DIVERSITY AND ABUNDANCE OF BUTTERFLY SPECIES AND FARMERS' PESTICIDE USE PRACTICES AND PERCEPTIONS ON INSECT POLLINATORS IN FARMLAND AND NGANGAO FOREST, TAITA HILLS, KENYA

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DECLARATION

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

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I dedicate this work to my parents, Mr. Jackson Mbondo and Mrs. Florence Mwinzi, my wife Beth Mbithe and my daughter Hope Mumo, for their love and support, which ensured successful completion of my studies.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BBT	Butterfly Baited Traps
EAM	Eastern Arc Mountains
EASAC	Ecosystem Services, Agriculture and Neonicotinoids
EFSA	European Food Safety Authority
GPS	Global Positioning System
IPPM	Integrated Pest and Pollinator Management
M a.s.l	Meters above sea level
NMK	National Museum of Kenya
TFCG	Tanzania Forest Conservation Group

ABSTRACT

Ngangao Forest is one of the relics of the Taita Hills ecosystem that forms the northernmost Eastern Arc Mountains (EAM). The mountains are globally regarded as biodiversity hotspots with a degree of endemism in both flora and fauna. Continuous anthropogenic disturbances threaten the rich biodiversity in Taita Hills. Farmers in Taita Hills use chemical pesticide to manage pests and diseases often at the expense of biodiversity and the environment. This study aimed at assessing the diversity of butterflies at the edge of Ngangao Forest and adjacent farmlands, and to document farmers' pesticide use practices and their perception on insect pollinators for conservation. Data on diversity and abundance of butterflies was collected for six months from December 2017 to May 2018 using line transect walks and butterfly-baited-traps. A survey on farmer pesticide use practices and perception on pollinators was conducted in small scale farms surrounding Ngangao Forest in March and April 2018. Seventy farmers were sampled randomly within ten farming villages and a structured questionnaire was administered.

A total of 17,438 specimens of butterflies were collected belonging to five families, 62 genera and 144 species. There was a significant difference in the number of butterfly species and their abundance along the forest edge compared to the farmlands. Mean species richness and abundance of butterflies among months sampled was also significantly different ($p<0.05$). The most abundant species in both habitats were *Belenois margaritacea kenyensis* 7.6%, *Eurema brigitta brigitta* 6.3%, *Zizula hylax* 5.9%, *Mylothis sagala* 5.4% and *Papilio nireus lyaeus* 5.2%. Three butterfly species that are endemic to Taita Hills, namely; *Cymothoe teita*, *Papilio desmondi teita* and *Charaxes xiphares desmondi*, were detected in the study area. These findings show that Ngangao forest edge harbors a higher diversity of butterfly species and endemism compared to the farmlands. Measures should be put in place to protect the indigenous cloud forests from anthropogenic activities in order to conserve the existing butterfly diversity within the area.

A total of 29 chemical pesticide active ingredients belonging to 14 chemical groups were used against different pests and diseases in the area. The most commonly used chemical groups were pyrethroids (49.2%) and organophosphates (20.7%). More than 50% of the farmers apply chemicals more than three times in a cropping season. Over 80% of the farmers reported that they follow the recommended rates of chemical application as stated on the label. Farmers dispose off used chemical pesticide containers in three main ways; burning 47.1%, burying 24.3% and disposing in pit latrine 15.7%. A few farmers disposed off in dustbins, left them in the field or disposed off in nearby bushes. More than 60% of the farmers are not trained on pesticide use. Majority of the farmers, 90%, were aware of beneficial insects and that some of the beneficial insects are pollinators. More than half of the farmers 62.9% were aware that pollinators are important in agriculture in fruit, seed and pod set. There is high chemical pesticide usage by farmers and with no adequate training on safe use and handling of the pesticides. There is need for farmers training on pesticide use and awareness creation on conservation of insect pollinators through use of alternatives to chemicals and management of pollinator habitat through creation of hedgerows and conserving the natural fore

CHAPTER ONE

INTRODUCTION

1.1 Background information

Pollination is an essential ecosystem service that helps to maintain the diversity of many cultivated crops and wild flora which are necessary for the survival of people and other animals. It is estimated that nearly 90 per cent of the native flowering plant species are dependent to some degree on the movement of pollen grains by animals (Potts *et al*., 2016). Wild insect pollinators like bees, butterflies, moths, flies, and beetles contribute to the pollination of major global food crops (Klein *et al*., 2015). In agricultural production, pollinators play a significant role in the quality and quantity of the produce. Approximately, 75% of the crops globally are dependent on pollinators for their production (Klein *et al*., 2007) and about 87% of the angiosperm plant species are dependent on animal pollinators for their production (Ollerton *et al*., 2011). According to Ashman *et al*. (2004), reproduction of 62% of flowering plant species is limited to the amount of pollen they receive.

Butterflies provide critical ecological services as they provide pollination service which is essential to human welfare. Pollination provides significant and measurable benefits to humanity and this is a potential economic argument for their conservation. According to Klein *et al.* (2015), butterflies are among the vast majority flower visitors, which are important in the pollination of many leading cash crops globally. Most studies on Lepidoptera pollination have been focused on butterflies as compared to moths. Butterflies are sensitive to changes in the environment hence they are regarded as good ecological indicators for other insect groups (Kumar *et al*., 2009).

Pollinating insects have been undergoing a decline in abundance, occurrence, and diversity in many parts of the world (Vanbergen & Insect Pollinators Initiative, 2013). The decline in pollinators is of much concern because it is associated with a critical ecosystem service (Garibaldi *et al.*, 2012). The loss of pollinators has a negative impact on reproduction for both cultivated and wild plants. A loss of pollinators is linked with the reduction of the plants they interact with (Biesmeijer *et al.,* 2006). The decline in pollinators is alarming that it raises questions regarding food security and stability of ecosystems functions (Potts *et al*., 2010). According to Boucher *et al*. (2013) the local wild bee diversity and abundance was in decline with respect to the distance from field margins and the natural habitat. It has also been recorded that non-bee pollinators like butterflies are declining in abundance and diversity (Carvalheiro *et al*., 2013). Assessment of insect pollinators at national and regional levels show high levels of threat mainly for bees and butterflies (Van Swaay *et al*., 2011).

The drivers for the decline in insect pollinators worldwide include habitat transformation or fragmentation (Kennedy *et al*., 2013), loss of diversity and abundance of floral resources (Kremen *et al*., 2007), inappropriate use of pesticides (Pettis *et al*., 2013) and effects of climate change (Schweiger *et al*., 2010).

Carvalheiro *et al*. (2012) on the effects of pesticide use on mango insect pollinators in South Africa asserts that isolation from natural habitat and use of pesticides were associated with declines in flying pollinators. A study by Otieno *et al*. (2011) found pesticide use has adverse effects on pollinator abundance in fields in Eastern Kenya.

1.2 Problem statement

The diversity, abundance and distribution of butterflies have been on decline worldwide as other pollinator insects. The decline has negatively affected agricultural production and the health of the ecosystem as butterflies play a crucial role in pollination of leading global cash crops. Butterflies also promote eco-tourism and foreign exchange, and with the current declines, these services will be lost. Majority of the butterfly species live in the tropics. Little information is known regarding butterfly ecology in tropical forest edges and farmlands. There is inadequate data on tropical butterfly species, impeding efforts to protect and conserve them in agricultural systems as pollinators. In Kenya, a considerable number of butterfly species have not been described, and their trends are unknown despite the increasing trend in habitat fragmentation, climate change, farmland intensification and chemical use. Chemical pesticides have been in use in Kenya for a long time which poses a threat to insect pollinators and data on the type, amount and how the pesticides are used is missing. Taita hills form part of the Eastern Arc Mountains which is highly rich in biodiversity, and Ngangao forest is one of the remaining indigenous forests in Taita hills. Despite the high biodiversity and endemism, there are threats by illegal deforestation, settlement, and farming causing a conservation threat to the butterflies. In this area, no studies have been carried out to determine the diversity and abundance of the butterflies. There is scarcity of data on butterfly species from the forest edge and the farmlands in this area. In addition, there is no readily available data showing pesticide use practices and farmers' awareness on pollinators in Taita Taveta County. The study is important in providing information for conservation of butterfly species in Taita Hills.

1.3 Justification

Butterflies have been recognized as a useful biodiversity indicator group of tropical land-use systems because they are sensitive and react quickly to subtle changes in environmental and habitat conditions. Therefore, butterflies are used as a measure of biodiversity richness of other species in a locality. Conservation of butterfly species is important as they provide critical service in the ecosystem which sustains production in both the natural and agricultural landscapes. Butterflies provide pollination service which is essential to human welfare; pollination provides significant and measurable benefits to humanity, and this is a potential economic argument for their conservation. Butterflies also offer eco-tourism activities and foreign exchange which can help improve the livelihood and the living standards of the community. This study will provide information on butterfly diversity and abundance in Ngangao forest edge and the surrounding farmlands for conservation and improvement of livelihoods in the area. Also, this study will provide information on pesticide use practices by farmers and their perception on insect pollinators and pollination.

1.4 Broad objective

To contribute to the conservation of butterflies as pollination service providers and promotion of ecofriendly chemical pesticides and enhancing farmer perception on insect pollinators in Taita Hills.

1.5 Specific objectives

i. To determine the diversity and abundance of butterflies at the edge of Ngangao forest and adjoining farms in Taita Hills, Kenya.

ii. To determine farmer' pesticide use practices and perception on insect pollinators and pollination in Taita Hills, Kenya.

1.6 Hypotheses

i. There is no significant difference in butterfly species diversity and their relative abundance in Ngangao forest edge and the surrounding farmlands.

ii. Farmer pesticide use practices are likely to pause dangers to the insect pollinators in Taita Taveta County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Ecological and economic significance of insect pollinators

Pollination is of much importance to the economy of all countries in the world. Pollinators are essential as they provide numerous benefits to humans, like improved crop yields, production of honey and other outputs from beekeeping, ecotourism, and export from butterfly farming (Potts *et al.,* 2016). Additional crop production value directly linked to pollination services globally is estimated to be about $577bn per year (Potts *et al*., 2016). In the absence of insect pollinators, there would be declines in global food supplies resulting in increased prices to consumers and losses to producers. According to Klein *et al*., (2007), 70 percent of global crops and 35 per cent of the crop production by volume are dependent on animal pollinators.

