 3.2) (Stubbs and Chandler, 1978). A single back and forth sweep covering a $150^0$to 180^0arc was considered as a single sweep. The researcher walked through the habitat and swept with the hand net with ease over the vegetation. This caused the insects to fly up only to land inside the net as anticipated. The time taken was not more than five minutes at any single plant or flowering patch and the collector did not have to re-visit the same patch again. Two 30 minutes surveys a day were carried out. The insects caught with a hand net were carefully put into a killing jar with 70% alcohol to be later identified at National Museums of Kenya.

The number of sweeps taken was recorded so that samples could be quantified as the number of insects per sweep. The sweep net (Plate3.2) captured mainly butterflies and few Hymenoptera. The Lepidoptera were pressed tightly at the thorax for killing and stored in specimen envelopes and the Hymenoptera were emptied into specimen bottles containing 70% alcohol for preservation.

Plate 3.1: A Sweep net

3.4. 1.2 Pan trap

The aim of this research was to examine on a small scale the overall species diversity in the area and yellow, blue and white pan traps were used (Plate 3.2). These colors were preferred because there was a variety of species and therefore colored traps would help develop consistent data about their ecological niche (Missa *et al*., 2009). The researcher filled the pan traps with water and added two drops of detergent in each bowl to act as wetter and help reduce the surface tension. To avoid the loss of (floating) specimensdue to rainfall, the pan traps had minute holes just below the upper rim to drainage off excess water.

At each site, 15 pan traps were put out in areas where pollinators were likely to be found, especially where the vegetation was open and the pans could be seen from some distance and where there were flowers which the pollinators might visit. The position of each pan trap in the arrangement was randomly chosen. The spacing between pan traps was 5cm. The three groups of pan traps containing one of each color served as replicates. This experiment was replicated through time by repeating the same experiment two seasons apart.

The collected insects were placed in sample tubes with 70% alcohol to help preserve them so that they would be numbered and easily identified later when needed. A label was written in pencil containing the following information; Country, site details, pan color, pan number, and collector were put in the sample tube. During identification, the specimens were placed into the major insect orders such as flies (Diptera) beetles (Coleoptera) bees and wasps (Hymenoptera). Unidentified insectswere put into an “other” group. Numbers for each pan trap were tallied and then the average numbers for the three bowls of each color in the five groups recorded and identified at the National Museums of Kenya.

Plate 3.2: Pan trap

3.4.1.3 Line transect

Line transect (Figure 3.2) was used to find out the distribution of insect pollinators in the study area. A total of 6 transects of length 200m and 100m apart on a baseline were followed in each habitat. Sampling points along the line transect were randomly marked using GPS system.

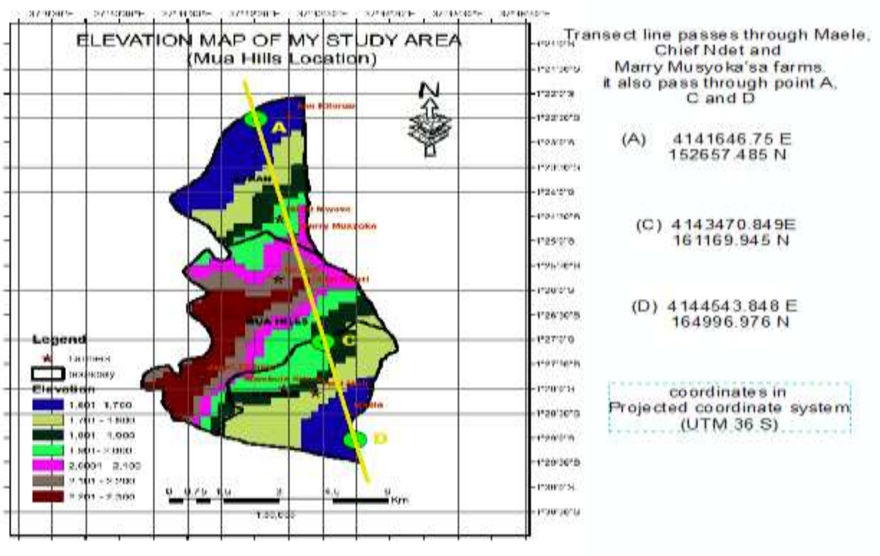

Figure 3.2: A map of Mua Hills showing the location of the line transect

3.4.2 Sampling design to determine passion fruit set

Three farms in each AEZ were selected and three passion fruit crops in each farm were sampled randomly. Two stems of each passion fruit were tied with a brightly colored string at the bottom of it for later in the season. A flag was placed there to mark the location and a sample number on the flag written in indelible ink. The total numbers of blossoms on the selected stem including those that were open, those that weren't open, and those that had lost their petals were counted. Visual observation was used to determine the insect pollinators that pollinated the flowers.

Shortly before harvest, when most of the fruits were ripe, a second count was performed, returning to the locations marked by the flags. At each stem selected previously, the total number of fruits was counted (leaving out any that was pinhead size) and their number recorded beside the number of blossoms for that stem.

3.4.3 Sampling Design used to assess the use of agrochemicals and their impact on the insect pollinators in the agro-ecosystems.

The required sample size of farmers who were given the questionnaires was determined by sampling methodology according to Anderson *et al* (2007) as below:

$$n = \frac{pqZ^2}{E^2}$$

where:

n= the desired sample size if the targeted population is greater than 10000

z= the standard normal derived at the required confidence level

p= the proportion in the target population estimated to have characteristics being measured.

q=1-p

d= the level of the statistical significant set.

Since the estimate of the proportion of the target population assumed to have the characteristics of interest was not provided, at least 30% of the total population is representative (Borg and Gall, 2003). Since 100 farmers were identified by Ministry of Agriculture extension officers, 30% of the accessible population was enough for the sample size, and the sample size was taken to be 30 respondents. Respondents were identified with the assistance of Ministry of Agriculture Extension Officers who were in-charge of Mua Ward. The Participatory Rural Appraisal (PRA) methods were used to gather data about the safety of the agrochemicals that were being used, the effects and challenges observed during their utilization. These techniques included group discussions and interviewing people who were knowledgeable (Bernard, 1994).

To ensure the research remains objective during data collection, the interviews involved the use of structured questions as a guideline. The researcher made personal visits to the representative sample of the farmers to collect information on agrochemical usage. The advantage of personal visits was that they enable the interviewer to view the farm and take note of the crops grown. During personal visits, respondents were more truthful and the data derived made a statistically valid sample. The agrochemicals considered in this study were pesticides (insecticides and fungicide) and foliar fertilizer.

The farmers had been given prior notice of the visit to allow them time to gather together their records and information. This had been done through a meeting with the herdsman, sub-chief and agricultural extension officers in which the objectives of the survey was clearly explained. The researcher used well-structured questionnaires to record the information (Appendix V).

The individual who was interviewed represented a household and the person was interviewed to assess his/her knowledge and practice towards agrochemicals management and its impact on the environment. The questions concerned; (i) If the farmer uses fertilizers and pesticides, (ii) How often they were used (iii) which pesticides were mostly applied and why, (iv) the knowledge of pesticides side effects on insect pollinators (v) types of agrochemicals application method (vi) the fate of the leftover agrochemicals and storage, (vii) disposal of empty pesticide containers, (viii) the pesticide impact on the environment, (ix) how the farmer can reduce the agrochemicals impact on the environment(Appendix V).

3.4.4 Sampling Design to determine the association between plant diversity and insect species richness

The vegetation was divided into strata during sampling and stratified random sampling was applied. A line transect measuring 12 km long was used and it runs across the three agro-ecological zones from point A to D (Figure 3.2). The line transect was divided into six subsections, with two subsections in each agro-ecological zone. The direction was from left to right, GPS readings were recorded at the point of departure of a line transect and at the end of transect. Any obstacle encountered on the transect line that could not be traversed (trees, streams), the researcher had to navigate around it.

At each subsection of the line transect, quadrat measuring100mx200m were randomly selected. The herbaceous vegetation, shrubs and tree species within the quadrat were identified, counted and recorded. The dominant species were determined on each sampling point for every agro-ecological zone being studied. Habitats in all agro-ecological zones in Mua hills Location during this study were classified as grassland, shrubs, woodland, and riverine forests.

Insect sampling was done using the strip transect method. Belt transects are most effective active sampling methodsfor bees (Banaszak, 1996).Two strip transects were established systematically in each of the sampling plot measuring 100m x 200m. Each strip transect was 200m long and 5m wide and they were 40m apart. Transect walks for insect observation, counts and identification were done in this strip transects. To carefully perform insect censoring, observation and identification, sweep- netting and trapping were majorly used. Observation and sweep- netting of insects were made in 30 minutes and, use of pan traps for three hours per strip transect in the selected quadrats within a specified period from 09:00 to 12:00 hours each day. Every agro-ecological zone in Mua was sampled twice a week during the month of March and August 2016. Individual insect samples were coded to be able to associate them with tree species which were their floral resources. During the transect walk, data recorded were GPS reading, altitude, insect species observed and the number of individuals detected in data sheets (Appendix I). A total of 48 sampling days were done along the line transect in a period covering two seasons (wet and dry).

3.5 Data analysis

3.5.1 Data analysis for insect diversity and abundance

To assess the diversity index of insect pollinators, Shannon-Weiner index was used because it puts into consideration the abundance as well as the consistency of the present species in the area. The Shannon-Weiner function (H’) is expressed as:

$$H = -\sum (Pi) \times (\ln Pi)$$

Where: Pi is the percentage of species ’i’ in the community.

The value of Shannon-Weiner function was chosen because of the assumption that it was more sensitive to the presence of rare insect species in the sample. Test for Homogeneity was calculated using the Levene's Test for equality of error variance across groups. The Null hypothesis was that the error variance of the dependent variable is equal across groups. Two-way ANOVA was conducted to determine the impact of land use types, agro-ecological zones, seasons and windward side on insect pollinator abundance in Mua hills Location Machakos County. The post-hoc comparison carried out using the Tukey test was used to compare the mean difference between different land use types.

3.5.2 Data analysis to determine passion fruit set

The passion fruit set mean was calculated in different agro-ecological zones. Passion fruit set was calculated as the ratio of the number of harvested fruits to the number of flowers. Pearson correlation was used as a measure of the strength and significance of a relationship between two variables; flowers and fruits.

The Pearson correlation coefficient was used to measure the strength of a linear association between two variables, where the value r = 1 means a perfect positive correlation and the value r = -1 means a perfect negative correlation. Requirements for Pearson's correlation coefficient: the scale of measurement should be interval or ratio, variables should be approximately normally distributed, the association should be linear and there should be no outliers in the data.

3.5.3 Data Analysis on the use of agrochemicals and their impact on the insect pollinators in the agro-ecosystems.

During pre-analysis, data cleaning and tabulation was carried out. This activity was meant to ascertain consistent and relevant presentation of the collected data. It, therefore, eases the data entry process and helps in ensuring the safety of the questionnaire data (Bogdam *et al*., 1999). Qualitative and quantitative data analysis was then done on the resulting data by descriptive statistics. Statistical Package for Social Sciences (SPSS version 16.0) software was used for analysis of the following: the use of fertilizers and pesticides; time of application; the amount applied; frequency of pesticide usage on a particular crop; information regarding leftover pesticides; disposal of pesticide containers and packages; knowledge about insect pollinators and their importance in agriculture; and effect of pesticides in the environment and insect pollinators.

Descriptive statistic (percentages) was used to organize and characterize the data sets. Inferential statistics- Spearman Correlation coefficient (Spearman, 1904; Wayne, 1990) was used to describe strength and direction and statistical dependence between the areas of focus. Spearman's Correlation in statistics significance test the p-value to indicate the level of relation of the independent variable to the dependent variable. If the significance number found is less than the critical value also known as the probability value (p) which is statistically set at 0.05, then the conclusion would be that the model is significant in explaining the relationship, however, if the significance number is greater than the critical value, then the model would be regarded as non-significant.

3.5.4 Analysis of data to determine the association between plant diversity and insect species richness

The Shannon-Weiner function was used to compare the community structure of plant species among the different agro-ecological zones. The Shannon-Weiner function (H') is expressed as:

H = -∑ (Pi) x (ln Pi)
Where: Pi is the percentage of species 'i' in the community
The value of Shannon-Weiner function was chosen because of the assumption that it was more sensitive to the presence of rare insect species in the sample.
Chi-square test was used to evaluate the level of association. The value of the chi-square teststatistic is given by:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

Where:

χ^2= Pearson's cumulative test statistic, which asymptotically approaches a χ^2 distribution
O_i= an observed frequency;
E_i= an expected (theoretical) frequency, asserted by the null hypothesis;
n= the number of cells in the table.

4.0 CHAPTER FOUR: RESULTS

4.1 The effect of land use on the diversity and abundance of insect pollinators in different agro-ecological zones.

4. 1. 1: Insect Diversity

In total, 1251 insects were collected belonging to 30 species, 10 genera and 8 families (Table 4.1). Order Lepidoptera had the highest abundance (54%) followed by Order Hymenoptera (19%) and the Order Coleoptera and Orthoptera had the least.

Table 4.1 Insect Diversity at Mua Hill location, Machakos County

Name of Insect Orders	Insect Abundance	%
Lepidoptera	670	54
Hymenoptera	240	19
Diptera	122	10
Coleoptera	14	1
Orthoptera	16	1
Hemiptera	29	2
Aranae	134	11
Blasttodea	26	2
TOTAL	**1251**	**100**

In the order Hymenoptera, the family Apidae had the highest species richness, *Apis mellifera* had a mean of 10, *Ceratina spp* a mean of 17, *Lassioglossum spp* had mean of 9.67 and *Macrogalea candida* a mean of 17.67. Likewise, *Megachile spp*, *Seladonia spp*, *Xylocopa flavorufa* and *Xylocopa nigrita* revealed a mean of 11.67, 9.63, 1.67 and 3 respectively (Table 4.2).