Insect pollinators improve on crop production and provide other benefits mainly to the local communities. Currently, butterflies have greater commercial returns to some Kenyan communities in the coastal regions. Butterfly farming has improved the livelihood of the local people in Taita Hills where farming of different butterfly species including the Taita Hills endemics species of *Cymothoe teita* and *Papilio desmondi teita* earned them up to US$ 600 from the sale of 61 percent of 1052 pupae after six months of rearing (Tanzania Forest Conservation Group (TFCG), 2007).

2.2 Status and trends of insect pollinators

Pollinating insects have been undergoing a decline in abundance, occurrence and diversity globally (Vanbergen *&* Insect Pollinators Initiative, 2013). Studies carried out in North West Europe and North America on wild bees and butterflies showed that there is a decline in diversity, abundance, and occurrence at national and regional levels (Potts *et al.,* 2010). The decline in pollinators is of much concern because it represents a critical ecosystem service

(Ollerton *et al.*, 2011; Garibaldi *et al.*, 2013). Change in pollinator diversity and abundance may lead to a decline in plants that are associated with them (Lever *et al*., 2014). According to Brosi and Briggs (2013) a loss of a single pollinator species can reduce the floral fidelity of other pollinators. The decline in pollinators is alarming that it raises questions regarding food security and stability of ecosystems functions (Potts *et al*., 2010). According to Boucher *et al*., (2013), diversity and abundance of wild bees were in decline with respect to the distance from field margins and the natural habitat. It has also been recorded that non-bee pollinators like butterflies and moths are declining in abundance and diversity (Carvalheiro *et al*., 2012). Assessment of insect pollinators at national and regional levels indicate high levels of threat mainly butterflies and bees (Van Swaay *et al*., 2010). For example, it has been found that in Europe, nine per cent of butterflies and nine per cent of bees are threatened, and the populations are declining, thirty-seven per cent for bees and thirty-one per cent for butterflies (Van Swaay *et al*., 2010). Assessment done by NatureServe on butterflies of United States found that from the total 800 species, 141 species, equivalent to 17 per cent are at risk of extinction (NatureServe, 2014). Also, in the United States, twenty-six species of butterflies are listed as threatened or endangered under the Federal Endangered Species Act (U.S. Fish and Wildlife Service, 2014). A survey carried out in Canada (Hall, 2009), showed some level of risk of one-third of the total butterfly species found in the country.

2.3 Drivers of changes in insect pollinators

Insect pollinators are exposed to environmental pressures that are linked to their shifts in diversity, abundance and occurrence. Habitat transformation may lead to change in the type of land cover that may consequently lead to the disappearance of habitats for many species (Fischer & Lindenmayer, 2007; Kennedy *et al*., 2013). It has been noted that pollinator species richness, composition, and their population sizes are directly affected by habitat degradation (Winfree *et al*., 2011; Kennedy *et al*., 2013). According to Vanbergen (2014), Lepidoptera pollinators decline significantly due to habitat conversion and loss of habitat elements like nesting or foraging sites. Kremen *et al*. (2012) reported crop intensification which involves growing of different crops in the production system promotes biodiversity across scales in contrast to mono-cropping in vast extensive of land. Therefore, crop intensification supports insect pollinator species.

Chemical pesticides are highly used in agricultural production to control pestswhich hinder production. However, pesticides particularly insecticides are of great concern as they pose a threat to the insect pollinators (EASAC, 2015). Inappropriate use of insecticides has the potential to cause directly insect pollinator mortality, therefore, affecting their diversity and abundance (Godfray *et al*., 2014). According to Rundlöf *et al*., (2015) sub-lethal effects of pesticides may affect pollinator populations.

2.4 Butterfly diversity and abundance

Butterflies are among the most widespread and widely recognizable and most studied insects in the world. They are regarded as one of the best taxonomically studied groups of insects (Larsen, 1991). Butterflies have been studied systematically, and about 19,238 species have been documented worldwide (Heppner, 1998). In Africa, about 3500 species of butterflies have been described which is about 20 per cent of the world total (Larsen, 1991). Kenyan Fauna, as compared to that of Africa as a whole is relatively rich as it has about 870 butterfly species which constitutes to a quarter of the African fauna (Larsen, 1991). Butterfly families found in East Africa are Papilionidae (Swallowtails), Pieridae (Whites), Nymphalidae (Brush-footed butterflies), Hesperidae (skippers) and Lycaenidae (Blues and coppers) (Larsen, 1991; Martins & Collins, 2016)

2.5 Butterflies as "indicator species."

According to Thomas (2005) butterflies can be used as indicator species since they are susceptible to their habitat patterns and fragmentation. Some butterfly species are disturbance-tolerant and can be found in areas altered by humans and are effectively tolerant to removal of the native vegetation (Davros *et al*., 2006) However, habitat-sensitive species have more specific requirements for habitat and vegetation composition to suit the needs of other life stages and are often found only in relatively natural areas with native vegetation.

Studies by Kremen (1992) in Madagascar indicated a correlation between habitat fragmentation and butterfly diversity but there was no correlation to anthropogenic disturbances. Lawton *et al*. (1998) discovered that butterfly species richness in tropical forests decreased with anthropogenic disturbance. Heikkinen *et al*. (2010) showed that change in climatic parameters like increasing temperature, humidity and rainfall could affect butterfly distribution.

2.6 Effects of pesticide use on pollinators

Pesticides are of different categories depending on the target which include insecticides for insect pests, fungicides for fungal infections and herbicides for weeds. Insecticides used to control insect pests vary in toxicity to insect pollinators based on their mode of action and target life-stage, and the toxicity also ranges from a few nano-grams to several thousand micrograms (Blacquière *et al*., 2012). According to Hladik *et al*. (2016) pesticide toxicity and the level of exposure are the main factors that endanger insect pollinators. It has been demonstrated that insecticides have lethal and sub-lethal effects on pollinators which affect pollination services negatively (Brittain *&* Potts 2011).

In fields in Eastern Kenya, it was found that pesticide use negatively affected pollinator abundance (Otieno *et al*., 2011). A study by Carvalheiro *et al*. (2012), on mango pollination in South Africa, found that declines in flying pollinators in mango fields is associated with pesticide use and isolation from natural habitat.

Insect pollinators are exposed to pesticides in different forms including direct exposure, through contaminated pollen or nectar. A wide range of factors including rate and method of pesticide application, the time of application, crop type, and the ecological traits pollinators (Defra, 2008) affects the exposure of insect pollinators to insecticides, impact and the potential for population change. There are some routes in which pesticides can directly enter into insect pollinators like through nectar, contaminated pollen, contact with residues on foliage and flowers and contact with overspray or drift during foliar application of the pesticides (EFSA, 2012)). Insect pollinators are prone to the pesticides in the soil as residues and on plant nesting material (EFSA, 2012).

Systemic pesticides that are trans-located in all parts of the crop end up being transferred to the pollen grain and nectar, which may pose potential adverse effects on insect pollinators when collected and consumed by them (Cutler & Scott-Dupree, 2014). According to Bonmatin *et al*. (2015) pollinators may also be exposed to pesticide residues through guttation fluid. Application of pesticides in dust form similarly to liquid sprays may drift onto nearby flowering crops or weeds during application, which may be visited by pollinators, hence expose them to the pesticide (Pisa *et al*., 2015)

CHAPTER THREE

DIVERSITY AND ABUNDANCE OF BUTTERFLIES AT THE EDGE OF NGANGAO FOREST AND ADJOINING FARMS IN TAITA HILLS, KENYA

Abstract

Ngangao Forest, in south-eastern Kenya, is one of the relics of Taita Hills ecosystem that form northernmost Eastern Arc Mountains (EAM). The mountains are globally considered a biodiversity hotspot with a degree of butterfly endemism. This study aimed at assessing the butterfly diversity of Ngangao forest edge and adjacent farmlands. Butterfly data was collected for six months from December, 2017 to May, 2018 using line transects walks and butterfly-baited-traps. Plant species within the sampling transects were recorded. A total of 17438 butterfly specimens belonging to 144 species, 62 genera in five families were recorded. The butterfly diversity was higher in the forest edge (Shannon-Weiner diversity index (H') = 3.85 compared to the farmlands (H') = 3.62). Wet season recorded significantly higher butterfly species compared to the dry season ($P<0.0001$). Mean butterfly species richness and abundance among months sampled was significantly different. Three butterfly species endemics to Taita Hills; *Cymothoe teita*, *Papilio desmondi teita* and *Charaxes xiphares desmondi* were detected in the study area. These findings show that Ngangao forest supports a high diversity of butterfly species and endemism. Conservation of the indigenous forest fragments in Taita Hills is important to maintain the high butterfly diversity within the area.

Key words: Butterfly species diversity, endemism, forest edge, farmland, Taita Hills, Eastern Arc Mountains.

3.1 Introduction

Natural habitats are important in the conservation of insects and other arthropods in the tropics. These ecosystems provide shelter and food for many arthropods. Disturbance of the natural habitats negatively affects the diversity composition (Cubides *et al.,* 2014). Ngangao forest is an indigenous cloud forest in Taita Hills. The Hills form part of the Eastern Arc Mountains (EAM) which is a biodiversity hotspot with high level of endemism of both flora and fauna (Myers *et al*., 2000).

Taita Hills is estimated to have lost the greatest percentage of forest area (98%) over the last 2000 years (Newmark, 1998). The loss of forest cover is attributed to fuel wood cutting, legal and illegal logging, livestock grazing, forest fire and agricultural expansion (Madoffe *et al*., 2005; Pellikka *et al*., 2005). The increased population pressure, forest fragmentation, pesticide use by farmers and climate change are potential drivers of biodiversity loss in Taita Hills (Rogers *et al*., 2008). Given the anthropogenic disturbances, butterfly species may be affected and possibly the endemics will be the first casualties, in a worst-case scenario.