Table 4.2: Insect Diversity Order Hymenoptera in Mua Hills Location, Machakos County

Order	Family	Species	Mean	Std. Dev	N
Hymenoptera	Apidae	*Apis mellifera*	10	5	3
		Ceratina spp	17	18.028	3
		Lassioglossum spp	9.67	7.371	3
		Macrogalea candida	17.67	11.24	3
		Megachile spp	11.67	9.504	3
		Seladonia spp	9.33	7.095	3
		Xylocopa flavorufa	1.67	2.887	3
		Xylocopa nigrita	3	5.196	3
		Total	10	9.56	24

The order Lepidoptera was represented by four families namely; Nymphalidae, Pieridae, Lycaenidae and Crambidae. There were 8 genera under the family Pieridae (Table 4.3).

Table 4.3: Insect Diversity Order Lepidoptera in Mua hills Location, Machakos County

Dependent Variable: Insect richness					
Order	**Family**	**Species**	**Mean**	**Std. Dev**	**N**
Lepidoptera					
	Pieridae	*Belenois creona*	16	8.888	3
		Catopsilia florella	9	4.583	3
		Colotis anterippe	11	9.849	3
		Colotis aurigineus	15.33	4.163	3
		Colotis auxoinca	26.33	9.074	3
		Colotis evagore	46	4.583	3
		Colotis hetaera	65	19.313	3
		Eurema brigitta	6.67	4.509	3
		Total	24.42	21.295	24

Shannon Diversity Index for Hymenoptera family Apidae for Zone III had (2.37), Zone IV (2.38) and Zone V (2.54) respectively (Table 4.4). The results indicated that diversity and evenness of Order Apidae are much higher in Zone V than in Zone III and Zone IV. The other Orders included Diptera, Aranae, Orthoptera, Coleoptera, Hemiptera, and Blattodea (Table 4.4).

Table 4.4: Shannon Diversity Index and Evenness in the three AEZ of Mua hills Location

		Shannon Diversity Index (H')		
Family	**Order**	**Zone II**	**Zone III**	**Zone IV**
Hymenoptera	Apidae	2.37 (0.90)	2.38 (0.90)	2.54 (0.96)
	Halictidae	1.90 (0.98)	1.86 (0.96)	1.74 (0.89)
Lepidoptera	Pieridae	2.02 (0.97)	2.07 (0.94)	1.93 (0.88)
	Nymphalidae	1.06 (0.96)	1.04 (0.95)	1.10 (1.00)
Others		1.59 (0.82)	1.66 (0.93)	1.13 (0.63)

The evenness value for the species richness is indicated in the parentheses.

Analysis of variance test which was performed on the family Apidae, Order Hymenoptera (Table 4.5), indicated that there was no significance of the diversity between the three zones and the Null hypothesis was rejected at $p < 0.05\%$ level.

Table 4.5: ANOVA for Hymenoptera for the three AEZ in Mua hills Location

Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Order Hymenoptera	613.5897	12	51.13248	1.033158	0.452074	2.18338
Zones	1186.205	2	593.1026	11.98394	0.000246	3.402826
Error	1187.795	24	49.49145			
Total	2987.59	38				

4.1.2: Insect abundance during Wet and Dry Season in Mua hills Location

During the wet season natural patch land use of Zone III had a high mean in abundance of insect pollinators while horticulture had a low mean in abundance of insect pollinators (11.88889 v2.851852) (Table 4.6). In Zone IV, the mean abundance of insect pollinators was high in natural patch as compared to horticulture which had the lowest mean in abundance of insect pollinators (14.59259 v 5.851852). Additionally in zone V, the results indicated a high mean abundance of insect pollinators in natural patch as compared to horticulture which had the lowest mean in abundance of insect pollinators (8.796296 v 2.296296).

Table 4.6: Insect Abundance during Wet Season in Mua hills Location

Dependent Variable: abundance of insect					
Season	**Zone**	**land use type**	**Mean**	**Std. Deviation**	**N**
Wet	ZONE III	Natural patch	11.88889	3.02765	9
		Horticulture	2.851852	0.959038	9
		mixed cropping	6.606061	3.495452	11
		Total	7.08046	4.529143	29
	ZONE IV	Natural patch	14.59259	5.051891	9
		Horticulture	5.851852	1.879059	9
		mixed cropping	7.740741	2.797706	9
		Total	9.395062	5.098212	27
	ZONE V	Natural patch	8.796296	2.979536	18
		Horticulture	2.296296	1.322944	18
		mixed cropping	3.583333	1.336108	16
		Total	4.942308	3.515742	52
	Total	Natural patch	11.01852	4.273168	36
		Horticulture	3.324074	2.027566	36
		mixed cropping	5.546296	3.065582	36

4.1.3 Insect abundance in Dry season in Mua hills Location

During the dry season the results portrayed a slightly same trend. Zone III indicated the highest average abundance of insect pollinators in natural patch while the lowest in horticulture (8.037037 v 5.62963) (Table 4.7). In Zone IV the results indicated the highest average abundance of insect pollinators in natural patch and lowest in horticulture (12.11111 v 4.074074). In Zone V results showed that the mean abundance of insect pollinators was highest in natural patch and lowest in horticulture (9.166667 v 4.722222).

Table 4.7: Insect Abundance during Dry Season Mua hills Location

Dry	ZONE III	Natural patch	8.037037	2.468943	9
		Horticulture	5.62963	1.851759	9
		mixed cropping	6.851852	1.537595	9
		Total	6.839506	2.159001	27
	ZONE IV	Natural patch	12.11111	2.783882	9
		Horticulture	4.074074	1.942062	9
		mixed cropping	10.11111	1.732051	9
		Total	8.765432	4.072857	27
	ZONE V	Natural patch	9.166667	2.770644	18
		Horticulture	4.722222	1.753614	18
		mixed cropping	8.833333	2.777712	18
		Total	7.574074	3.175784	54
	Total	Natural patch	9.62037	3.039583	36
		Horticulture	4.787037	1.858746	36
		mixed cropping	8.657407	2.524151	36
		Total	7.688272	3.261937	108
Total	ZONE III	Natural patch	9.962963	3.333116	18
		Horticulture	4.240741	2.022118	18
		mixed cropping	6.716667	2.727969	20
		Total	6.964286	3.558276	56
	ZONE IV	Natural patch	13.35185	4.15779	18
		Horticulture	4.962963	2.067138	18
		mixed cropping	8.925926	2.565624	18
		Total	9.080247	4.581402	54
	ZONE V	Natural patch	8.981481	2.841802	36
		Horticulture	3.509259	1.963939	36
		mixed cropping	6.362745	3.443989	34
		Total	6.283019	3.583558	106
	Total	Natural patch	10.31944	3.748526	72
		Horticulture	4.055556	2.066954	72

	mixed cropping	7.101852	3.198023	72

This was an indication that insect pollinators thrive well in different ecological zones despite the season i.e. wet or dry. It also indicated that on an average, many insect pollinators thrive in natural patch as compared to mixed cropping and horticultural land.

4.1.4: Test for Homogeneity

The null hypothesis was that the error variance of the dependent variable is equal across groups. According to the Levene's Test of Equality of Error Variance (Table 4.8), the Null hypothesis was rejected since the p value was less than 0.05 .of 0.000<0.05.

Table 4.8: Levene's Test of Equality of Error Variance

Dependent Variable: abundance of insect			
F	df1	df2	Sig.
2.71	17	198	0.000

4.1.5: Two Way Anova

The study found that season explained about 0.1% of the abundance of insects. Given the F value of the chance to observe the difference between the wet and the dry season (6.62963 vs 7.688272) if the Null hypothesis were true was 0.098. However, the value was greater than the standard P value of 0.098>0.05. The study therefore accepted the Null hypothesis that there was no significant difference in the average (Table 4.9).

Table 4.9: Two way Anova for differences between Land use types, Zones and Seasons

Tests of Between-Subjects Effects Dependent Variable: abundance of insect						
Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	2209.398a	17	129.965	20.911	0.000	0.642
Intercept	10818.69	1	10818.69	1740.71	0.000	0.898
Season	17.176	1	17.176	2.764	0.098	0.014
Zone	291.784	2	145.892	23.474	0.000	0.192
Land use type	1382.632	2	691.316	111.232	0.000	0.529
Season * Zone	132.944	2	66.472	10.695	0.000	0.097
Season * land use type	181.086	2	90.543	14.568	0.000	0.128
Zone * land use type	55.54	4	13.885	2.234	0.067	0.043
Season * Zone * land use type	71.523	4	17.881	2.877	0.024	0.055
Error	1230.589	198	6.215			
Total	14510.11	216				
Corrected Total	3439.987	215				

a R Squared = .642 (Adjusted R Squared = .612)

The study also found that AEZ zones explained 19.2% of the abundance of insects. The chance for observing the mean difference in the abundance of insects in the three types of zones (zone III, IV and V) and land use type was 0.000 respectively. The Null hypotheses were rejected, upholding the alternative that there were significant differences in mean abundance of insects in the zones and the land use type.

In addition, the study found out that land use type explained 52.9% of the abundance of insects in the zones. Moreover, there was a significant interaction between the mean abundance of insects in the seasons and the land use type, that is, Season * Zone (0.000<0.05). However, there was no significant difference between the zone and the land use type at 0.067>0.05. Furthermore, the study found that the seasons had a significant interaction with zone and the land use type.

4.1.6: Post-Hoc Comparisons between Zones in Mua hills Location

There was a significant difference in the average abundance of insects (Table 4.10), between Zone III and Zone IV (0.000<0.05). However there was no significant difference in the average abundance of insects between Zone III and Zone V (0.226>0.05)

Table 4.10: Tukey HSD test for Agro-ecological Zones

(I) Zone	(J) Zone	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
ZONE III	ZONE IV	-2.115961*	0.475477	0.000	-3.23879	-0.99314
	ZONE V	0.681267	0.411846	0.226	-0.2913	1.65383
ZONE IV	ZONE III	2.115961*	0.475477	0.000	0.993135	3.238788
	ZONE V	2.797228*	0.416806	0.000	1.812951	3.781505
ZONE V	ZONE III	-0.68127	0.411846	0.226	-1.65383	0.291296
	ZONE IV	-2.797228*	0.416806	0.000	-3.78151	-1.81295

Based on observed means.
The error term is Mean Square (Error) = 6.215.
* The mean difference is significant at the .05 level.

The study also revealed that there was a significant difference in the average abundance of insects between Zone IV and ZoneIII (0.000<0.05). In addition, there was a significant difference in the average abundance of insects between Zone IV and ZoneV (0.000<0.05).

The study further, indicated that there is no significant difference in the average abundance of insects between ZoneV and ZoneIII (0.226>0.05). However, there was a significant difference in the average abundance of insects between Zone V and Zone IV (0.000<0.05).

4.1.7: Post-Hoc Comparisons between Land Use types in Mua hills location

The study revealedthat there was a significant difference in the average abundance of insects between Natural patch and Horticulture (0.000<0.05) (Table 4.11). In addition, there was a significant difference in the average abundance of insects between Natural patch and mixed cropping (0.000<0.05).

Table 4.11: Tukey HSD Land Use Types

(I) land use type	**(J) land use type**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Natural patch	Horticulture	6.263889*	0.415502	0.000	5.282693	7.245085
	mixed cropping	3.217593*	0.415502	0.000	2.236396	4.198789
Horticulture	Natural patch	-6.263889*	0.415502	0.000	-7.24509	-5.28269
	mixed cropping	-3.046296*	0.415502	0.000	-4.02749	-2.0651
mixed cropping	Natural patch	-3.217593*	0.415502	0.000	-4.19879	-2.2364
	Horticulture	3.046296*	0.415502	0.000	2.0651	4.027493

Based on observed means.
The error term is Mean Square (Error) = 6.215.
* The mean difference is significant at the .05 level.

The study further, revealed that there was a significant difference in the average abundance of insects between Horticulture and Natural patch (0.000<0.05). There was also a significant difference in the average abundance of insects between Horticulture and mixed cropping (0.000<0.05).

The study also, showed that there was a significant difference in the average abundance of insects between mixed cropping and Natural patch (0.000<0.05). There was also a significant difference in the average abundance of insects between mixed cropping and Horticulture (0.000<0.05).

4.2: To determine the influence of insect diversity and abundance on purple passion fruits set in order to identify pollination limitation to the fruit production

4.2.1: Pearson's Correlation Analysis

In statistics significance testing the p-value indicates the level of relation of the independent variable to the dependent variable. If the significance number found is less than the critical value also known as the probability value (p) which is statistically set at 0.05, then the conclusion would be that the model is significant in explaining the relationship; else the model would be regarded as non-significant.

The results revealed that there was a positive and significant association between the abundance of the insects and the number of flowers ($r = 0.513$, $p = 0.001$) (Table 4.12).

Table 4.12: Correlation Analysis for Flowers recorded during the study

Statement		Flowers	
Flowers	Pearson Correlation	1	
	Sig. (2-tailed)		
Insect abundance	Pearson Correlation	.513**	1
	Sig. (2-tailed)	0.001	

** Correlation is significant at the 0.01 level (2-tailed).

The results in table 4.13 revealed that there was a positive and significant association between the abundance of the insects and the number of fruits ($r = 0.504$, $p = 0.002$).

Table 4.13: Correlation Analysis for Fruits recorded during the study

Statement		Fruits	
Fruits	Pearson Correlation	1	
	Sig. (2-tailed)		
Insect abundance	Pearson Correlation	.504**	1
	Sig. (2-tailed)	0.002	

** Correlation is significant at the 0.01 level (2-tailed).

4.3: To assess the use of agrochemicals and their impact on the insect pollinators in the agro-ecosystems

4.3.1 Descriptive Statistics

The results revealed that 76.7% of the farmers use the MAP, CAN and DAP type of agrochemicals while 23.3% of the respondents use other types of agrochemicals (Table 4.14).

The results also revealed that 80% of the farmers use insecticides and fungicides while 20% of them use other types of insecticides and fungicides in the zones.

A majority of the farmers (87.3%) applied the pesticides during the flowering stage while 16.3% applied the pesticides before flowering.

The results also revealed that majority (76.3%) of the farmers determine the amount of pesticide to be applied by estimating the amounts while 23.3% of the farmers use a stipulated scale by the manufacturer.

Table 4.14 Farmers' response on the use of agro-chemicals in Mua hills Location

Statement	Response	Frequency	Percent
Type of fertilizers	any other	6	23.3
	DAM,CAN, DAP	24	76.7
type pesticides	any other	5	20
	Insecticide& fungicide	25	80
When are pesticides used	before flowering	7	16.7
	during flowering	23	83.3
amount of pesticide to be applied	use a scale	7	23.3
	Estimate	23	76.7
Determination of the amount of pesticide to be applied	use a scale	7	23.3
	Estimate	23	76.7
Frequency of use the agrochemical	When there is need	4	13.3
	Every season	26	86.7
place of diluting the pesticide	any other place	8	26.7
	farm or river	22	73.3
Application	any other	7	23.3
	Spraying	23	76.7
Disposal of leftover pesticides	pour in the soil /bush/river	13	43.3
	use all on the crops	17	56.7
disposal of the empty containers	bury in the soil/burn	12	40
	throw in the bush/farm/river	18	60
Have you ever collected a pesticide container in your neighbourhood	No	8	26.7
	Yes	22	73.3
Do you have any pesticide in your homestead	No	4	13.3
	Yes	26	86.7
When did you buy the pesticide	cannot remember	6	20
	Recently	24	80
Insects mostly found on plant flowers	I do not know	9	30
	bees & butterflies	21	70
Are these insects important to the crops in any way	No	9	30
	Yes	21	70

Source: (Emily, 2018)

The results further revealed that majority (86.7%) of the farmers apply the pesticide every season while 13.3% of the farmers apply the agrochemicals when there is need to. The results also added to the findings that majority of the farmers (73.3%) diluting the pesticide in the farm and/or the river while 26.7% of them use other types of insecticides and fungicides in the zones.

Additionally, the data collected revealed that majority of the farmers (76.7%) apply the pesticide in the farm through the spraying method while 23.3% of them use other types of methods of application. The results also showed that majority of the farmers (56.7%) use all the pesticide on the crops while 43.3% of them discard leftover pesticides in the soil/bush/River. The results further revealed that majority of the farmers (60%) dispose the empty containers/papers which had the pesticide in the bush/farm/river while 40% bury the empty containers/papers which had the pesticide in the soil/burn.

The findings also showed that majority of the farmers (73.3%) agreed that they have ever collected a pesticide container in their neighbourhood while 26.7% of them have never collected a pesticide container in their neighbourhood. In addition majority of the farmers (86.7%) agreed that they have pesticide in the homestead while 13.3% of them didn't have pesticide in the homestead. The results also indicated that majority of the farmers (80%) recently bought the pesticides while 20% of the respondents cannot remember when the pesticide was purchased. Majority of the farmers (70%) indicated that insects mostly found on the plant flowers were bees and butterflies. In addition, majority of them (70%) indicated that these insects are important to the crops.

4.3.2 Spearman's Correlation

In statistics significance testing the p-value indicates the level of relation of the independent variable to the dependent variable. If the significance number found is less than the critical value also known as the probability value (p) which is statistically set at 0.05, then the conclusion would be that the model is significant in explaining the relationship; else the model would be regarded as non-significant (Table 4.15).

Table 4.15: Correlational Analysisfor Insect Abundance and Agrochemical use

Statement		Insect Abundance	type pesticides	time of pesticides use	amount applied	Frequency of use	application method	Disposal of leftover pesticides	disposal of empty containers	insects mostly found on plant flowers	importance of insect
Insect Abundance	Correlation Coefficient	1									
	Sig. (2-tailed)	.									
type pesticides	Correlation Coefficient	-.402*	1								
	Sig. (2-tailed)	0.028	.								
time of pesticides use	Correlation Coefficient	-.562**	0.176	1							
	Sig. (2-tailed)	0.001	0.352	.							
amount applied	Correlation Coefficient	-.398*	.388*	0.068	1						
	Sig. (2-tailed)	0.029	0.034	0.72	.						
Frequency of use	Correlation Coefficient	-0.402*	0.351	0.247	0.015	1					
	Sig. (2-tailed)	0.028	0.057	0.188	0.935	.					
application method	Correlation Coefficient	-.398*	-0.035	0.255	-0.304	0.247	1				
	Sig. (2-tailed)	0.029	0.853	0.174	0.102	0.188	.				
Disposal of leftover pesticides	Correlation Coefficient	-.451	0.331	-0.005	.472**	0.251	-0.005	1			
	Sig. (2-tailed)	0.214	0.074	0.978	0.008	0.182	0.978	.			
disposal of empty containers	Correlation Coefficient	-.367	0	.515**	-0.129	-0.12	0.193	-0.027	1		
	Sig. (2-tailed)	0.146	1	0.004	0.498	0.527	0.307	0.885	.		
insects mostly found on plant flowers	Correlation Coefficient	-0.257	0.293	0.327	0.155	0.171	0.155	0.015	0.059	1	
	Sig. (2-tailed)	0.171	0.116	0.078	0.414	0.366	0.414	0.939	0.755	.	
importance of insects	Correlation Coefficient	-.408*	0.098	.499**	0.327	.385*	-0.017	0.015	0.208	0.048	1
	Sig. (2-tailed)	0.025	0.608	0.005	0.078	0.036	0.928	0.939	0.27	0.803	.

*** Correlation is significant at the 0.05 level (2-tailed).**

**** Correlation is significant at the 0.01 level (2-tailed).**

Given the three zones, the results in revealed that there was a negative and significant association between type pesticides and fertilizers and the abundance of insects (r = -0. 402, p = 0.028) (Table 4.15).

The application of pesticides had a negative and significant relationship with the abundance of insects (r=-0.562, p=0.001).

The results indicated that the amount of applied pesticides had a negative and significant relation with the abundance of insects in the zones (r=-0.504, p=0.000).

Similarly, the results showed that the frequency of application of the agrochemicals related negatively and significant with the abundance of insects (r=-0.402, p=0.028).

In addition, the application method proved a negative and significant relationship with the abundance of insects (r=-0.398, p=0.029). However the disposal of left overs and pesticides cans proved a negative but an insignificant association with the increase in the number of insects in the respective zones. That is (r=-0.451, p=0.214) and (r=-0.367, p=0.146) respectively. The location where the insects were mostly found on the flower parts also had a negative but an insignificant relationship with the number of insects in the respective zones (r=-0.257, p=0.1716).

4.4. The association between plant diversity and insect species richness.

4.4.1 Plant diversity

A total of 6 (six) sites were sampled and herbs belonging to 12 families, three (3) shrubs and fifteen (15) higher plant species were recorded in the three AEZ (Appendix VI). In relation to the family type the abundance of herbaceous vegetation had a high mean compared to the family type at 11.44 v 6.5. The abundance of herbaceous vegetation had a standard deviation of 11.49 (Table 4.16).

Table 4.16: The association between herbaceous vegetation and insect species richness

	N	Mean	Std. Deviation	Minimum	Maximum
Abundance of herbaceous vegetation	36	11.44	11.49	0	65
Insect species richness	36	11.1667	9.40061	0	37
Plant family type	36	6.5	3.501	1	12

4.4.2 Chi Square Statistics for plant family at Mua hills Location

The results indicated that Plant family had a significant association with the abundance of herbaceous vegetation. This was indicated by a p value of $0.042<0.05$ and a chi square statistics χ^2=20.222(Table 4.17).

Table 4.17: Chi Square Statistics

	abundance of herbaceous vegetation	insect species richness
Chi-Square	20.222	8.004
Df	11	11
Asymp. Sig.	0.042	0.713

a Kruskal Wallis Test
b Grouping Variable: Plant family type

4.4.3 Descriptive Statistics for Plant Species Type

In relation to the species type the insect species richness had a high mean compared to the abundance of herbaceous vegetation which had the lowest mean abundance at 9.9 v 5.9 (Table 4.18). The insect species richness had a standard deviation of 7.98.

Table 4.18: Plant Species and Insect Abundance at Mua hills Location

	N	Mean	Std. Deviation	Minimum	Maximum
Abundance of herbaceous vegetation	48	5.9	4.239	0	21
Insect species richness	58	9.913 8	7.98086	0	37
Plant species type	48	8.5	4.659	1	16

4.4.4 Chi Square Statistics

In relation to the species type revealed that the insect species richness had a high mean compared to the abundance of herbaceous vegetation which had the lowest mean abundance at 9.9 v 5.9. The insect species richness had a standard deviation of 7.98 (Table 4.19).

Table 4.19: Chi Square Statistics for herbaceous vegetation and insect richness

	abundance of herbaceous vegetation	insect species richness
Chi-Square	13.07	14.379
Df	15	15
Asymp. Sig.	0.597	0.497

a Kruskal Wallis Test

b Grouping Variable: Plant species type

5.0 CHAPTER FIVE: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter covers the interpretation of the results of the study. The results of the study are discussed from Mua hills Location context. The chapter also looks at the findings in view of what has been reported in the literature with the aim of assessing the underlying factors that possibly explain the observed trends and outcomes. In the chapter, existing gaps are identified and sets a basis for recommending the necessary policies to address the identified gaps.

5.1.1 Discussion of results on effects of land use on the diversity and abundance of insect pollinators in contrasting agro-ecological zones.

5.1.1.1 The contrasting Agro-ecological Zones

In order to understand agricultural activities, two classifications are currently present in Kenya which are: the one of Sombroek *et al* (1982) referred to as *agroclimatic zones* (ACZ) and that of Jaetzold and Schmidt (2010), referred to as agro-ecological zones. Jaetzold and Schmidt (2010) classification has been adopted for the present study as a basis for sampling. By use of this method, three AEZs have emerged in Mua hills Locations which are III, IV and V. According to FAO (1996), Agro-ecological Zoning (AEZ) is the division of an area of land into small units, which have similar characteristics related to land suitability, potential production, and environmental impact. An agro-ecological Zone is a land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use (FAO, 1996).

This research observed that Zone V has the medium-low potential for arable farming. It is planted with mainly rain-fed maize and less of legumes and vegetables. The land in Zone VI is mainly fallow with shrubs, bushed grassland, and some localized forest remnants. It is planted with citrus fruits, bananas, and vegetables (cabbages, kales, tomatoes). There is indigenous plant richness in this area while Zone III has a shrub, grass with tall bushes and trees in some places along the streams banks. There is the cultivation of maize, legumes, vegetables (spinach, cabbage, kales), and fruits (grapes, tangerines, pawpaw, banana, avocados, strawberries) also in this area. Pest infestation easily occurs in horticultural crops than maize which is why pesticides are often used in horticultural farms compared to maize farms. According to Ricketts (2004), pollinator activity occur at large extent on farms that are surrounded by forests. Farmers indicated that the main hindrance to crop production was pest infestation. Willian *et al* (2009) argue that shifts in land use can lead to the extinction of particular pollinator species in the area which in turn affects both the structure and function of plant-pollinator communities (Williams, *et al*., 2009; Burkle, *et al*., 2013). Mixed cropping and the different types of land use practiced in horticulture in the Mua hills Location directly or indirectly affect the ecosystem function among insect pollinators.

5.1.1.2 Insect Diversity

During sampling, the researcher collected 1251 insects belonging to 30 species, 10 families and 8 orders. The insect Orders represented in the samples were Lepidoptera (53%), Hymenoptera (26%), Diptera (9%), Coleoptera (2%), Orthoptera (2%), Hemiptera (2%), Aranae (2%) and Blattodea (2%). The order Lepidoptera had the highest species richness followed by Hymenoptera and Diptera respectively. Order Lepidoptera was represented by four families namely; Nymphalidae, Pieridae, Lycaenidae and Crambidae. There were 8 genera under the family Pieridae and one genera under the family Crambidae. The order Hymenoptera, the family Apidae had the highest species richness, *Apis mellifera* had a mean of 10, *Ceratina spp* a mean of 17, *Lassioglossum spp* had mean of 9.67 and *Macrogalea candida* a mean of 17.67. Likewise, *Megachile spp, Seladonia spp, Xylocopa flavorufa* and *Xylocopa nigrita* revealed a mean of 11.67, 9.63, 1.67 and 3 respectively. The rare species were

Xylocopa nigrita (Fabricius, 1775) and *Xylocopa flavorufa*. Shannon Diversity Index for order Hymenoptera family Apidae for Zone III was (2.37), Zone IV (2.38) and Zone V (2.54) respectively. The results indicated that diversity and evenness of Order Apidae are much higher in Zone V than in Zone III and Zone IV.

A different number of species and individuals of insect pollinators found in each land-use type indicates the environmental niche, species needs and probably tolerance limits to environmental disturbance. Insect species adapt to exploit habitat resources and the resources in each plant community and in turn, influence the population of species in the habitat together with their relative abundance.

Most of the insect species sampled were generalists in their diet with the exception of the carpenter bees. Not all species of pollinators respond equally to environmental stresses, with both winners (mostly species that are a generalist in their habitat or food needs) as well as losers (often specialists) emerging from environmental changes (DEFRA. 2013). While the loss of specialist species due to environmental change may not have direct impacts on crop pollinator community, it entails lower rates of ecosystem processes, and some functions performed by specialists may not be carried out at all (Elmqvist *et al*., 2003), potentially leading to greater biodiversity loss and ecosystem instability in the long run. More attention should be given to measures to conserve rare *Xylocopa* bees.