Butterflies carry out pollination, an essential ecosystem service for maintaining the population of many cultivated crops and wild flora, necessary for the survival of people and other animals. Nearly 90% of the native flowering plant species are dependent at some degree on the movement of pollen grains by animals (Potts *et al*., 2016). Butterflies are among the vast majority flower visitors (Klein *et al*., 2015) and are important in the pollination of many leading cash crops globally. These pollinating insects have been undergoing a decline in abundance, occurrence, and diversity in many parts of the world (Ollerton *et al*., 2014). The decline in insect pollinators is result of anthropogenic activities including habitat transformation and fragmentation (Kennedy *et al*., 2013), loss of diversity and abundance of floral resources (Kremen *et al*., 2007), inappropriate use of pesticides (Pettis *et al*., 2013) and climate change (Schweiger *et al*., 2010).

Butterflies are susceptible to slight changes in their habitat, therefore they have been used as indicators of environmental degradation (Thomas, 2005). However, some butterfly species are disturbance-tolerant and can be found in areas altered by humans and are effectively tolerant to removal of the native vegetation (Davros *et al*., 2006). Habitat-sensitive butterfly species have more specific requirements for habitat and vegetation composition to suit the needs of other life stages and are often found only in relatively natural areas with native vegetation. According to Lawton *et al*., (1998), butterfly species richness in tropical forests decreased with anthropogenic disturbance. Change in climatic parameters like increasing temperature, humidity and rainfall could affect butterfly distribution (Heikkinen *et al*., 2010).

Despite the role of butterflies in pollination, as indicator species and their endemism in Taita Hills, there is limited comprehensive data of their diversity and abundance. The objective of the study was to assess diversity and abundance of butterfly species along Ngangao forest edge and the adjacent farmlands in Taita Hills.

3.2 Materials and Methods

3.2.1 Description of study area

The study was done along the forest edge and surrounding farmlands at Ngangao (Figure 1) during the dry and wet season, December 2017 to February 2018 and, March to May 2018 respectively. The study site was in Ngangao forest, Taita Hills; an indigenous cloudy forest which forms the northern Eastern Arc Mountains (03025’S, 38020’E). Ngangao forest covers about 120 hectares, and its 10 km from away Wundanyi town at an altitude range of 1700 to 1900 m a.s.l. The study area has distinct weather seasons; short rains (September, October and November), dry (December, January and February) long rain (March, April and May) and cold season (June, July and August) (Odanga, 2017).

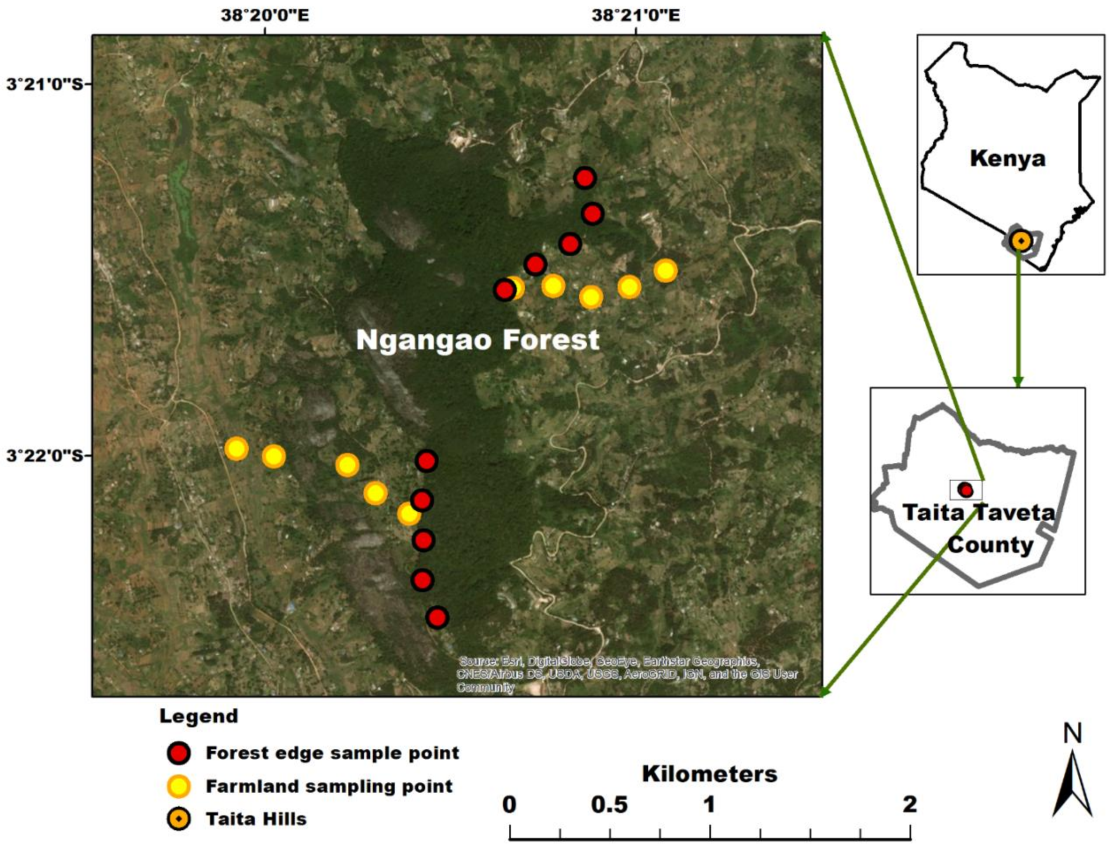

Figure 3. 1**: Study map-depicting sampling transects and points (Developed using ArcGIS, ILRI database)**

High canopy trees and shrubs characterize the forest edge. The most common indigenous tree in the forest edge include; *Syzygium guineense, Macaranga conglomerata, Albizia gummifera, Phoenix reclinata, Newtonia buchananii, Rytigynia eickii, Rytigynia uhligii, Tabarnaemontana stapfiana, Psychotria* sp, *Dracaena steudneri, Dichapelatum eickii, Piper capense, Streptocarpus mantanus*, and *Lycopodium holstii* (Rogers et al., 2008, Thijs et al., 2014). The surrounding farmlands are characterized by small-scale farming of subsistence crops such as bean (*Phaseolus vulgaris* L.), maize (*Zea mays*), kale (*Brassicae*), black nightshade (*Solanaceae*), tomato (*Lycopersicon esculentum*), and Irish potato (*Solanum tuberosum*) (Maenda et al., 2010). Different shrubs and weed species occur in the farmlands and farmland edges.

3.2.2 Field sampling of butterflies

Field sampling of butterflies was conducted along Ngangao forest edge and adjacent farmlands. Two line transects of 1000 m were established along the forest edge and along the farmland using Global Positioning System (GPS-Germin). The two 1000 m farmland transects were perpendicular to the forest edge transects. Five sampling points per transect were established (100m long by 10 m width) (Fig. 1). From one sampling plot to the next, 100 m walking distance was kept where sampling was not done.

Butterflies were sampled for six consecutive months from December, 2017 to May, 2018. In each month, sampling was done for two weeks and each transect was sampled twice in a week. Sampling was done from 0900 hours to 1600 hours. Two sampling methods were employed; line transect counts (Pollard and Yates, 1993) and butterfly-baited traps.

In line transect sampling (Plate 2), butterflies were observed and recorded while walking at an average speed of 5m per minute frequently stopping, observing and hand netting butterfly species within the transect range. A total of 20 minutes was taken in a sampling point within a transect. Butterfly baited traps were used to sample frugivorous butterflies, which are attracted to fermenting fruits (Holloway *et al*., 2013; Lucci *et al*., 2014). The bait was prepared using smashed ripe pineapples and bananas and left to ferment for three days. The traps were made of local materials based on Van Someren-Rydon Trap design (Molleman *et al*., 2006) (plate 1). The traps were placed at 100 m intervals, with 10 traps per transect. Each baited butterfly trap contained two spoonsful of fermented pineapple and banana and was suspended at about 2m above the ground. The butterfly-baited traps were installed before 0900 hours in the morning with samples being collected at 1800 hours by counting and recording all butterfly species captured in the trap. Voucher specimens for each species were collected, pinched at the thorax and stored in butterfly envelopes. The remaining butterfly individuals released back to the wild.

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Plate 1 Butterfly baited trap (*Photo source; Mwinzi, 2019)*

Plate 2 Line transect butterfly sampling along forest edge (*Photo source; Mwinzi, 2019)*

Butterfly specimens were identified by consulting manuals and colored plates "Butterflies of Kenya and their Natural History" (Larsen, 1991), "Butterflies of Afrotropical Regions" (d'Abrera, 1980) and "Butterflies of Tanzania" (Kielland, 1990). Butterfly species were confirmed using National Museums of Kenya (NMK) butterfly reference collection. Butterfly voucher specimens from the study were deposited at the Invertebrates Zoology reference collection at the Zoology Department, National Museums of Kenya.Plant species survey was carried out within the sampling transect by a botanist. Plant species survey was conducted at each butterfly sampling point measuring 100m by 10m and plant species in the sampling plots recorded.

3.3 Statistical analysis

Shannon-Wiener (H') diversity index was used to determine butterfly diversity (Magurran, 2013; Kindt & Coe, 2005). The formula below was used to determine Shannon Index (H)

$$(\mathrm{H}) = - \sum_{i=1}^{s} p_i \ln p_i$$

Where; **p**, is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), **In** is the natural log, **Σ** is the sum of the calculations, and **s** is the number of species. T-test and Analysis of Variance (ANOVA) was used to compare the diversity and relative abundance of butterflies between and among points as described by Magurran, (2013) and Odanga, (2011). Correlation analysis was used to compare the relationship between butterflies and plant species.