5.1.1.3 Insect Abundance in during Dry and Wet Season

During the dry season Zone III natural patch had a high mean in abundance of insect pollinators while horticulture had a low mean in abundance of insect pollinators (11.9 v 2.9). In Zone IV, the mean abundance of insect pollinators was high in natural patch as compared to horticulture which had the lowest mean in abundance of insect pollinators (14.6 v 5.9). Additionally in zone V, the results indicated a high mean abundance of insect pollinators in natural patch as compared to horticulture which had the lowest mean in abundance of insect pollinators (8.8 v 2.3). During the wet season the results portrayed a slightly same trend. Zone III indicated the highest average abundance of insect pollinators in natural patch while the lowest in horticulture (8.0 v 5.6). In Zone IV the results indicated the highest average abundance of insect pollinators in natural patch and lowest in horticulture (12.1 v 4.1). In Zone V results showed that the mean abundance of insect pollinators was highest in natural patch and lowest in horticulture (9.2 v 4.7). Two way ANOVA was conducted to establish the effects of seasons and on insect pollinator abundance in Mua hills Location Machakos County. The analysis showed that there was a statistically significant main effect for seasons on insect pollinator abundance. There was seasonal variation in abundance although this did not affect the diversity of the insect pollinators. William *et al* (2001) suggest that "the natural abundance of many invertebrates, including pollinators, varies greatly between seasons" (Cane *et al*., 2005; Williams *et al*., 2001; Kearns, 2001; Roubik, 2001). Our findings that overall abundances of insects peak in wet season are consistent with a study done in Brazil (Pinheiro *et al*., 2008). The seasonal variation during this research was attributed to high presence of host plants during the wet season.

5.1.1.4 Abundance of Insects in the contrasting Agro-ecological Zones

There was a significant difference in the average abundance of insects between Zone III and Zone IV (0.000<0.05). However there was no significant difference in the average abundance of insects between Zone III and Zone V (0.226>0.05). The study also revealed that there was a significant difference in the average abundance of insects between Zone IV and Zone III (0.000<0.05). In addition, there was a significant difference in the average abundance of insects between Zone IV and Zone V (0.000<0.05). However, there was a significant difference in the average abundance of insects between Zone V and Zone IV (0.000<0.05).

Post-Hoc Comparisons between Land Use types was done and found out that there was a significant difference in the average abundance of insects between Natural patch and Horticulture (0.000<0.05). In addition, there was a significant difference in the average abundance of insects between Natural patch and mixed cropping (0.000<0.05). The study further, revealed that there was a significant difference in the average abundance of insects between Horticulture and Natural patch (0.000<0.05). There was also a significant difference in the average abundance of insects between Horticulture and mixed cropping (0.000<0.05).The study also, showed that there was a significant difference in the average abundance of insects between mixed cropping and Natural patch (0.000<0.05). There was also a significant difference in the average abundance of insects between mixed cropping and Horticulture (0.000<0.05).

The Natural patch had the highest level of insect pollinator abundance, then mixed cropping and finally horticulture with agro-ecological Zone IV having the highest number, then Zone III and lastly Zone V. Natural patches acted as refuge areas for the pollinators. Long-term set aside lands are being recognized for their value in the conservation of biodiversity in mostly agricultural settings, and pollinators are benefitting (Corbet, 1995). All such areas support much rural wildlife, mammals, birds, and insects that depend on pollination of wild plants for sustenance. The natural patches need to be protected as the habitat of wild pollinators which provide pollination services in farms where intensive farming is practiced. The protection of native pollinators is critical (Kevan, 1991, 1993; Krell, 1995). The natural patches offer increased niche differentiation for the insect pollinators that potentially promote co-existence of a large number of insect species. These areas encourage insect populations by providing forage and nesting sites for their conservation (Corbet, 1995; Krell, 1995).

Horticulture farmers in Kenya reportedly apply pesticides more than usual in controlling the pests while others use concentrations higher than those recommended (Wilson *et al*., 2001; Sithanantham, 2004). Piles of dead honeybees under mango trees were observed during the field work and these could be bio-indicators of serious environmental problems. The horticultural farmers of Mua hills Location could be using agrochemicals carelessly leading to the elimination of some pollinator species from the ecosystem. Smith (1968) argues that "when ecosystems become degraded by pollution or over-exploitation it results in losses of biodiversity and declines in ecosystem function" (Smith, 1968; Lecren *et al*., 1972; Pearson *et al*., 1976; Vitousek *et al*., 1979).

5.1.2 Discussion of results on the influence of insect diversity and abundance on purple passion fruits set in order to identify pollination limitation to the fruit production

Results of Pearson's correlation analysis between number of fruits and insect abundance per AEZ revealed that there was a positive and significant association between the abundance of the insects and the number of fruits ($r = 0.504$, $p = 0.002$). In addition a correlation analysis of passion fruit flowers and insect abundance indicated that there was a positive and significant association between the abundance of the insects and the number of flowers ($r = 0.513$, $p = 0.001$). The passion fruit set number varied from 5.05 to 7.32. Fruit set was recorded highest (7.32) in Zone V compared with the other zones, although it had the least diversity and abundance of insect pollinators. This is the only agro-ecological zone which had the carpenter bee, *Xylocopa nigrita*, and *Xylocopa flavorufa*. Passion fruit crop is known to benefit from pollination by *Xylocopa spp* (Kasina *et al*., 2010). Pollination is an important criterion for fruit set in passion fruit. In this study, the carpenter bee was noted as the most efficient pollinator. It was also noted that Agro-ecological Zone IV had moderately high temperatures. Moderately high temperatures are favorable for fruit growth and quality in purple passion fruit (Utsunomiya, 1992).

In Zone IV and III, the insect pollinator for purple passion fruit was *A. mellifera* and *A. cerena.* Neither honey bees (Apis mellifera) nor social stingless bees are effective pollinators (Corbet *et al*., 1980), due to their small size, they take nectar without achieving pollen transfer (Sazima *et al*., 1989; Siqueira *et al*., 2009) such bees are sometimes referred to as "thieves" (Camillo, 2003).The self-incompatibility in the passion fruit is an important factor to be considered regarding fruit production. Solitary and facultative social bees of the genus *Xylocopa*, the carpenter bees, are the effective pollinators of this crop because they present appropriate size and foraging behavior (Corbet *et al*., 1980;Camillo, 2003). To minimize the effects of insufficient pollination, we suggest that the presence of carpenter bees in the landscape should then be enhanced. Methods that increase the population of these bees, such as habitat management and the adoption of good agricultural practices should be promoted (Corbet *et al*., 1980). Studies in Kenya show that horticultural crops that are traded and consumed for their fruits and seeds require pollination to enhance yield (Kasina *etal*., 2009a,b,c; Oronje, 2012). These studies have shown evidence that there is increased fruit and seed yield when bees are provided, for those crops dependent on bee pollination. Such evidence is similar to scientific reports in other parts of the world (Free, 1993; Shipp *et al*., 1994; Klein *et al*., 2007; Hajjar *et* al., 2008).

5.1.3 Discussion of results on the assessment on the use of agrochemicals and their impact on the insect pollinators in the agro-ecosystems for Objective Three.

The results in revealed that 76.7% of the farmers use the DAM, CAN and DAP type of agrochemicals while 23.3% of the respondents use other types of agrochemicals. The results also revealed that 80% of the farmers use Insecticides and fungicides while 20% of them use other types of Insecticides and fungicides in the zones. Given the three zones, Spearman correlation analysis revealed that there was a negative and significant association between type pesticides and fertilizers and the abundance of insects ($r = -0.402$, $p = 0.028$). This implies that the continuous use of DAM, CAN and DAP in the zones deprives the insects of their normal ecological by increasing the acidity in the soil and thus the insects' survival rate is minimized.

The results showed that majority of the farmers (87.3%) applied the pesticides during flowering while 16.3% applied the pesticides before flowering. The results on application of pesticides had a negative and significant relationship with the abundance of insects (r=-0.562, p=0.001). This implies that the increased use of insecticide and fungicide in the soil reduces the flourishing number of insects in the soil.

The results also indicated that majority (76.3%) of the farmers determine the amount of pesticide to be applied by estimating the amounts while 23.3% of the farmers use a stipulated scale by the manufacturer. The amount of applied pesticides had a negative and significant relation with the abundance of insects in the zones (r=-0.504, p=0.000). This is an indication that the application of the agrochemicals during flowering affects the abundance of the pollinators. This is the time the pollinators flourish due to the abundance of flower nectar and thus if the agrochemicals are applied at the time, the pollinators are not able to withstand the chemicals. Their number therefore reduces significantly.

The results further revealed that majority (86.3%) of the farmers apply the pesticide every season while 13.3% of the farmers apply the agrochemicals when there is need to. The frequency of application of the agrochemicals related negatively and significant with the abundance of insects (r=-0.402, p=0.028). This is an indication that the more frequently (i.e. every season) the agrochemicals are used in the soil, the more the increase in the acidity of the soil and thus affecting the habitat of the insects. This kills the insects in the soil due to the increase in acidity and thus reducing the abundance of insects.

The results also added to the findings that majority of the farmers (73.3%) diluting the pesticide in the farm and/or the river while 26.7% of them use other types of Insecticides and fungicides in the zones.

Additionally, the data collected revealed that majority of the farmers (76.7%) apply the pesticide in the farm through the spraying method while 23.3% of them use other types of methods of application. The application method proved a negative and significant relationship with the abundance of insects ($r=-0.398$, $p=0.029$). This implies that the application of agrochemicals through the spraying method reduces the abundance of insects. This might be attributed to the wide coverage of the agrochemicals in the area and thus a huge number of insects will be affected.

However the disposal of leftovers and pesticides cans proved a negative but an insignificant association with the increase in the number of insects in the respective zones. That is ($r=-0.451$, $p=0.214$) and ($r=-0.367$, $p=0.146$) respectively. The location where the insects were mostly found on the flower parts also had a negative but an insignificant relationship with the number of insects in the respective zones ($r=-0.257$, $p=0.1716$).

The results further revealed that majority of the farmers (60%) dispose the empty containers/papers which had the pesticide in the bush/farm/river while 40% bury the empty containers/papers which had the pesticide in the soil/burn. The results also showed that majority of the farmers (73.3%) agreed that they have ever collected a pesticide container in their neighbourhood while 26.7% of them have never collected a pesticide container in their neighbourhood. In addition majority of the farmers (86.7%) agreed that they have any pesticide in your homestead while 13.3% of them don't have any pesticide in your homestead. This implies that the disposal of the left-over chemicals, containers and the location where the insects were mostly found on the flower parts have a reducing effect on the number of the insects in the zones. However, the reducing effect is not statistically significant. On an average the results implied that an increase in any unit of the measured variables resulted to a decrease in the abundance of insects in the zones.

These results indicate that the majority of the farmers in this study area have been relying more on increased use of agrochemicals such as pesticides and chemical fertilizers and, these are placing extreme pressure on the agro-ecosystem functions and biodiversity. Over-reliance on using agro-chemicals is likely to cause soil degradation and affect plant growth according to Altieri and Anderson (1992). There is significant evidence that these agro-chemicals are affecting the environmental health since few insect diversity and abundance were found in horticultural farms. Pesticides often kill directly, but sub-lethal amounts can also be detrimental to bees and other, pollinators by impeding their ability to navigate or forage (FAO, 2012).

The chemicals mostly used by the farmers were identified as Actara, Thunder and Duduthrin accounting 18 (60%), Score, Ridomil and Ortiva are accounting 5 (15%) and Tecamin max, Agrofeed, Booster and Tecamin brix accounting 7 (25%). Actara is a systemic insecticide that provides excellent, fast-acting and long-lasting elimination of a broad range of foliar and soil pests. It is a broad spectrum insecticide which controls a wide range of insects on field crops, trees, and horticultural crops, it contains pirimiphos-methyl. Duduthrin is a fast-acting synthetic pyrethroid insecticide for use in vegetables, flowers, fruits, and cereals, it contains lambda-cyhalothrin. Thunder acts by contact and ingestion through systemic action, it contains imidacloprid. It is used on Lepidopterans, mites and Whiteflies pests.

Ortiva is a broad spectrum contact and systemic fungicide for the control of rusts, leafspots, botrytis and powdery mildews in vegetables, watermelon, fruit trees, rust in peas and beans. Score is a systemic fungicide for long-lasting preventive and strong curative action. It has broad-spectrum disease control against powdery mildew, leafspot diseases, Alternaria and rusts in fruit trees, pulses, ornamentals, and vegetables. Ridomil is a systemic and contact fungicide for the control of early and late blight, damping off and downy mildew in potatoes, tomatoes, and vegetables. Insecticides are often used more than fungicides.

Vegetables are grown throughout the year with the highest peak during the short rain season. Most Pesticides are used during the short rain season (October to December) when farmers grow vegetables in bulk. Majority of the farmers are literate, but most of them have never used safety information and instruction on pesticide container. Pesticides are used more frequently in vegetable production than in maize. In maize and vegetable production, no herbicides are used since the households practice weeding instead of using herbicides. The farmers use between four and six different compounds. Systemic pesticides are used in the Mua hills Location. According to the farmers, the most significant environmental effects of pesticides usage were piles of dead bees under fruit trees. None of the farmers was aware of any significant environmental effects of pesticides usage on the decline in abundance of pollinating insects. The dangers of pesticides, especially insecticides, to pollinators are well documented and understood (Johansen, *et al*., 1990; Sihag, 1995).

Wandiga *et al* (1996) stated that the potential for bioaccumulation and bioconcentration of these pesticides pose serious ecological and health concerns for the environment. Point sources arising from stored obsolete pesticides have been identified as locally very important threats to the African environment (Elfvendahl, *etal*., 2004; NES, 2006). Work by Sereda *et al*., (2009) indicated that pyrethroids found in human breastmilk may come from agricultural use. Safe storage and disposal of pesticides and fertilizers remain a challenge in this agricultural area, 42% of households store pesticides in grain storage. The farmers at Mua hills location need to be sensitized to use and store pesticides properly to reduce risk to the environmental health.