3.4 Results

3.4.1 Butterfly composition in Ngangao forest

A total 17,438 butterfly records consisting of 144 species and 62 genera were recorded during the period of study on the forest edge and the adjoining farmlands (Table 3.2). The highest number of butterfly species was recorded under family Nymphalidae 62 (43.1%) followed by Lycaenidae 30 (20.8%) in second place. The others were; Pieridae 28 (19.4%), Hesperiidae 16 (11.1%) and Papillionidae 8 (5.6%) in decreasing numbers (Table 3.1). The genera with the highest species recorded was *Acraea* 16 (11.1%), *Colotis* 11 (7.6%) came in second while *Charaxes* 11 (7.6%) was the third. Nymphalidae recorded highest abundance 35.8%, Pieridae 33.5%, Lycaenidae 13.4%, Papilionidae 12.1% and Hesperiidae 5.1%. The most dominant (≥5% of total individuals recorded) butterfly species were *Belenois margaritacea kenyensis* 7.6%, *Eurema brigitta brigitta* 6.3%, *Zizula hylax* 5.9%, *Mylothis sagala* 5.4% and *Papilio nireus lyaeus* 5.2%.

Table 3. 1**: Taxonomic profile of butterfly families recorded at the edge of Ngangao forest and adjacent farmlands in Taita Hills**

Family	**Genera**	**Number of species (%)**	**Abundance (%)**
Nymphalidae	21	62 (43.1)	6241 (35.8)
Pieridae	9	28 (20.8)	5834 (33.5)
Lycaenidae	18	30 (19.4)	2339 (13.4)
Papilionidae	2	8 (11.1)	2128 (12.2)
Hesperiidae	12	16 (5.6)	896 (5.1)
Totals	**62**	**144**	**17438**

Table 3. 2**: Butterfly species diversity, abundance and presence along the edge of Ngangao forest and in the adjoining farmlands, in Taita Hills.**

Family	Butterfly species	Total & % abundance for both habitats	Total & % abundance for Forest edge	Total & % abundance for Farmland	Ecological category
Hesperiidae	*Acleros mackenii*	47 (0.27)	23 (0.22)	24 (0.34)	FDS
Hesperiidae	*Andronymus neander neander*	1 (0.01)	0	1 (0.01)	MS
Hesperiidae	*Borbo fallax*	4 (0.02)	2 (0.02)	2 (0.03)	SS
Hesperiidae	*Coeliades anchises Anchises*	5 (0.03)	4 (0.04)	1 (0.01)	FEW
Hesperiidae	*Coeliades forestan forestan*	5 (0.03)	4 (0.04)	1 (0.01)	FEW
Hesperiidae	*Coeliades sejuncta*	1 (0.01)	1 (0.01)	0	FDS
Hesperiidae	*Eagris nottoana nottoana*	1 (0.01)	1 (0.01)	0	FDS
Hesperiidae	*Eagris sebadius*	92 (0.53)	89 (0.85)	3 (0.04)	FEW
Hesperiidae	*Eretis umbra maculifera*	19 (0.11)	10 (0.1)	9 (0.13)	OPHS
Hesperiidae	*Gegenes niso brevicornis*	77 (0.44)	14 (0.13)	63 (0.91)	MSM
Hesperiidae	*Metisella orientalis*	320 (1.84)	212 (2.02)	108 (1.55)	FDS
Hesperiidae	*Pelopidas mathias*	3 (0.02)	1 (0.01)	2 (0.03)	WSS
Hesperiidae	*Sarangesa maculata*	7 (0.04)	2 (0.02)	5 (0.07)	SS
Hesperiidae	*Spialia colotes transvaaliae*	4 (0.02)	2 (0.02)	2 (0.03)	OPHS
Hesperiidae	*Spialia dromus*	135 (0.77)	63 (0.6)	72 (1.03)	FEW
Hesperiidae	*Zenonia zeno*	175 (1)	146 (1.39)	29 (0.42)	FEW
Lycaenidae	*Actizera lucida lucida*	202 (1.16)	14 (0.13)	188 (2.7)	SS
Lycaenidae	*Anthene indefinita*	3 (0.02)	1 (0.01)	2 (0.03)	FEW
Lycaenidae	*Anthene princeps princeps*	2 (0.01)	2 (0.02)	0	SS

Lycaenidae	*Axiocerses harpax ugandana*	5 (0.03)	0	5 (0.07)	OPHS
Lycaenidae	*Axiocerses sp1*	1 (0.01)	1 (0.01)	0	U
Lycaenidae	*Axiocerses tjoane*	9 (0.05)	4 (0.04)	5 (0.07)	OPHS
Lycaenidae	*Azanus jesous*	15 (0.09)	3 (0.03)	12 (0.17)	WSS
Lycaenidae	*Cacyreus lingeus*	88 (0.5)	24 (0.23)	64 (0.92)	SS
Lycaenidae	*Cacyreus palemon palemon*	37 (0.21)	27 (0.26)	10 (0.14)	MSM
Lycaenidae	*Cacyreus virilis*	4 (0.02)	3 (0.03)	1 (0.01)	SS
Lycaenidae	*Euchrysops osiris*	1 (0.01)	1 (0.01)	0	SS
Lycaenidae	*Euchrysops subpallida*	1 (0.01)	1 (0.01)	0	SS
Lycaenidae	*Freyeria trochylus trochylus*	28 (0.16)	24 (0.23)	4 (0.06)	U
Lycaenidae	*Iolaus yalae*	4 (0.02)	4 (0.04)	0	FDS
Lycaenidae	*Lachnocnema bibulus*	1 (0.01)	1 (0.01)	0	WSS
Lycaenidae	*Lachnocnema durbani*	3 (0.02)	3 (0.03)	0	OPHS
Lycaenidae	*Lampides boeticus*	260 (1.49)	76 (0.73)	184 (2.64)	WSS
Lycaenidae	*Leptotes pirithous*	394 (2.26)	148 (1.41)	246 (3.53)	FEW
Lycaenidae	*Leptotes Sp1*	2 (0.01)	1 (0.01)	1 (0.01)	U
Lycaenidae	*Leptotes Sp2*	1 (0.01)	1 (0.01)	0	U
Lycaenidae	*Leptotes Sp3*	1 (0.01)	1 (0.01)	0	U
Lycaenidae	*Pentila tropicalis*	31 (0.18)	2 (0.02)	29 (0.42)	FDS
Lycaenidae	*Pseudonacaduba sichela sichela*	1 (0.01)	1 (0.01)	0	FEW
Lycaenidae	*Spalgis lemolea*	2 (0.01)	2 (0.02)	0	FDS
Lycaenidae	*Tarucus grammicus*	50 (0.29)	49 (0.47)	1 (0.01)	OPHS
Lycaenidae	*Uranothauma falkensteini*	118 (0.68)	75 (0.72)	43 (0.62)	FDS
Lycaenidae	*Uranothauma heritsia intermedia*	1 (0.01)	0	1 (0.01)	FDS
Lycaenidae	*Uranothauma nubifer*	8 (0.05)	2 (0.02)	6 (0.09)	FDS
Lycaenidae	*Zizeeria knysna*	32 (0.18)	21 (0.2)	11 (0.16)	WSS
Lycaenidae	*Zizula hylax*	1034 (5.93)	351 (3.35)	683 (9.81)	WSS

Nymphalidae	*Acraea aganice montana*	2 (0.01)	0	2 (0.03)	SS
Nymphalidae	*Acraea baxteri*	1 (0.01)	1 (0.01)	0	FDS
Nymphalidae	*Acraea boopis ama*	1 (0.01)	0	1 (0.01)	FDS
Nymphalidae	*Acraea braesia*	5 (0.03)	4 (0.04)	1 (0.01)	SS
Nymphalidae	*Acraea cabira*	526 (3.02)	178 (1.7)	348 (5)	FDS
Nymphalidae	*Acraea chilo*	20 (0.11)	9 (0.09)	11 (0.16)	SS
Nymphalidae	*Acraea encedon encedon*	1 (0.01)	1 (0.01)	0	OPHS
Nymphalidae	*Acraea eponina eponina*	221 (1.27)	124 (1.18)	97 (1.39)	SS
Nymphalidae	*Acraea equatorialis*	27 (0.15)	5 (0.05)	22 (0.32)	OPHS
Nymphalidae	*Acraea esebria esebria*	2 (0.01)	2 (0.02)	0	FDS
Nymphalidae	*Acraea insignis insignis*	18 (0.1)	17 (0.16)	1 (0.01)	FDS
Nymphalidae	*Acraea johnstoni johnstoni*	5 (0.03)	5 (0.05)	0	FDS
Nymphalidae	*Acraea lycoa*	59 (0.34)	50 (0.48)	9 (0.13)	FDS
Nymphalidae	*Acraea neobule neobule*	8 (0.05)	4 (0.04)	4 (0.06)	OPHS
Nymphalidae	*Acraea quirina*	107 (0.61)	104 (0.99)	3 (0.04)	FDS
Nymphalidae	*Acraea zetes*	18 (0.1)	6 (0.06)	12 (0.17)	SS
Nymphalidae	*Amauris albimaculata*	64 (0.37)	48 (0.46)	16 (0.23)	FDS
Nymphalidae	*Amauris niavius*	134 (0.77)	122 (1.16)	12 (0.17)	FDS
Nymphalidae	*Antanartia dimorphica dimorphica*	152 (0.87)	149 (1.42)	3 (0.04)	MSM
Nymphalidae	*Antanartia schaeneia dubia*	16 (0.09)	16 (0.15)	0	MSM
Nymphalidae	*Bicyclus campinus*	95 (0.54)	87 (0.83)	8 (0.11)	FEW
Nymphalidae	*Bicyclus safitza safitza*	2 (0.01)	2 (0.02)	0	SS
Nymphalidae	*Byblia ilithyia*	70 (0.4)	35 (0.33)	35 (0.5)	WSS
Nymphalidae	*Catacroptera cloanthe cloanthe*	4 (0.02)	0	4 (0.06)	SS
Nymphalidae	*Charaxes aubyni*	57 (0.33)	56 (0.53)	1 (0.01)	FDS
Nymphalidae	*Charaxes baumanni*	32 (0.18)	30 (0.29)	2 (0.03)	FDS
Nymphalidae	*Charaxes brutus*	131 (0.75)	115 (1.1)	16 (0.23)	FDS
Nymphalidae	*Charaxes candiope candiope*	127 (0.73)	123 (1.17)	4 (0.06)	WSS

Nymphalidae	*Charaxes cithaeron*	1 (0.01)	1 (0.01)	0	FDS
Nymphalidae	*Charaxes druceanus*	72 (0.41)	66 (0.63)	6 (0.09)	FDS
Nymphalidae	*Charaxes pollux pollux*	131 (0.75)	123 (1.17)	8 (0.11)	FDS
Nymphalidae	*Charaxes saturnus*	19 (0.11)	17 (0.16)	2 (0.03)	SS
Nymphalidae	*Charaxes varanes vologeses*	135 (0.77)	130 (1.24)	5 (0.07)	WSS
Nymphalidae	*Charaxes xiphares desmondi*	61 (0.35)	61 (0.58)	0	FDS
Nymphalidae	*Charaxes zoolina zoolina*	2 (0.01)	2 (0.02)	0	SS
Nymphalidae	*Cymothoe teita*	67 (0.38)	67 (0.64)	0	FDS
Nymphalidae	*Danaus chrysippus chrysippus*	185 (1.06)	90 (0.86)	95 (1.36)	WSS
Nymphalidae	*Eurytela dryope angulate*	2 (0.01)	1 (0.01)	1 (0.01)	FEW
Nymphalidae	*Eurytela hiarbas lita*	3 (0.02)	2 (0.02)	1 (0.01)	FDS
Nymphalidae	*Henotesia perspicua*	1 (0.01)	1 (0.01)	0	OPHS
Nymphalidae	*Hypolimnas anthedon*	1 (0.01)	1 (0.01)	0	FDS
Nymphalidae	*Hypolimnas misippus*	130 (0.75)	92 (0.88)	38 (0.55)	WSS
Nymphalidae	*Junonia hierta cebrene*	179 (1.03)	83 (0.79)	96 (1.38)	MS
Nymphalidae	*Junonia natalica natalica*	155 (0.89)	75 (0.72)	80 (1.15)	FDS
Nymphalidae	*Junonia oenone oenone*	365 (2.09)	224 (2.14)	141 (2.03)	WSS
Nymphalidae	*Junonia sophia infracta*	419 (2.4)	70 (0.67)	349 (5.01)	WSS
Nymphalidae	*Junonia terea*	56 (0.32)	35 (0.33)	21 (0.3)	WSS
Nymphalidae	*Neocoenyra duplex*	2 (0.01)	1 (0.01)	1 (0.01)	SS
Nymphalidae	*Neocoenyra gregorii*	769 (4.41)	402 (3.84)	367 (5.27)	MSM
Nymphalidae	*Neptis aurivillii*	69 (0.4)	68 (0.65)	1 (0.01)	FDS
Nymphalidae	*Neptis penningtoni*	97 (0.56)	27 (0.26)	70 (1.01)	FEW
Nymphalidae	*Neptis saclava marpessa*	6 (0.03)	6 (0.06)	0	WSS
Nymphalidae	*Phalanta phalantha aethiopica*	236 (1.35)	107 (1.02)	129 (1.85)	MS
Nymphalidae	*Precis antilope*	4 (0.02)	4 (0.04)	0	OPHS
Nymphalidae	*Precis archesia*	122 (0.7)	115 (1.1)	7 (0.1)	SS
Nymphalidae	*Precis limnoria taveta*	26 (0.15)	19 (0.18)	7 (0.1)	SS
Nymphalidae	*Precis tugela*	329 (1.89)	232 (2.21)	97 (1.39)	FEW
Nymphalidae	*Salamis anacardii anacardii*	3 (0.02)	3 (0.03)	0	FEW

Nymphalidae	*Salamis parhassus parhassus*	431 (2.47)	333 (3.18)	98 (1.41)	FDS
Nymphalidae	*Tirumala formosa*	123 (0.71)	106 (1.01)	17 (0.24)	FDS
Nymphalidae	*Vanessa cardui cardui*	134 (0.77)	66 (0.63)	68 (0.98)	WSS
Nymphalidae	*Ypthima asterope asterope*	1 (0.01)	0	1 (0.01)	OPHS
Papilionidae	*Graphium leonidas Leonidas*	2 (0.01)	1 (0.01)	1 (0.01)	MS
Papilionidae	*Graphium policenes*	20 (0.11)	18 (0.17)	2 (0.03)	FDS
Papilionidae	*Papilio dardanus*	59 (0.34)	41 (0.39)	18 (0.26)	FDS
Papilionidae	*Papilio demodocus demodocus*	194 (1.11)	96 (0.92)	98 (1.41)	MS
Papilionidae	*Papilio desmondi teita*	228 (1.31)	204 (1.95)	24 (0.34)	FDS
Papilionidae	*Papilio echerioides*	157 (0.9)	131 (1.25)	26 (0.37)	FDS
Papilionidae	*Papilio nireus lyaeus*	905 (5.19)	606 (5.78)	299 (4.3)	FDS
Papilionidae	*Papilio ophidicephalus ophidicephalus*	563 (3.23)	394 (3.76)	169 (2.43)	FDS
Pieridae	*Appias sabina*	2 (0.01)	1 (0.01)	1 (0.01)	FDS
Pieridae	*Belenois aurota aurota*	121 (0.69)	78 (0.74)	43 (0.62)	SS
Pieridae	*Belenois creona severina*	513 (2.94)	303 (2.89)	210 (3.02)	SS
Pieridae	*Belenois margaritacea kenyensis*	1165 (6.68)	1076 (10.27)	89 (1.28)	FDS
Pieridae	*Belenois zochalia agrippinides*	336 (1.93)	242 (2.31)	94 (1.35)	FEW
Pieridae	*Catopsilia florella*	715 (4.1)	451 (4.3)	264 (3.79)	MS
Pieridae	*Colias electo pseudohecate*	3 (0.02)	0	3 (0.04)	MSM
Pieridae	*Colotis amatus amatus*	10 (0.06)	6 (0.06)	4 (0.06)	SS
Pieridae	*Colotis aurigineus*	8 (0.05)	6 (0.06)	2 (0.03)	SS
Pieridae	*Colotis auxo incretus*	12 (0.07)	10 (0.1)	2 (0.03)	SS
Pieridae	*Colotis daira jacksoni*	1 (0.01)	0	1 (0.01)	SS
Pieridae	*Colotis danae*	1 (0.01)	1 (0.01)	0	SS
Pieridae	*Colotis eris eris*	6 (0.03)	0	6 (0.09)	SS
Pieridae	*Colotis eucharis evarne*	5 (0.03)	5 (0.05)	0	SS
Pieridae	*Colotis euippe*	44 (0.25)	31 (0.3)	13 (0.19)	FEW
Pieridae	*Colotis evagore Antigone*	7 (0.04)	2 (0.02)	5 (0.07)	SS

Pieridae	*Colotis hetaera*	1 (0.01)	1 (0.01)	0	SS
Pieridae	*Colotis regina*	5 (0.03)	1 (0.01)	4 (0.06)	U
Pieridae	*Eurema brigitta brigitta*	1105 (6.34)	501 (4.78)	604 (8.68)	FEW
Pieridae	*Eurema desjardinsi oberthuri*	90 (0.52)	52 (0.5)	38 (0.55)	FEW
Pieridae	*Eurema hecabe solifera*	10 (0.06)	0	10 (0.14)	MS
Pieridae	*Eurema regularis regularis*	36 (0.21)	27 (0.26)	9 (0.13)	WSS
Pieridae	*Eurema senegalensis*	43 (0.25)	27 (0.26)	16 (0.23)	FDS
Pieridae	*Mylothris agathina*	147 (0.84)	36 (0.34)	111 (1.59)	WSS
Pieridae	*Mylothris rueppelli tirikensis*	6 (0.03)	5 (0.05)	1 (0.01)	FDS
Pieridae	*Mylothris sagala*	937 (5.37)	690 (6.59)	247 (3.55)	FDS
Pieridae	*Pinacopteryx eriphia melanarge*	2 (0.01)	1 (0.01)	1 (0.01)	OPHS
Pieridae	*Pontia helice johnstoni*	503 (2.88)	93 (0.89)	410 (5.89)	MS

Codes for different ecological habitat categories. FDS: "forest-dependent species"; FEW; "forest and woodland specialist; MS: "migratory species"; OHPS: "open habitat specialist species"; WSS: "widespread species"; MSM: "Montane and semi-montane species; N: "uncertain ecological category"—species of unknown (un-described) habitat preference

3.4.2 Comparison of butterfly species composition

The forest edge recorded 133 butterfly species with 60.1% while the farmlands recorded 113 butterfly species with 39.9% abundance. The butterfly diversity was higher in the forest edge (Shannon-Weiner diversity index (H') = 3.85 with the farmlands having lower diversity (Shannon-Weiner diversity index (H') = 3.62). Species accumulation curve and rank curve show more butterfly diversity in forest edge compared to the farmlands (Fig 3.2 and Fig 3.3). There was significant difference in species richness between forest edge and the adjoining farmlands (One-way ANOVA; F1, 118, =24.8552, P=0.00000214 for species and F1, 118, =12.993, P=0.0004593 for abundance). The species diversity between the habitats was significantly different (One-way ANOVA; F1, 118, =13.929, P=0.000296)

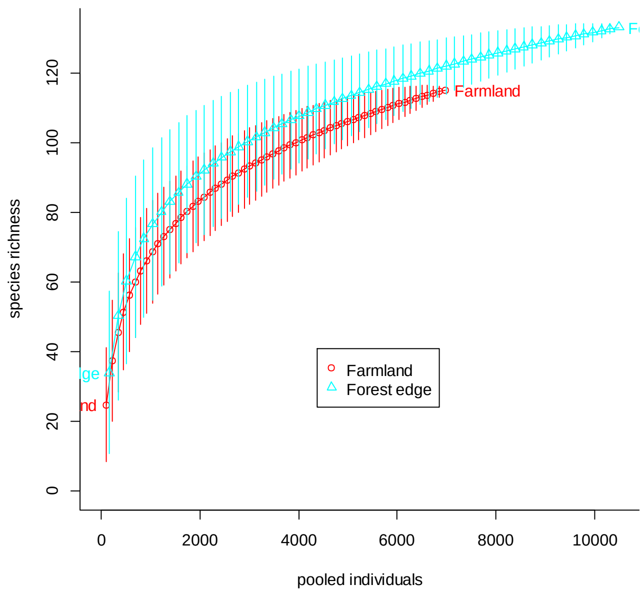

Figure 3. 2**: Butterfly species accumulation curve between Ngangao forest edge and surrounding farmlands**