The majority of the farmers were dependent on subsistence farming.We observed that use of pesticides in intensively farmed land harm insect pollinators, the mostly affected insect were the bees and butterflies. Brittain *et al*. (2010) did landscape-scale surveys of wild bees and butterflies, they findings showed that species richness tended to be lower where pesticide loads and cumulative exposure risk of pesticides are high and this was similar to our observation. There is a need to limit the use of agro-chemicals to stop pollinator declines for ecological function, agricultural production, and human health. The key drivers of pollinator decline are identified as: (1) habitat destruction, degradation and fragmentation – resulting in a loss of foraging, mating and nesting sites, particularly driven by changes in agricultural management practices (Kearns *et al*.,1998; Taki *et al*.,2008; Brown and Paxton 2009), (2) pollution- in particular by agro-chemicals including neonicotinoids (Kevan 1999; Brittain *et al*., 2010), (3) invasive alien species- including introduced plants, pollinators, pests and diseases (Stout and Morales 2009; Dafni *et al*., 2010), and (4) climate change- which affects the spatial-temporal dynamics of plant-pollinator interactions (Memmott *et al*., 2007; Hegland *et al*., 2009). Pollinators are indicators of environmental health and their declines may destabilize the ecosystem.

5.1.4 Discussion of results on the association between plant diversity and insect species richness

Mua hills Location occurs at an elevation of 1600m – 2300m above the sea level. For plant richness, a total of 7 (six) sites were sampled. In all fifteen (15) higher plant species, three (3) shrubs and sixteen herbs (16) were recorded. Data from twelve (12) samples were used in the analysis. The Shannon Wiener Index (H) for Zone V, Zone IV, and Zone III was; 2.347, 2.578 and 2.266 respectively and the distribution evenness was; 0.812, 0.892 and 0.784 for Zone V, Zone IV, and Zone III respectively. In all cases, it was observed that there was average abundance and almost completes evenness of all the species present. In relation to the family type the abundance of herbaceous vegetation had a high mean compared to the family type i.e. (11.44 v 6.5). The abundance of herbaceous vegetation had a standard deviation of 11.49. In relation to the species type, the insect species richness had a high mean compared to the abundance of herbaceous vegetation which had the lowest mean abundance i.e. (9.9 v 5.9). The insect species richness had a standard deviation of 7.98. The Chi-square results, however, indicated that an insignificant relationship between plant family type and the insect species richness. This was indicated by a p value of $0.713>0.05$ and a chi square statistics $\chi^2=8.004$.

The study area had Acacia trees which included *Acacia seyal, Acacia Senegal, Acacia brevispica*, *Acacia xanthophloea,* and *Acacia nilotica*. Euphobia trees occur in some drier parts of this location, *Combretum spp* and *Croton spp* are also common. Besides Acacia, other important legumes include *Indigofera spp* and *Crotalaria spp*. Grasses found include *Themeda triandra, Pennisetum mezianum, Pennisetum straminium, Pennisetum meassalense, Eragrostis spp, Hyperemia spp, Setecia spp, Sigiteria spp, Brotriciochloa insculpta* and *Cenchrus ciliaris*. Grasses such as *Chloris spp* and *Cynodon spp* are rare in this area. Five major types of plant types of particular biological interest in relation to insect pollinator diversity were identified and have been recommended for conservation protection. Most insect-plant species were recorded in agro-ecological Zone IV but Zone III had the least plant species. Invasive plant species such as *Lantana camara* was a good indicator of habitat disturbance and we observed that this could be a factor likely to affect the more specialized pollinator species (Beismeijer *et al*., 2006; Williams and Osborne 2009).

Insect pollinator plant species were found to decrease with increase in land use practices. Certain insect species such as *Xylocopa* species were on specific plant shrub species which were only recorded on *Crotalaria spp*. This plant was mostly found in Zone V, it is mostly herbaceous and slightly woody shrub reaching close to 1½ m tall, the pea flowers are yellow and maroon-tinged arranged on a spike, the leaves are compound with three broad, elliptical leaflets attached at one point. We concluded that carpenter bee has a plant-pollinator relationship with very specific niche requirements for the plants and their pollinators, loss of this pollinator can have cascading effects in the production of passion fruit in the agro-ecosystem. We also observed that there is habitat fragmentation in Mua hills Location as a result of deforestation, human settlement, and increased road-building. Fragmentation not only causes loss of the amount of habitat but by creating small isolated patches it also changes the properties of the remaining habitat (van den Berg *et al*., 2001). This is of significant concern because increased human activities are a threat to biodiversity. In Europe, bumble bees have suffered from the decline in the amount of relatively undisturbed land in hedgerows and other non-cultivated areas (Corbet *et al*., 1991). In the Tropics, inadequate pollination of cacao by midges in plantations followed when oviposition substrates, i.e., rotting vegetation, had been too fastidiously removed (Winder, 1977). In Malaysia, the additional substrate of rotting palmtrunks is provided to increase pollinator populations (Ismail and Ibrahim, 1986).

As far as is known, this study is the first to report the effect of land use in contrasting agro-ecological zones on insect pollinator diversity and abundance in relation to passion fruit set. Insect diversity and abundance in the natural patch were different from that of farms were agro-chemicals were been used. This result confirms a study done at Kakamega forest (Gikungu *et al*., 2011) where well-managed farms had more species per unit area than the adjacent pristine rainforest habitat. The findings from this research also agree with Potts *et al*(2003) were open habitats and fallow farms were high in bee abundance respectively. The order Hymenoptera had the highest abundance of insect pollinators across the three agro-ecological zones similar to a study at Mt. Carmel (Potts et al., 2003).

This study revealed that land use type and agro-chemicals are key factors in determining insect pollinator diversity and abundance in different agro-ecological zones. Natural patches and high plant diversity in neighboring habitats have the potential to support diverse insect pollinator communities. However, current land use practices which include the use of chemical fertilizers and pesticides lead to agro-ecosystem degradation and will need to be controlled as they threaten insect pollinator communities. The findings from this research echo the need for environmental management of agro-ecosystems to support ecosystem services in particular pollination and contribute to our understanding of the effects of land use and agrochemicals on insect pollinators. Human activities such as the use of agrochemical in horticultural farming results in ecosystem disservices such as loss of insect pollinators. There is a need to strike a balance between providers of ecosystem services and drivers of ecosystem disservices to ensure sustainable agro-ecosystems (Appendix vii).

5.2Conclusions and Recommendations

5.2.1 Conclusions

1. The analysis showed that there was a statistically significant main effect for land use type in different agro-ecological zones on insect pollinator diversity and abundance.
2. Passion fruit set was recorded highest in the agro-ecological zone which had the carpenter bee, *Xylocopa nigrita*, and *Xylocopa flavorufa*
3. Farmers were frequently using agrochemicals in horticultural farming and for passion fruit spraying with pesticides is done during flowering stage of the crop.
4. There was a significant difference among the plant species richness in AEZ

5.2.2 Recommendations of the study

Further studies should combine both pan traps and malaise traps for longer periods of times in similar areas to sample insect diversity.

In areas of intensive farming, field margins/natural patches, are important refuges for many pollinators. There is a need for research on the value of these areas to agricultural productivity.

There is a need to alert the general public, policy makers and planners on the importance of pollination and pollinators, the seriousness of their demise, and the urgency for their conservation.

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APPENDICES

APPENDIX I: INSECT DIVERSITY

Order	Family	Genera & species	Code
Hymenoptera	Apidae	*Macrogalea candida*	1
		Apis mellifera	2
		Xylocopa nigrita	3
		Megachile spp	6
		Seladonia spp	7
		Lassioglossum spp	8
Hymenoptera	Halictidae	*Lipotriches spp*	9
Lepidoptera	Pieridae	*Colotis anterippe*	10
		Colotis hetaera	11
		Colotis auxoinca	12
		Colotis evagore	13
		Colotis aurigineus	14
	Pieridae	*Eurema brigitta*	15
		Belenois creona	16
	Nymphalidae	*Vanessa cardui*	17
	Nymphalidae	*Junoniaoenone*	18
		Junonia terea	19
	Lycaenidae	*Lycaena phlaeas*	20
	Pieridae	*Catopsilia florella*	21
	Nymphalidae	*Danaus chrysippus*	22
		Hypolimnas misippus	23
Moth Crambidae		*Spoladea recurvalis*	24
	*	*Bicyclus saftiza*	25
	Nymphalidae	*Neptis saclava*	26
		Neocoenyra gregorii	27
		Amauris albimaculata	28

	Lycaenidae	*Leptotes pirithous*	29	
		Zizula hylax	30	
Diptera Muscidae		*Muscidae spp*	31	
Diptera Bombyliidae		*Bombyliidae spp*	32	
Diptera Calliphoridae		*Calliphoridae spp*	33	
Diptera		*Syrphidae spp*	34	
Aranae	-		35	
Orthoptera	-		36	
Coleoptera	-		37	
Hemiptera	-		38	
Blattodea	-		39	
* unknown	-		40	

APPENDIX II :INSECT DIVERSITY AND ABUNDANCE IN THREE AGROECOLOGICAL ZONES

SPECIES	1	2	3	4	5	6	7	8	9	10	14	15	16	17	18	19	20	21	22	23	24	25
Sample A	30	10	9	5	37	21	17	18	32	22	12	7	26	14	37	28	50	8	7	6	41	18
Sample B	15	5	0	0	12	2	3	4	7	8	14	2	13	5	7	8	9	10	11	4	4	7
Sample C	8	15	0	0	2	12	8	7	4	3	20	11	9	8	7	5	13	12	10	8	7	4
TOTAL	53	30	9	5	51	35	28	29	43	33	46	20	48	27	51	41	62	20	28	18	52	29

SPECIES		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Sample A		16	3	12	41	16	19	15	11	9	100	2	4	19	20	0
Sample B		8	10	12	3	2	5	2	4	14	20	10	8	5	4	0
Sample C		4	11	10	0	4	5	8	10	20	14	4	2	2	2	3
TOTAL		28	24	34	44	22	29	25	25	43	134	16	14	29	26	3

Key

Sample A- Agro ecological Zone IV
Sample B- Agro ecological Zone III
Sample C- Agro ecological Zone II

APPENDIX III : LAND USE TYPE AND INSECT ABUNDANCE

i. Wet season (Oct-Dec 2015)

ZONE IV													
	Abundance of insect per land use type												
land use type				Sampling points &		Replicates							
Natural patch			1	2	3	1a	2a	3a	1b	2b	3b	Total	
	Farmers	i	18	12	10	13	16	14	12	9	6	110	
		ii	5	7	14	15	8	9	6	10	8	82	
		iii	12	15	13	10	12	11	15	6	10	104	
		iv	14	3	2	10	14	9	5	10	12	79	
		v	7	5	4	8	9	6	9	14	0	62	
		vi	4	8	7	7	2	9	8	2	11	58	
Horticulture	Farmers	i	5	6	1	2	8	2	4	9	10	47	
		ii	9	3	9	3	2	7	5	11	5	54	
		iii	3	2	3	4	5	0	3	7	6	33	
		iv	2	3	1	3	6	12	0	9	11	47	
		v	4	2	0	7	5	9	2	0	3	32	
		vi	0	5	7	9	10	8	1	2	0	42	
Mixed cropping	Farmers	i	12	13	0	19	10	9	1	6	3	73	
		ii	11	9	14	21	3	2	1	7	10	78	
		iii	9	3	17	6	14	4	7	9	8	77	
		iv	5	17	1	9	0	2	30	13	12	89	
		v	4	21	5	24	0	4	7	17	12	94	
		vi	8	13	6	20	7	0	0	1	11	66	

ZONE III												
	Abundance of insect per land use type											
land use		sampling points & replicates										
Natural patch			1	2	3	1a	2a	3a	1b	2b	3b	TOTAL
	Farmers	i	14	15	9	14	16	21	3	5	18	115
		ii	10	17	13	7	13	2	11	6	8	87
		ii	-	-	19	-	-	13	12	14	15	73
Horticulture	Farmers	i	3	7	8	9	1	7	2	5	8	50
		ii	0	5	2	3	7	3	3	1	2	26
		iii	2	6	7	0	6	2	2	4	5	34
Mixed cropping	Farmers	i	7	15	9	11	12	9	11	14	10	99
		ii	9	6	8	9	15	12	10	12	13	94
		iii	9	13	4	5	7	6	14	11	12	81

ZONE II	Abundance of insect per land use type											
	Sampling points & replicates											
			1	2	3	1a	2a	3a	1b	2b	3b	TOTAL
natural patch	Farmers	i	1	5	10	5	4	7	13	10	12	67
		ii	3	9	10	4	6	10	4	8	7	62
		ii	10	13	5	9	14	17	3	7	11	79
horticulture	Farmers	i	4	5	8	5	0	5	3	2	1	33
		ii	3	9	9	8	2	7	4	8	3	42

		iii	6	8	11	12	4	8	8	9	0	56
Mixed cropping	Farmers	i	6	8	5	8	11	6	9	3	4	60
		ii	7	5	6	5	7	13	7	0	6	56
		iii	11	4	8	7	10	9	8	9	3	69

ii. Dry- Season (Jan-March 2016)

ZONE IV												
	Abundance of insect per land use type											
Land use type				Sampling points &		Replicates						
Natural patch			1	2	3	1a	2a	3a	1b	2b	3b	Total
	Farmers	i	9	6	3	10	22	4	17	21	5	113
		ii	12	2	13	5	13	11	7	5	6	76
		iii	11	13	7	8	10	16	19	4	10	98
		iv	10	8	3	6	9	5	11	13	15	80
		v	3	5	12	2	18	9	12	4	2	67
		vi	4	3	10	17	2	4	2	9	8	63
Horticulture	Farmers	i	8	1	9	3	4	6	3	0	1	35
		ii	0	3	7	1	5	3	0	1	1	21
		iii	2	2	3	5	4	0	4	1	2	23
		iv	2	3	4	3	0	1	2	1	1	17
		v	3	4	5	2	1	1	0	1	1	18
		vi	1	2	3	0	2	1	1	0	0	10
Mixed cropping	Farmers	i	4	3	1	9	8	7	0	3	2	30
		ii	0	1	2	8	3	0	2	6	4	21
		iii	0	1	3	8	8	9	7	3	5	39

		iv	3	5	6	0	0	9	7	1	2	29
		v	4	4	1	7	2	0	3	0	6	22
		vi	2	4	3	3	9	5	0	6	2	36

ZONE III	**Abundance of insect per land use type**											
	Sampling points & replicates											
			1	2	3	1a	2a	3a	1b	2b	3b	TOTAL
Natural patch	Farmers	i	18	20	16	23	13	10	26	12	22	67
		ii	17	19	15	20	16	18	17	13	21	55
		ii	2	11	10	9	13	14	7	8	4	71
Horticulture	Farmers	i	10	5	6	9	0	9	7	3	8	10
		ii	7	5	0	10	3	5	2	10	5	17
		iii	6	6	6	8	4	6	5	7	6	14
Mixed cropping	Farmers	i	6	7	11	7	4	10	8	6	7	36
		ii	8	12	6	10	11	5	13	3	8	26
		iii	9	10	9	13	6	2	16	4	14	22