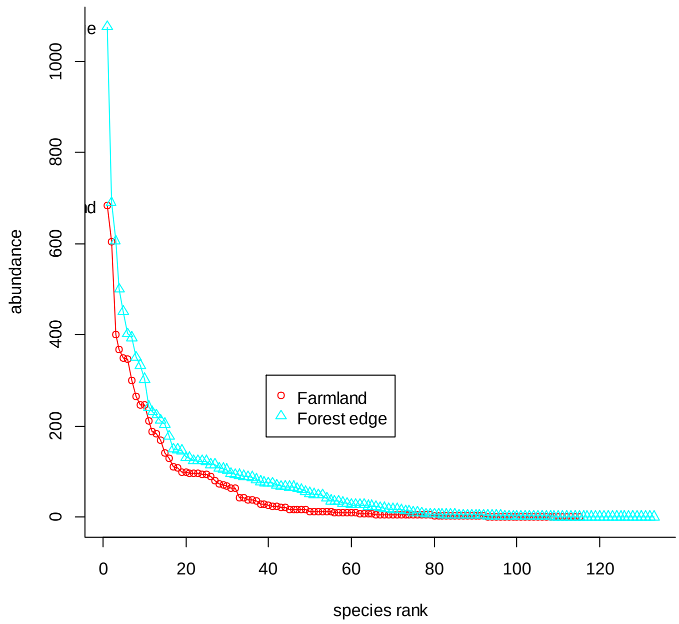

Figure 3. 3**: Butterfly species rank curve between Ngangao forest edge and surrounding farmland**

3.4.3 Endemism in Ngangao forest

Three butterfly species (about 2% of the total species recorded) namely; *Cymothoe teita, Papilio desmondi teita* and *Charaxes xiphares desmondi* endemic to Taita Hills were recorded in Ngngao forest (Table 3.3 and Plate 3a,3b, 4a, 4b and 5)

Table 3. 3**: Abundance of endemic butterfly species along the Ngangao forest edge and adjoining farmlands, during wet and dry seasons**.

Family	Scientific name	Abundance Forest edge	Abundance Farmland	Wet season	Dry season
Nymphalidae	*Cymothoe teita*	67	0	42	25
Papilionidae	*Papilio desmondi teita*	204	24	83	145
Nymphalidae	*Charaxes xiphares desmondi*	61	0	51	10

Plate 3a. *Cymothoe teita* (Teita Glider), Male (*Photo source; Mwinzi, 2019*)

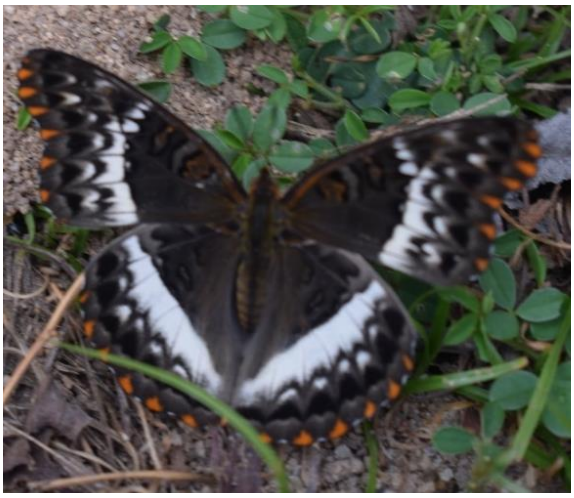

Plate 3b. *Cymothoe teita (*Teita Glider*)* Female (*Photo source; Mwinzi, 2019*)

Plate 4a. *Charaxes xiphares desmondi* (Forest King Charaxes), male (*Photo source; Mwinzi, 2019*)

Plate 4b. *Charaxes xiphares desmondi* (Forest King Charaxes), female (*Photo source; Mwinzi, 2019*)

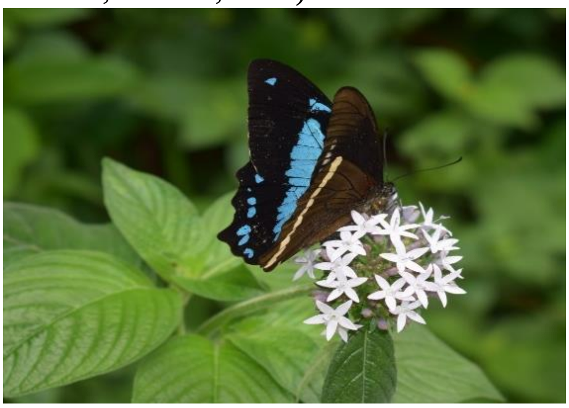

Plate 5. *Papilio desmondi teita* (Desmonds' Green Banded Swallowtail (*Photo source; Mwinzi, 2019*)

The wet season (March to May 2018) recorded 133 butterfly species in both habitats while dry season (December 2017 and January to February 2018) recorded 108 butterfly species. Abundance during wet season was (47.3%) while dry season had 53.7%. The difference in number of species diversity in dry and wet seasons for both habitats was significantly different ($F_{3, 116}$, F=8.4978, P=0.00003772). Turkey simultaneous tests was done to determine the specific differences between habitat and seasons (Table 3.4)

Table 3. 4: **Tukey Simultaneous Tests for Differences of Means between habitat and season**

Difference of Levels	Difference of Means	SE of Difference	T-Value	P-Value
Farmland wet - Farmland dry	0.5667	2.6365	0.215	0.99647
Forest edge wry - Farmland dry	8.3333	2.6365	3.161	0.01061
Forest edge wet - Farmland dry	10.7333	2.6365	4.071	0.001
Forest edge dry - Farmland wet	7.7667	2.6365	2.946	0.02020
Forest edge wet - Farmland wet	10.1667	2.6365	3.856	0.00109
Forest edge wet - Forest edge dry	2.4000	2.6365	0.910	0.79939

3.4.5 Temporal species composition

There was significant difference in monthly species composition and their abundance (One-way ANOVA; F=27.57, p<0.0001 for species and F=16.41, p<0.0001 for abundance (Fig 3.4).

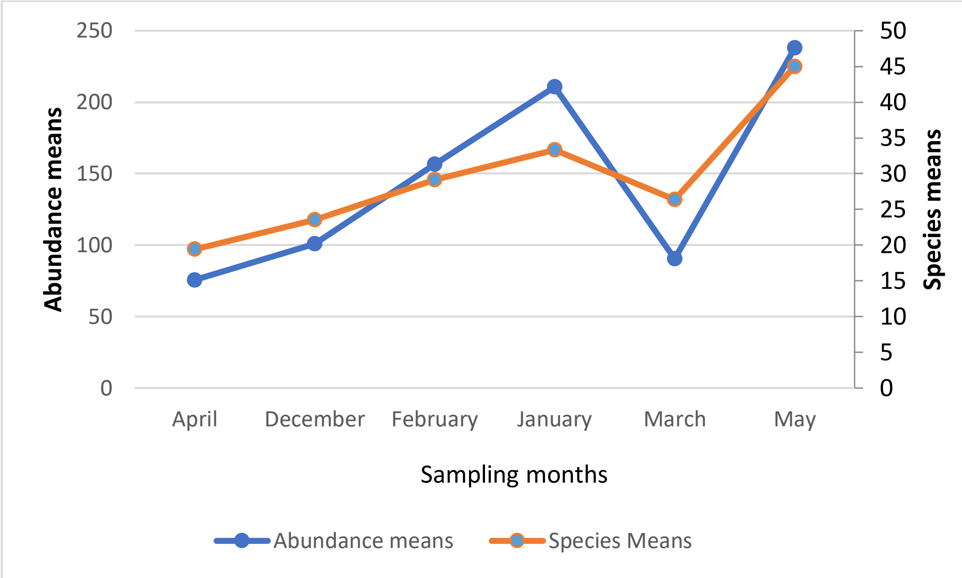

Figure 3. 4**: Monthly butterfly species richness and abundance in Ngangao forest, Taita Hills.**

3.4.6 Plant species within butterfly sampling transect

A total of 261 plant species belonging to 77 families were recorded in both forest edge and adjacent farmland. The forest edge had 186 while 136 plant species were recorded at the adjoining farmlands (Table 3.5).

Table 3. 5**: Plant species recorded in butterfly sampling points along Ngangao forest edge and adjoining farmlands**

Family	**Plant species**	**Forest edge**	**Farmland**	**Family**	**Plant species**	**Forest edge**	**Farmland**
Acanthaceae	*Asystasia gangetica*	√	√	Asparagaceae	*Asparagus setaceus*	√	x
Acanthaceae	*Dyschoriste nagchana*	x	√	Aspleniaceae	*Asplenium theciferum*	√	x
Acanthaceae	*Isoglossa sp.*	√	X	Asteraceae	*Ageratum conyzoides*	√	√
Acanthaceae	*Justicia striata*	x	√	Asteraceae	*Anisopappus chinensis*	X	√
Acanthaceae	*Justicia pseudorungia*	√	X	Asteraceae	*aspilia mossambicensis*	X	√
Acanthaceae	*Phaulopsis imbricata*	√	X	Asteraceae	*Bidens pilosa*	√	√
Acanthaceae	*Thunbergia alata*	√	√	Asteraceae	*Bothriocline longipes*	√	√
Adiantaceae	*Cheilanthes multifida*	√	X	Asteraceae	*Conyza bonariensis*	√	√
Adiantaceae	*Pellaea viridis*	√	√	Asteraceae	*Conyza newii*	√	√
Agavaceae	*Agave sisalana*	√	√	Asteraceae	*Crassocephalum picridifolium*	X	√
Amaranthaceae	*Achyranthes aspera*	√	√	Asteraceae	*Crassocephalum vitellinum*	X	√
Amaranthaceae	*Aerva lanata*	x	√	Asteraceae	*Crepis sp.*	X	√
Amaranthaceae	*Amaranthus hybridus*	x	√	Asteraceae	*Dichrocephala integrifolia*	X	√
Amaranthaceae	*Celosia trigyna*	x	√	Asteraceae	*Emilia discifolia*	X	√
Amaranthaceae	*Cyathula cylindrica*	√	√	Asteraceae	*Euryops chrysanthemoides*	√	√
Anacardiaceae	*Rhus longipes*	√	√	Asteraceae	*Galinsoga parviflora*	X	√
Anacardiaceae	*Rhus vulgaris*	x	√	Asteraceae	*Galinsoga quadriradiata*	X	√
Apiaceae	*Agrocharis incognita*	√	X	Asteraceae	*Gamochaeta purpurea*	X	√
Apiaceae	*Coriandrum sativum*	x	√	Asteraceae	*Gutenbergia cordifolia*	√	√

Apocynaceae	*Acokanthera oppositifolia*	√	X	Asteraceae	*Helichrysum schimperi*	√	√
Apocynaceae	*Acokanthera schimperi*	√	X	Asteraceae	*Helichrysum odoratissimum*	√	x
Apocynaceae	*Landolphia buchananii*	√	X	Asteraceae	*Hypochaeris glabra*	X	√
Apocynaceae	*Oncinotis tenuiloba*	√	X	Asteraceae	*Lactuca inermis*	√	√
Apocynaceae	*Pleiocarpa pycnantha*	√	X	Asteraceae	*Microglossa densiflora*	√	x
Apocynaceae	*Rauvolfia mannii*	√	X	Asteraceae	*Microglossa sp.*	√	x
Apocynaceae	*Tabernaemontana stapfiana*	√	X	Asteraceae	*Mikania chenopodiifolia*	X	√
Araceae	*Colocasia esculanta*	x	√	Asteraceae	*Osteospermum vaillantii*	X	√
Araliaceae	*Cussonia spicata*	√	√	Asteraceae	*Psiadia punctulata*	√	x
Araliaceae	*Polyscias sp.*	√	X	Asteraceae	*Richardia braziliensis*	√	x
Arecaceae	*Phoenix reclinata*	√	√	Asteraceae	*Senecio deltoideus*	√	x
Asparagaceae	*Asparagus falcatus*	√	X	Asteraceae	*Senecio syringifolius*	√	x
Asteraceae	*Solanecio mannii*	√	√	Cyperaceae	*Kyllinga brevifolia*	√	√
Asteraceae	*Sonchus oleraceus*	x	√	Cyperaceae	*Kyllinga pumila*	X	√
Asteraceae	*Tagetes minuta*	√	√	Dennstaedtiaceae	*Pteridium aquilinum*	√	√
Asteraceae	*Tithonia diversifolia*	x	√	Dichapetalaceae	*Dichapetalum eickii*	√	x
Asteraceae	*Tridax procumbens*	x	√	Dracaenaceae	*Dracaena laxissima*	√	x
Asteraceae	*Vernonia aemulans*	x	√	Euphorbiaceae	*Acalypha volkensii*	√	√
Asteraceae	*Vernonia auriculifera*	√	√	Euphorbiaceae	*Bridelia micrantha*	√	x
Asteraceae	*Vernonia galamensis*	√	√	Euphorbiaceae	*Clutia abyssinica*	√	√
Asteraceae	*Vernonia hochstetteri*	x	√	Euphorbiaceae	*Drypetes gerrardii*	√	x
Asteraceae	*Vernonia lasiopus*	√	√	Euphorbiaceae	*Euphorbia heterophylla*	X	√
Asteraceae	*Vernonia usambarensis*	√	√	Euphorbiaceae	*Euphorbia engleri*	√	x
Basellaceae	*Basella alba*	√	√	Euphorbiaceae	*Macaranga conglomerata*	√	x
Brassicaceae	*Erucastrum arabicum*	x	√	Euphorbiaceae	*Manihot esculenta*	X	√
Brassicaceae	*Lepidium bonariense*	x	√	Euphorbiaceae	*Meineckia ovata*	√	x
Burseraceae	*Commiphora eminii*	x	√	Euphorbiaceae	*Neoboutonia macrocalyx*	√	x

Campanulaceae	*Cyperus cyperoides*	√	√	Euphorbiaceae	*Phyllanthus odontadenius*	X	√
Campanulaceae	*Lobelia holstii*	√	X	Euphorbiaceae	*Phyllanthus sp.*	√	x
Capparaceae	*Ritchiea albersii*	√	X	Euphorbiaceae	*Ricinus communis*	√	√
Caryophyllaceae	*Drymaria cordata*	x	√	Flacourtiaceae	*Aphloia theiformis*	√	x
Caryophyllaceae	*Silene gallica*	x	√	Flacourtiaceae	*Dasylepis integra*	√	x
Celastraceae	*Apodostigma sp.*	√	X	Flacourtiaceae	*Dovyalis abyssinica*	√	x
Celastraceae	*Simirestis goetzei*	√	X	Icacinaceae	*Apodytes dimidiata*	X	√
Commelinaceae	*Aneilema aequinoctiale*	√	X	Lamiaceae	*Aeollanthus repens*	√	x
Commelinaceae	*Commelina benghalensis*	x	√	Lamiaceae	*Clerodendrum johnstonii*	√	x
Commelinaceae	*Commelina diffusa*	x	√	Lamiaceae	*Hyptis pectinata*	X	√
Commelinaceae	*Cyathula sp.*	√	X	Lamiaceae	*Leucas grandis*	X	√
Commelinaceae	*Murdannia simplex*	x	√	Lamiaceae	*Leucas deflexa*	√	x
Convolvulaceae	*Ipomoea wightii*	√	√	Lamiaceae	*Ocimum gratissimum*	√	√
Crassulaceae	*Kalanchoe densiflora*	√	√	Lamiaceae	*Plectranthus sp.*	X	√
Cruciferae	*Brassica oleracea*	x	√	Lamiaceae	*Plectranthus barbatus*	√	x
Cucurbitaceae	*Cucubita sp.*	x	√	Lamiaceae	*Plectranthus sp.*	√	x
Cucurbitaceae	*Cucumis sp*	x	√	Lamiaceae	*Plectranthus sp.2*	√	x
Cupressaceae	*Cupressus lusitanica*	√	X	Lamiaceae	*Pycnostachys umbrosa*	X	√
Cyperaceae	*Cyperus distans*	x	√	Lamiaceae	*Vitex keniensis*	√	x
Cyperaceae	*Cyperus maranguensis*	√	√	Lauraceae	*Persea americana*	X	√
Cyperaceae	*Cyperus sp.*	√	X	Leguminosae	*Acacia mearnsii*	√	x
Leguminosae	*Albizia gummifera*	√	√	Myrtaceae	*Syzygium sp.*	√	x
Leguminosae	*Caesalpinia decapetala*	√	√	Ochnaceae	*Ochna holstii*	√	x
Leguminosae	*Chamaecrista sp.*	x	√	Olacaceae	*Strombosia scheffleri*	√	x
Leguminosae	*Craibia zimmermannii*	√	X	Onagraceae	*Ludwigia abyssinica*	X	√
Leguminosae	*Dalbergia lactea*	√	X	Oxalidaceae	*Oxalis corniculata*	√	√
Leguminosae	*Desmodium sandwicense*	x	√	Passifloraceae	*Passiflora edulis*	√	x

Leguminosae	*Indigofera arrecta*	x	√	Phyllanthaceae	*Margaritaria discoidea*	√	x
Leguminosae	*Millettia oblate*	√	X	Phytolaccaceae	*Phytolacca dodecandra*	√	x
Leguminosae	*Newtonia buchananii*	√	X	Piperaceae	*Piper capense*	√	x
Leguminosae	*Pterolobium stellatum*	√	X	Poaceae	*Digitaria abyssinica*	X	√
Leguminosae	*Senna septemtrionalis*	√	√	Poaceae	*Digitaria velutina*	√	√
Leguminosae	*Senna didymobotrya*	√	X	Poaceae	*Digitaria abyssinica*	√	x
Leguminosae	*Phaseolus vulgaris*	x	√	Poaceae	*Ehrharta erecta*	√	x
Loganiaceae	*Buddleja pulchella*	√	X	Poaceae	*Eleusine indica*	√	√
Malvaceae	*Abutilon sp.*	√	X	Poaceae	*Eragrostis aspera*	X	√
Malvaceae	*Hibiscus fuscus*	√	√	Poaceae	*Eragrostis tenuifolia*	√	√
Malvaceae	*Hibiscus vitifolius*	x	√	Poaceae	*Eragrostis schweinfurthii*	√	x
Malvaceae	*Hibiscus berberidifolius*	√	X	Poaceae	*Melinis repens*	X	√
Malvaceae	*Pavonia urens*	x	√	Poaceae	*Oplismenus sp.*	√	x
Malvaceae	*Triumfetta rhomboidea*	√	√	Poaceae	*Panicum trichocladum*	√	√
Meliaceae	*Ekebergia capensis*	√	X	Poaceae	*Panicum sp.*	√	x
Meliaceae	*Lepidotrichilia volkensii*	√	X	Poaceae	*Pennisetum clandestinum*	X	√
Meliaceae	*Turraea holstii*	√	X	Poaceae	*Pennisetum purpureum*	√	√
Melianthaceae	*Bersama abyssinica*	√	X	Poaceae	*Saccharum officinarum*	X	√
Menispermaceae	*Tiliacora funifera*	√	X	Poaceae	*Setaria megaphylla*	√	x
Monimiaceae	*Xymalos monospora*	√	X	Poaceae	*Setaria sp.*	√	x
Moraceae	*Ficus sur*	x	√	Poaceae	*Sporobolus pyramidalis*	√	√
Moraceae	*Ficus ottoniifolia*	√	X	Poaceae	*Sporobolus sp.*	√	x
Moraceae	*Morus sp.*	√	√	Poaceae	*Zea mays*	X	√
Musaceae	*Musa SP.*	√	√	Polygonaceae	*Oxygonum sinuatum*	X	√
Myricaceae	*Myrica salicifolia*	√	X	Polygonaceae	*Polygonum nepalense*	X	√
Myrsinaceae	*Maesa lanceolata*	√	√	Polygonaceae	*Polygonum salicifolium*	X	√