ZONE II	Abundance of insect per land use type											
	Sampling points & replicates											
			1	2	3	1a	2a	3a	1b	2b	3b	TOTAL
Natural patch	Farmers	i	12	9	15	8	6	22	10	14	13	79
		ii	10	12	14	20	8	7	5	24	16	62

		ii	15	13	20	10	5	-17	18	15	17	54
Horticulture	Farmers	i	5	4	3	0	5	2	1	1	2	13
		ii	0	5	4	1	4	3	2	4	3	16
		iii	2	4	5	6	0	3	2	5	1	18
Mixed cropping	Farmers	i	12	0	5	2	8	2	1	2	1	13
		ii	3	4	12	7	10	2	0	5	2	15
		iii	12	13	10	24	18	8	3	7	0	40

APPENDIX IV: DATA ON PASSIONFRUIT

The passion plant flowers and fruit ration in the three AEZ

	N	Flowers	Fruits	Ratio
Zone II	18	183 (10.17)	120 (6.67)	1.525
Zone III	18	199 (11.06)	140 (7.78)	1.422
Zone IV	18	204 (11.33)	189 (10.50)	1.08

APPENDIX V: AGRO-CHEMICAL USE

Questionnaire- Consent Statement

Dear respondent,

My name is Emily Nduku Kitivo Reg No. 1701/MAC/300037/2014 and am a student at South Eastern Kenya University. I am conducting a study on "Effects of Agroecosystem land use types on the Diversity, Abundance and Ecosytem functions of Insect Pollinators" as part of Fulfillment for requirements of doctorate degree in Environment management. I am talking to many farmers here at Mua hills location about use of agro-chemicals and you have been identified as one of the informants in this study. The information you give is purely for academic purposes and will not be used for any other purposes. You are also free to terminate your participation at any stage of our discussion. This will not in any way affect you or any services you may be receiving here in Mua hills location.

I have fully understood the contents of this statement and willingly agree to take part in this study

Signature……………….Date……………..Sub-location…………………………………

Carefully listen to the question and respond appropriately. Thank you for your co-operation.

Do you use fertilizers and pesticide? (1)Yes (2) No

What is the type of fertilizers you use? (1) DAM, CAN, DAP (2) any other

What are the type pesticides you use? (1) Insecticide& fungicide (2) any other

When are pesticides used? (1) during flowering (2) before flowering

How do you determine the amount of pesticide to be applied? (1) Estimate (2) use a scale

How often do you use the agrochemical? (1) Every season (2) When there is need

Where is the diluting of the pesticide done? (1) farm or river (2) any other place

How do you apply it? (1) spraying (2) any other

How do you get rid of leftover pesticides? (1) use all on the crops (2) pour in the soil /bush/river

How do you dispose the empty containers/papers which had the pesticide? (1) Throw in the bush/farm/river (2) bury in the soil/burn

Have you ever collected a pesticide container in your neighbourhood? (1) Yes (2) No

Do you have any pesticide in your homestead? (1) Yes (2) No

When did you buy the pesticide? (1) recently (2) cannot remember

When do you intend to use the pesticide? (1) this season (2) any other time

Which insects are mostly found on plant flowers in the farm? (1) bees& butterflies (2) I do not know

Are these insects important to the crops in any way? (1) Yes (2) No

Have you ever noticed what happens to these insects when you apply pesticides on the crops? (1) Yes (2) No

Questionnaire

The questionnaire in page 122-123 questions has been used to come up with the data in page 124

	Questions															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Respondent 1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1
2	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0
3	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0
4	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
5	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0
6	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0
7	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1
8	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	0
9	1	1	1	1	1	1	1	1	0	0	0	1	0	1	1	0
10	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
11	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0
12	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0
16	1	1	1	1	0	1	1	1	0	1	0	1	0	1	1	1
17	1	1	1	1	1	0	1	0	0	0	1	1	1	1	0	0
18	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0
19	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0
20	1	1	1	1	1	1	1	0	0	0	1	1	0	1	0	0

21	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0
22	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0
23	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	0
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
25	1	1	1	1	1	0	1	1	0	1	1	1	1	1	0	0
26	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1
27	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0
28	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1
29	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1
30	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1

APPENDIX VI: PLANT SPECIES DIVERSITY AND ABUNDANCE:

The abundance herbaceous vegetation sampled in each zone

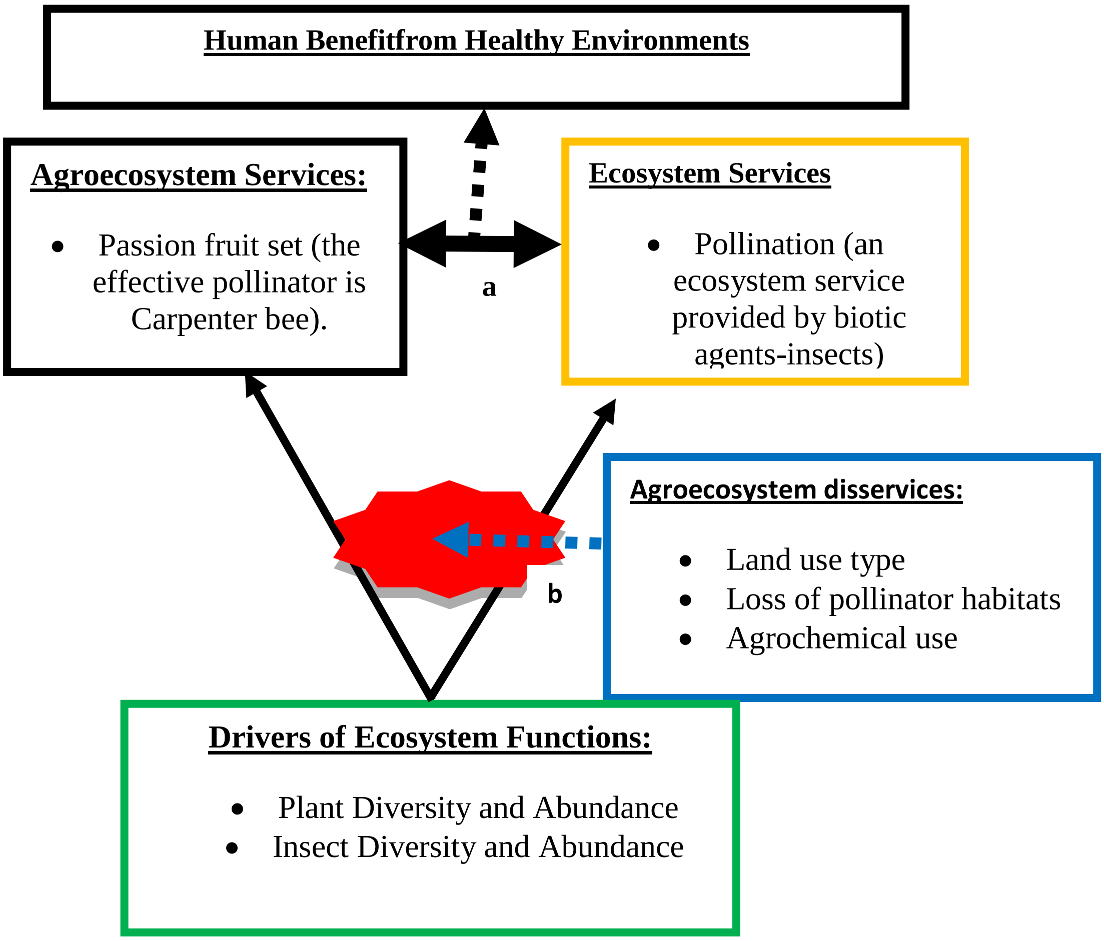
	Agro-ecological Zones			
Family	Zone II	Zone III	Zone IV	Total
Polygonaceae	6	18	8	32
Compositae	24	65	23	112
Commelinaceae	3	6	0	9
Amaranthaceae	6	19	11	36
Cruciferae	7	20	9	36
Labiatae	17	24	7	48
Acanthaceae	8	5	3	16
Lamiaceae	15	24	4	43
Vitaceae	10	9	8	27
Solanaceae	8	8	7	23
Sterculiaceae	0	0	7	7
Aspleaceae	10	5	8	23
Total	114	203	95	

The tree diversity at AEZ Mua hills location, 2015

Species	Zone II	Zone III	Zone IV
Erythrina absyssinica	0	11	4
Eucalyptus sp	0	9	5
Euphorbia candelabrum	4	12	1
Euphorbia tirucali	8	0	0
Croton megalocarpus	6	21	7
Rhusnatalensis	5	8	3
Eucleadivinorum	4	6	2
Dodonea viscose	5	9	3
Acacia xanthophloea	5	10	2
Acacia tortilis	2	7	9
Acacia seyal	2	2	8
Acacia nilotica	5	13	10
Vangueriamadascariensis	6	8	12
Grewia bicolor	9	12	5
Combretummolle	3	7	0
Terminaliabrownii	4	7	2
TOTAL	68	142	73

Shrubs	Zone II	Zone III	Zone IV
Lantana camara	6	12	8
Lantana viburnoides	7	5	9
Crotolaria spp	10	2	15
	23	19	32

APPENDIX VII



It is delicate balance (a) of the tradeoffs and synergies between ecosystem services, and current agro-ecosystem services that can guarantee sustainability. However, this balance being bombarded with a host of ecosystem disservices (b) which need to be managed or controls to minimal levels.

APPENDIX VIII: PUBLICATIONS

Kifuo et al., Expert Opin Environ Biol 2018,
7:1 DOI: 10.4172/2325-9655.1000150

Expert Opinion on Environmental Biology

Research Article

A SCITECHNOL JOURNAL

Effects of Agro ecosystem Land Use Types on the Diversity, Abundance and Ecosystem Functions of Insect Pollinators

Kifuo EN, Njoroge GN, Kinoti JM and Kimathi JK

Abstract

Land degradation in agricultural farms is mainly manifested through loss of ecosystem services such as pollination. In Kenya, farmers knowledge of pollination is limited, many farmers lump pollinators together with insect pests and do not explicitly manage to conserve them, although pollinators may contribute substantially to yields at no cost to the farmer. Insect pollinators of crops and wild plants are threatened worldwide by pesticide use and the spread of disease and parasites. This research is multidisciplinary in approach. In this research niche theory and ecosystem functions concepts to determine the status of insect pollinators in agro-ecosystems of Mua Hills location were used. The aim of this research was to determine the diversity and abundance of pollinator insects for their role in ecosystem function (pollination) and increase of passion fruit yield. The diversity and abundance of insect pollinators was found to be least in horticultural land use type and this was attributed to the use of agro-chemicals. This research is an issue of environmental management because it focuses on natural patch land use type for sustainable use of agro-ecosystems to avoid decline of pollinators. It advocates for conservation of the environment and management of carpenter bee (*Xylocopa spp*) because it is an efficient pollinator of passion fruit thus makes farming more profitable through higher yield of the crop. The findings from this research are aimed to help the subsistence farmers achieve good produce in passion fruit farming. The study promotes the conservation of insect biodiversity within the existing land use types to improve pollination of horticultural crops.

Keywords

Ecosystem function; Land use type; Insect pollinator; Agro-chemicals; Passion fruit

Introduction

Kenyan agriculture has largely been mixed with cropping of field crops, which favor pollination. There has been consistent presence of shrubs in farms and low utilization of pesticides in most farms. These farm practices have sustained insect pollinator overtime. However, reports of low pollinator abundance and diversity have started appearing [1-5]. Some crops that require wild pollinators are already showing deficiency of pollination, such as passion fruits [6]. The pollinator decline might be due to changes in the farm practices such as mono cropping, high pesticide use, continuous farming and lack of shrubs within a farm area, although causes and trends need better documentation [7].

Wild insect pollinators including moths, butterflies [8] and bees [9-11] have declined in both abundance and diversity, while, at least in some parts of the world, managed populations of honey bees *Apis Mellifera* have experienced large scale, sudden colony losses [12]. Understanding the causes of these declines is an absolute priority in ecological research, and an increase in the number of studies on pollinators and pollination is one of the response to widespread pollinator losses [13].

The key drivers of pollinator decline are identified as:

(1) Habitat destruction, degradation and fragmentation-resulting in a loss of foraging, mating and nesting sites, particularly driven by changes in agricultural management practices [14]

(2) Pollution- in particular by agro-chemicals including neonicotinoids [15,16]

(3) Invasive alien species- including introduced plants, pollinators, pests and diseases

(4) Climate change- which affects the spatial-temporal dynamics of plant-pollinator interactions Pollinators are indicators of environmental health and their declines may destabilize the ecosystem.

Problem statement

Passion fruit production is gaining importance in Kenya and pollination is a challenge in its production. In the recent past, passion fruit production in Kenya has been on the decline. In 2007 about 5193 ha were under passion fruit cultivation yielding 71000 tons worth Kshs. 2.1 billion. In 2008 less than 2800 ha were farmed yielding an estimated 33800 tons worth about Ksh. 1.05 billion. These data suggest a massive 50% decrease across all parameters within a single year. Reduced production has adversely affected the livelihoods of growers and industrial processors with many operations below installed capacity. For example SANMANGO Company which had capacity to process 100 ton/week has decreased to 25 ton/week while others such as Delmonte were importing pulp from South Africa and Brazil [17]. Many farmers are uprooting passion fruit because of low fruit set and this may be expected to impact on family income, food and nutrition security.

This research determined whether passion fruit farms are getting affected by pollination limitation resulting from land use types at different agro-ecological zones.

Significance of the study

There is need for systematic monitoring of pollinator diversity and densities in order to identify regions and stakeholders at greater risk of pollination service losses and develop appropriate mitigation measures to ensure that land managers and farmers are engaged in conservation. In this research a special focus has been laid on the consequences of changes in land use particularly with respect to its effects on insect pollinator diversity and abundance.

*Corresponding author: Emily N Kifuo, Department of Environmental Science and technology, South Eastern Kenya University, Kenya, E-mail: emilykifuo@yahoo.co.uk

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Research questions

1. Which pollinator functional groups are present and in what numbers?

2. How does insect pollinator abundance fluctuate within seasons?

3. What is the correlation between insect pollinator abundance and land use practices?

4. What are the geographical trends in pollinator diversity (in terms of species or functional groups) in the Mua Hill location?

5. What is the relationship between pollinator diversity and passion fruit set?

Hypothesis

There is no significance difference in the diversity of insect pollinators.

There are no difference in of the insect functional groups abundance within seasons

There is no significance difference in the abundance of insect pollinators in different types of land use.

The diversity and abundance of insect pollinators do not vary in the three Agro-ecological Zones

There is no correlation between species richness of pollinators and passion fruit set.

The pollinators systems are not threatened by environmental degradation.

Objective

To evaluate the trend in diversity and abundance of insect pollinators in agro-ecosystems, and its correlation to percent passion fruit set.

Study area

The Mua Hills location has three Agro-ecological zones namely; Zone IV, Zone III and Zone II. It is a good representation of the large Ukambani region which is situated on a predominantly semi-arid, eastward-facing slope, which becomes progressively lower and drier to the east. This part of Kenya forms an environmental gradient of decreasing altitude (2,100 m to 440 m), increasing temperatures and decreasing moistures. Elevation controls the quantity of rainfall at the regional scale, whereas topography influences rainfall distribution at the local level. The farms sampled in each Agro-ecological zone in this study were categorized according to two types of land use; horticulture, mixed cropping and natural patches near each farm which served as control sites.

This study area is important for horticulture. In Kenya horticulture is the fastest growing agricultural subsector in the country, ranked third in earnings from export after tourism and tea. Mua Hills location has also experienced habitat fragmentation and coming up human settlements such as Lukenya and Katelembo. These factors are likely to impact on the biodiversity of the area. A decline in fruit production in Mua Hill location led to relocating of Kenya Orchards Limited to Ruiru. A study done on the pollinators of *Carica papaya* in Kathekakai location showed a decrease in the density of hawk moth [18] (Figure 1).

Jaetzold et al. [19] classification has been adopted for the present study as a basis for sampling. By use of this method three Agro-ecological zones (AEZs) have emerged in Mua Hills location which are II, III and IV. The farms sampled in each Agro- ecological Zone was categorized according to two farming practices; horticulture and mixed cropping. Sampling of the diversity and abundance of both insect pollinators was done in the natural patches near each farm and these served as the control sites.

The study was carried out during the wet season in December, 2015 and the dry season early in March, 2016. The surveys covered the peak blooming period of crops. Data collection was carried out in the early morning 9.00 am-12.00 pm. The location of sites for pan traps and hand net surveys were changed each round of sampling selecting different sites gave a better reflection of the overall community of insect pollinators in the land use type.

Materials and Methods

Sampling insect pollinators

Insect pollinator diversity and abundance was sampled using colored pan trap, hand net and line transect methods. Colored pan traps was used because of the visual acuity of insects and the color also mimic flower. They captured both diurnal and nocturnal insects. Hand net was used during the day and for short periods. Hand netting is effective in capturing very large mobile bodied insect species. Line transect was used to illustrate gradient pattern along which the insect pollinator communities change.

At each site, 15 pan traps were put out in areas where pollinators were likely to be found, especially where the vegetation was open and the pans could be seen from some distance and where there were flowers which the pollinators might visit. The position of each pan trap in the arrangement was randomly chosen. Spacing between pan traps was 5 cm. The three groups of pan traps containing one of each color served as replicates. This experiment was also been replicated through time by repeating the same experiment two seasons apart.

The insects were placed in sample tubes with 70% alcohol, this preserved them so that they could be counted and identified at a later date. A label written in pencil containing the following information; country, site details, pan color, pan number and collector were put in the sample tube. During identification the specimens were placed into the major orders of insects such as flies (Diptera) beetles (Coleoptera) bees and wasps (Hymenoptera). Unidentified insect were put into an “other” group. Numbers for each pan trap were tallied and then the average numbers for the three bowls of each color in the five groups recorded. Identification was done later at the National Museums of Kenya.

Hand net method

During the survey the collector walked through the habitat for a set time catching insect pollinators with a hand net. The collector moved around but could not be allowed to spend more than five minutes at any single plant or flowering patch or to re-visit the same patch again. This was carried out during the peak times of pollinator activity (usually between mid-morning and early afternoon). Two 30 minutes surveys a day were carried out. The insects caught with a hand net were carefully put into a killing jar with 70% alcohol to be later identified at NMK.

Line transect

It was used to find out the distribution of insect pollinators in the study area. A total of 20 transect of 500 m and 20 m apart on a

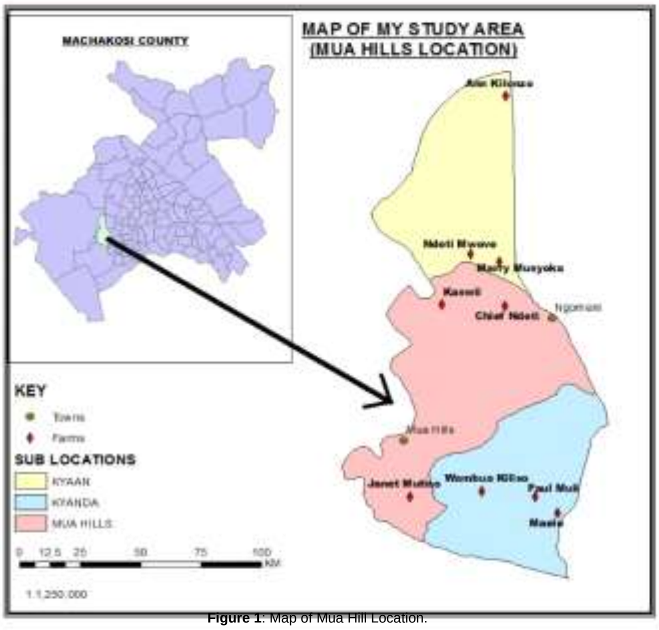

Figure 1: Map of Mua Hill Location.

base line were followed in each habitat. Sampling points along the line transect were randomly marked using GPS system.

Determining fruit set in passion fruit

Three farms in each agro-ecological zone were selected and ten passion fruit crops in each farm were sampled randomly. Two stems of each passion fruit were tied with a brightly colored string at the bottom of it for later in the season. A flag was placed there to mark the location, and a sample number on the flag written in indelible ink. The total numbers of blossoms on the selected stem including those that are open, those that aren't open, and those that have lost their petals were counted. Visual observation was used to determine the insect pollinators that pollinated the flowers.

Shortly before harvest, when most of the fruits are ripe, a second count was performed, returning to the locations marked by the flags. At each stem selected previously, the total numbers of fruits were counted (leaving out any that was pinhead size) and their number recorded beside the number of blossoms for that stem.

Data analysis

Shannon-Weiner index was used to assess the diversity index of insect pollinators because it accounts for both abundance and consistency of the species present. Two way ANOVA was conducted to determine the impact of land use types, agro ecological zones, seasons and wind ward side on insect pollinator abundance in Mua hills location Machakos County. The post-hoc comparison using the Turkey test was used to compare the mean difference between different land use types. The passion fruit set mean was calculated in different agro-ecological zones.

Results

In total, we collected 3783 insects belonging to 30 species, 18 genera and11 families. Halitidae and Pieridae were the richest family (3 genera each), followed by Apidae (2 genera), Nymphalidae (2 genera) and Lyaeridae (1 genus). The rare species were *Xylocopa nigrita* and *Xylocopa flavorufa* (Figure 2 and Table 1).

Two way ANOVA was conducted to determine the impact of land use types, agro ecological zones, seasons and wind ward side on insect pollinator abundance in Mua hills location Machakos County (Table 2).

The post-hoc comparison using the Turkey test indicated that the mean score difference for natural patch to horticulture was (mean difference=6.28, std error=0.430), then natural patch to mixed farming was (mean difference=3.23, std error=0.430) and then finally from mixed cropping to horticulture we had (mean difference=3.05, std error=0.430) which were all significantly different from one another at α=0.05 as summarized in multiple comparison Table 2 below (Tables 3 and 4).

The post-hoc comparison using the Turkey test indicated that the mean score difference for agro ecological zone (iv) to (iii) was the highest and most significant (mean difference=2.23, std error=0.380), then zone (ii) to (iii) with (mean difference=1.64, std error=0.574) which was also significantly different and then finally from zone (ii) to (iv) we had (mean difference=0.58, std error=0.556) which was not significantly different at α=0.05, as summarized in multiple comparison (Table 3).

The passion fruit set number varied from 5.05 to 7.32. Fruit set was recorded highest (7.32) in Zone IV compared with the other zones (Table 5 and Figure 3).

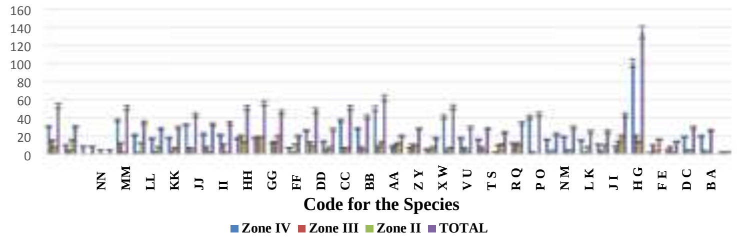

Figure 2: Species of Insect Pollinators recorded in Mua Hills Location.

Table 1: Mean abundance and diversity of insect pollinators (Shannon weiner diversity was performed).

Agro-ecological Zones	Mean abundance of insect pollinators during Dry Season	Shannon Weiner Diversity Index
IV	20.5 ± 8.5a	1.1 ± 0.02a
II	7.9 ± 4.5b	1.2 ± 0.07b
II	7.6 ± 4.4c	1.0 ± 0.33c
	$F_{2,108}$=P=0.005	$F_{2,108}$=P=0.005
F- Test is used to compare two variances (null hypothesis- the variances are equal) and the assumptions are:- The population is approximately normally distributed -Samples are independent events.		

Table 2: Analysis of Variance (ANOVA) of the land use, at various zones at different seasons.

Tests of Between-Subjects Effects					
Dependent Variable: abundance Source of variance	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	23446.995	1	23446.995	42772.666	0.000
Land use	2333.331	2	1166.666	25.515	0.005
Agro ecological zone	799.981	2	399.990	20.757	0.008
Seasons	116.976	1	116.976	11.305	0.078
Wind side	237.037	1	237.037	64.484	0.015
Land use*zones	413.544	4	103.386	5.102	0.024
Land use*seasons	670.832	2	335.416	42.743	0.002
Zones*seasons	250.980	1	250.980	5.953	0.135
Season*wind side	10.704	1	10.704	1.850	0.307
Land use*zone*seasons	9.881	2	4.940	0.711	0.544

Table 3: Multiple comparisons of land use activities at the Mua location.

(I) land use	(J) land use	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural patch	Mixed cropping	3.23*	.430	.000	2.22	4.24
	Horticulture	6.28*	.430	.000	5.27	7.29
Mixed cropping	Natural patch	-3.23*	.430	.000	-4.24	-2.22
	Horticulture	3.05*	.430	.000	2.04	4.06
Horticulture	Natural patch	-6.28*	.430	.000	-7.29	-5.27
	Mixed cropping	-3.05*	.430	.000	-4.06	-2.04
Based on observed means. The error term is Mean Square (Error) = 20.000.						
*. The mean difference is significant at the .05 level.						

Discussion and Conclusion

In total, we collected 3783 insects belonging to 30 species, 18 genera and 11 families. Halitidae and Pieridae were the richest family (3 genera each), followed by Apidae (2 genera), Nymphalidae (2 genera) and Lyaeridae (1 genus). The rare species were *Xylocopa nigrita* and *Xylocopa flavorufa*.

Two way ANOVA was conducted to determine the impact of land use types, agro ecological zones, seasons and wind ward side on insect pollinator abundance in Mua hills location Machakos County.

The analysis showed that there was statistically significant main effect for land use, agro ecological zones and seasons on insect pollinator abundance. The post-hoc comparison using the Turkey test indicated that the mean score difference for natural patch to horticulture was mean difference=6.28 (std error=0.430), then natural patch to mixed cropping was mean difference=3.23 (std error=0.430), and then finally from mixed cropping to horticulture we had mean difference=3.05 (std error=0.430) which were all significantly different from one another at α=0.05. The post-hoc comparison using the Turkey test indicated that the mean score difference for Agro ecological Zone

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Table 4: Multiple comparisons.

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Ii	Iii	-1.64*	.574	.012	-2.99	-.29
	Iv	.58	.556	.546	-.72	1.89
Iii	Ii	1.64*	.574	.012	.29	2.99
	Iv	2.23*	.380	.000	1.33	3.12
Iv	Ii	-.58	.556	.546	-1.89	.72
	Iii	-2.23*	.380	.000	-3.12	-1.33

Based on observed means.
The error term is Mean Square (Error)=20.000.
*: The mean difference is significant at the .05 level.

Table 5: Passion fruit set mean in different zones.

	N	Mean	SD	Sum	Min	Max
Zone IV	11	7.31818 0.78335	80.5	6	8.5	
Zone III	11	5.86364 0.89696	64.5	4.5	7.5	
Zone IV	11	5.86364 0.89696	55.5	4	6	

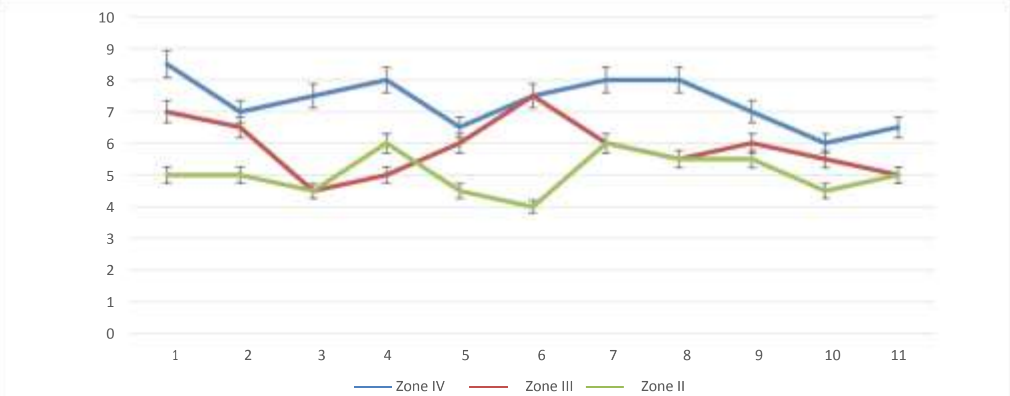

Figure 3: Passion fruit set mean per Agro-ecological zones.

IV to III was the highest and most significant mean difference=2.23 (std error=0.380), then Zone II to III with mean difference=1.64 (std error=0.574) which was also significantly different and then finally from Zone II to IV we had mean difference=0.58 (std error=0.556) which was not significantly different at α=0.05. The Natural patch had the highest level of insect pollinator abundance, then mixed cropping and finally horticulture with agro ecological Zone III having the highest number, then Zone II and lastly Zone IV. The passion fruit set number varied from 5.05 to 7.32. Fruit set was recorded highest (7.32) in Zone IV compared with the other zones.

The natural patches had the highest levels of diversity and numbers of insect pollinators although the adjacent farms were been used intensively for farming. Natural patches acted as refuge areas for the pollinators. Long-term set aside lands are being recognized for their value in the conservation of biodiversity in mostly agricultural settings, and pollinators are benefitting [20]. All such areas support much rural wildlife, mammals, birds, and insects that depend on pollination of wild plants for sustenance. The natural patches need to be protected as habitat of wild pollinators which provide pollination services in farms were intensive farming is practiced. The protection of native pollinators is critical [21]. The natural patches offer increased niche differentiation for the insect pollinators that potentially promote co-existence of large number of insect species. These areas encourage insect populations by providing forage and nesting sites for their conservation [20,21].

Horticulture in this study area is practiced in areas with land scarcity, farm sizes are less than 1 ha and in order to maximize on the produce land is intensively used. There is regular spraying of pesticides to control pests and diseases and heavy application of chemical fertilizers to ensure high yields. This land use type does not practice pollination management and we found the least diversity and number of insect pollinator in such farms. The dangers of pesticides, especially insecticides, to pollinators are well documented and understood [22,23].

According to the agro-climatological zones boundary criteria of Braun [24], Zone IV has medium low potential for arable farming. It is planted with mainly rain-fed maize and less of legumes and

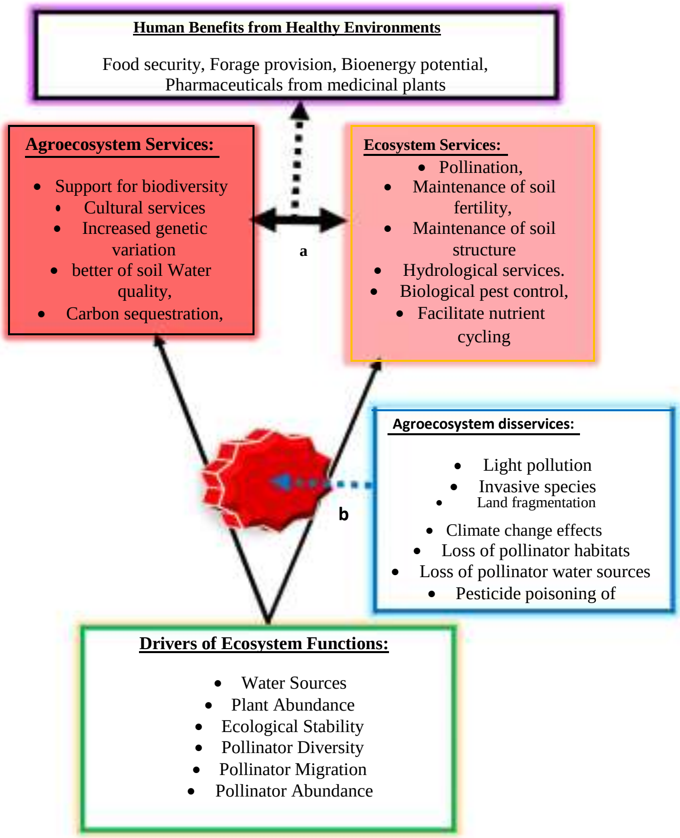

Figure 4: It is delicate balance (a) of the tradeoffs and synergies between ecosystem services, and current agro-ecosystem services that can guarantee sustainability.

vegetables. This research found out that monocultures of maize had the least diversity and number of insect pollinators. This could be attributed to high level of soil disturbance through tilling. Such high levels of disturbance hamper the establishment of pollinator populations and most cereal crops do not depend on insects for pollination. Zone IV had the highest passion fruit set although it had the least diversity and abundance of insect pollinators. This is the only agro-ecological zone which had the carpenter bee, *Xylocopa nigrita* and *Xylocopa flavorufa*. Passion fruit crop is known to benefit from pollination by *Xylocopa spp* [6]. Pollination is an important criterion for fruit set in passion fruit. In this study carpenter bee was noted as the most efficient pollinator. It was also noted that Agro-ecological Zone IV had moderately high temperatures. Moderately high temperatures are favorable for fruit growth and quality in purple passion fruit [25].

The land in Zone III is mainly fallow with shrubs, bushed grassland and some localized forest remnants. It is planted with citrus fruits, bananas, and vegetables (cabbages, kales, tomatoes). There is indigenous plant richness in this area, which could have resulted to insect pollinator richness. Zone II has shrub, grass with tall bushes and trees in some places along the streams banks. There is cultivation of maize, legumes, vegetables (spinach, cabbage, kales), and fruits (grapes, tangarines, pawpaw, banana, avacadoes, strawberries). In Zone III and II the insect pollinator for purple passion fruit was *A. mellifera* and *A. cerena.*

As far as it is known, this study is the first to report effect of land use in contrasting agro ecological zones and seasons on insect pollinator diversity and abundance in relation to passion fruit set. The population of insect pollinators sampled at Mua Hills location showed a high variance between the dry and wet season and it suggests the agro-ecosystem is destabilized and this could lead to loss of insect biodiversity [26]. A healthy agro-ecosystem is stable and provides human being with food security, forage provision, bio-energy potential and pharmaceuticals from medicinal plants. Human activities such as use of agro-chemical in horticultural farming results in ecosystem disservices such as loss of insect pollinators [27]. There is a need to strike a balance between providers of ecosystem services and drivers of ecosystem disservices to ensure sustainable agro-ecosystems (Figure 4).

However, this balance is being bombarded with a host of ecosystem disservices (b) which need to be managed or controls to minimal levels [28].

Recommendation

Further studies should place both pan traps and malaise traps for longer periods of times in similar areas to sample insect diversity more completely.

In areas of intensive farming, field margins/natural patches, are important refuges for many pollinators. There is need for research on the value of these areas to agricultural productivity.

There is need to alert the general public, policy makers and planners, and politicians to the importance of pollination and pollinators, the seriousness of their demise, and the urgency for their conservation

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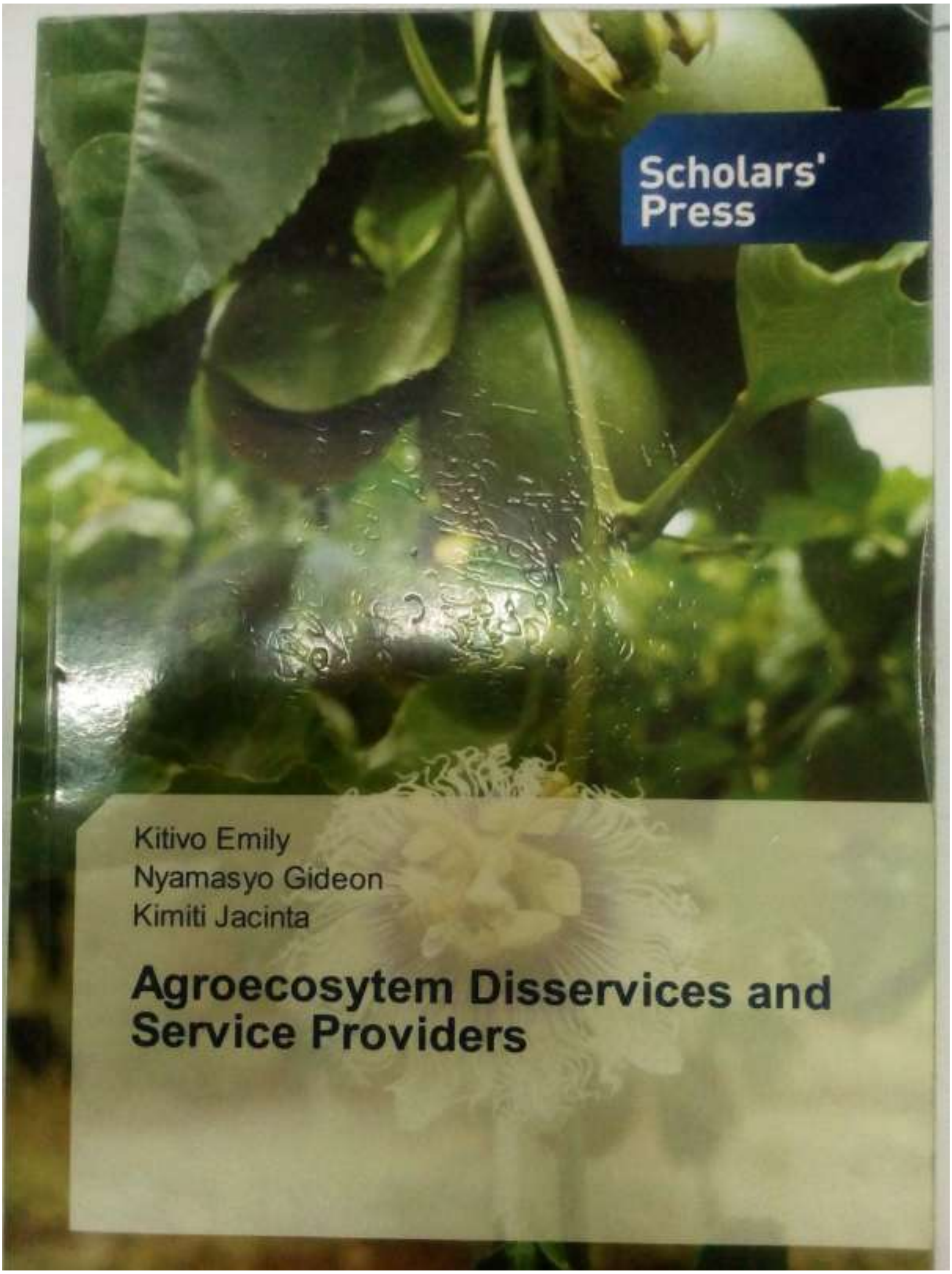
Author Affiliations

Top

[1]*Department of Environmental Science and technology, South Eastern Kenya University, Kenya*
[2]*School of Biological sciences, Department of Entomology University of Nairobi, Kenya*
[3]*Department of Biology, South Eastern Kenya University, Kenya*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CHAPTER TWO

ARE AGRO-CHEMICALS POISONING POLLINATORS

Horticultural farming is very important in Kenya and between 40-60% of the horticultural producers are small and medium scale farmers. As many as 60,000 farming families and up to one million Kenyans out of a total population of above 45 million depend directly or indirectly on export of the vegetables for their living (World Bank, 2014). The horticultural sub-sector employs approximately 4.5million people countrywide directly in production, processing, and marketing, while another 3.5million people benefit indirectly through trade and other activities (Horticultural Crops Development Authority, 2009). Horticulture is a major source of livelihood to farmers generating in excess of $1.0 billion in foreign earnings annually (HCDA, 2010). Horticulture production therefore offers the best alternative for increased food self-sufficiency, improved nutrition and ensuring the generation of increased incomes and employment (Ganry, 2007; 2009).

The main horticultural crops grown in Kenya can be broadly grouped into fruits, vegetables and flowers. The major fruits grown include avocadoes, bananas, citrus, pineapples, mangoes and papaya, while the vegetables include cabbages, spinach, tomatoes, onions, chilies, pepper, carrots, French beans and Asian vegetables (karella, dhudi, brinjals). Rapid growth in horticultural production has been accompanied by heavy use of pesticides. Heavy pesticide use occurs in part because numerous pests attack horticultural crops reducing market value and yield on high value crops. Pesticide use raises safety concern about environmental health for insect pollinators in the agro ecosystems.

The Pest Control Products Board (PCPB) is a statuary organization of Kenya government established under the Pest Control Products Act, Cap 346 laws of Kenya of 1982 to regulate the importation and exportation, manufacture, distribution and use of pest control products in Kenya.

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