Myrsinaceae	*Rapanea melanophloeos*	√	X	Polygonaceae	*Rumex abyssinicus*	X	√
Myrtaceae	*Eucalyptus sp.*	√	X	Proteaceae	*Grevillea robusta*	√	√
Myrtaceae	*Psidium guajava*	√	√	Proteaceae	*Macadamia tetraphylla*	√	√
Pteridaceae	*Pteris usambarensis*	x	√	Rutaceae	*Toddalia asiatica*	√	x
Ranunculaceae	*Clematis brachiata*	√	X	Rutaceae	*Vepris simplicifolia*	√	x
Rhamnaceae	*Gouania longispicata*	√	X	Salicaceae	*Trimeria grandifolia*	√	x
Rosaceae	*Eriobotrya japonica*	√	X	Sapindaceae	*Allophylus abyssinicus*	√	x
Rosaceae	*Prunus Africana*	√	X	Sapindaceae	*Deinbollia kilimandscharica*	√	x
Rosaceae	*Rubus apetalus*	√	√	Sapindaceae	*Dodonaea viscosa*	√	√
Rosaceae	*Rubus sp.*	√	√	Sapotaceae	*Englerophytum natalensis*	√	x
Rosaceae	*Rubus pinnatus*	√	X	Scrophulariaceae	*Cycnium herzfeldianum*	√	√
Rosaceae	*Rubus scheffleri*	√	X	Simaroubaceae	*Brucea antidysenterica*	√	x
Rubiaceae	*Coffea Arabica*	√	X	Solanaceae	*Physalis peruviana*	X	√
Rubiaceae	*Heinsenia diervilleoides*	√	X	Solanaceae	*Solanum campylacanthum*	X	√
Rubiaceae	*Keetia gueinzii*	√	X	Solanaceae	*Solanum lycopersicum*	X	√
Rubiaceae	*Mitracarpus villosus*	x	√	Solanaceae	*Solanum scabra*	X	√
Rubiaceae	*Oxyanthus speciosus*	√	X	Solanaceae	*Solanum sp.*	√	√
Rubiaceae	*Pentas zanzibarica*	√	√	Solanaceae	*Solanum incanum*	√	x
Rubiaceae	*Psychotria lauracea*	√	X	Solanaceae	*Solanum schumannianum*	√	x
Rubiaceae	*Psychotria pseudoplatyphylla*	√	X	Solanaceae	*Solanum terminale*	√	x
Rubiaceae	*Psychotria sp.*	√	X	Sterculiaceae	*Cola greenwayi*	√	x
Rubiaceae	*Psydrax parviflora*	√	X	Sterculiaceae	*Leptonychia usambarensis*	√	x
Rubiaceae	*Psydrax sp.*	√	X	Thelypteridaceae	*Christella chaseana*	X	√
Rubiaceae	*Richardia scabra*	√	√	Thelypteridaceae	*Christella dentata*	X	√
Rubiaceae	*Rytigynia eickii*	√	X	Thelypteridaceae	*Christella gueinziana*	X	√

Rubiaceae	*Rytigynia uhligii*	√	X	Thymelaeaceae	*Dicranolepis usambarica*	√	x
Rubiaceae	*Spermacoce princeae*	√	X	Ulmaceae	*Celtis africana*	√	x
Rubiaceae	*Vangueria infausta*	√	X	Ulmaceae	*Trema orientalis*	√	x
Rubiaceae	*Vangueria volkensii*	√	X	Urticaceae	*Urera hypselodendron*	√	x
Rutaceae	*Clausena anisata*	√	X	Urticaceae	*Urera trinervis*	√	x
Rutaceae	*Fagaropsis angolensis*	√	X	Verbenaceae	*Lantana camara*	√	√
Vitaceae	*Cissus olivieri*	√	X				

Key: √ for presence in the habitat and X absence of plant species along the forest edge and adjoining farmlands

3.4.7 Relationship between plant species and butterfly species

There was a highly positive correlation between plant species and butterfly species (R=0.9291) (Fig 5). There was no correlation between plant species between plants and butterfly species in the farmlands

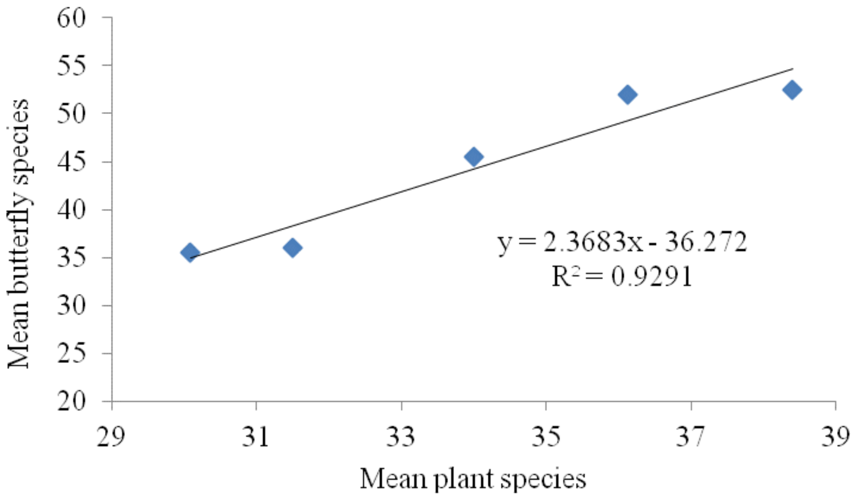

Figure 3. 5**: Relationship between butterfly species and plants species along forest edge transect.**

3.5 Discussion

Ngangao forest is one of the remaining indigenous cloud forest fragments in Taita Hills harbors high diversity of butterfly species and abundance. The high diversity can be attributed to the nature of the forest as it is mainly consisting of indigenous flora with minimal human disturbance. Also, the high diversity and abundance can be linked to the location of Taita Hills in the Eastern Arc Mountains known to be among the world's biodiversity hotspots, highly rich in diversity of both flora and fauna. Butterfly studies in Kenya have been focused in coastal forests and Kakamega forest. A study in Arabuko Sokoke forest (Ayiemba, 1995) recorded 134 species, Muhaka forest and Mrima forest (Rogo & Odulaja 2001), recorded 63 species in each forest and Kaya Muhaka forest recorded 97 species (Chiawo *et al*., 2011). In Kaya Muhaka Lehmann and Kioko (2000) recorded 112 butterfly species. A study by Namu *et al*., (2008) recorded 169 butterfly species from three forest types. The family Nymphalidae recorded the highest number of species observed in both habitats followed by Lycaenidae. Family Papilionidae recorded the lowest number of species in both habitats (Table 1). The family species composition is in agreement with other butterfly studies in the tropics (Rogo & Odulaja, 2001; Namu *et al*., 2008; Chiawo *et al*., 2011 and Munyuli, 2012). This also concurs with diversity of Kenya butterflies as recorded by Larsen (1991) with Nymphalidae 38.4%, Lycaenidae 31.1% and Papilionidae 3.1% of total butterfly in Kenya.

The forest edge recorded significantly higher butterfly species and abundance compared to the surrounding farmlands. Species richness was higher in the forest edge than the farmlands. These concurs with Chiawo *et al*., (2011), where more butterfly species were recorded along the forest edge in Kaya Muhaka forest. Higher floral resources on the forest edge could be contributing to the higher species diversity and abundance. This shows that the forests and forest edges are important in maintaining high diversity of butterflies. According to Majumder *et al*., (2012), mature secondary forests are important in butterfly communities while disturbed environments have a negative impact on species composition. Baz and Garcia-Boyero, (1995), butterflies exhibit specific habitat requirements like adequate numbers of a single or a few host-plants for oviposition and nectar-source plants. Lower diversity and abundance of butterflies was recorded in the farmlands. The farmlands have undergone a series of disturbances like pesticide use interfering with the composition within the farmlands.

Taita Hills are characterized by high endemism in both fauna and flora. Three butterfly species endemics to the Taita Hills were recorded; *Papilio desmondi teita*, *Cymothoe teita*, and *Charaxes xiphares desmondi*. *Cymothoe teita* (Van Someren), is limited to the montane forests of Taita Hills (Larsen, 1991) and was only recorded along the forest edge. Its food plant

Dasylepis integra Warb (Flacourtiacea) is endemic to Eastern Arc Mountains (Rogers *et al*., 2008) and is only found within indigenous forests fragments. Collins & Morris, (1985) and Larsen (1991) reported *Cymothoe teita* as endangered that it will not survive the destruction of the natural forest fragments in Taita Hills. This study ascertains to the previous findings as it only recorded in the forest edge where the larval host plant is found. *Papilio desmondi teita* (Van Someren), known to be montane species was recorded in both habitats but more abundant in forest edge. The species was reported to be a threatened species (Collins & Morris, 1985), but Larsen (1991) disputed this claim as the species can survive effectively away from the natural forest fragments. From the study, the species may not be threatened as suggested as it occurs in high numbers and away from the natural forests. *Charaxes xiphares desmondi* (Van Someren), a specialist of cool semi-montane habitat is endemic to Taita Hills (Larsen, 1991). This species was only recorded along the forest edge and not on the farmlands signifying specialization in forest habitat.

The wet season recorded significantly high butterfly species diversity compared to the dry season. The difference in diversity mainly occurred between farmland dry season and forest edge wet season and between forest edge wet season and farmland wet season. This finding does not concur with Roy *et al*., (2001) where more butterflies are recorded in summer within British butterfly populations. The seasonal difference in butterfly diversity may be due reduction in floral resources in the farmlands during dry season. During dry season, the seasonal weeds and other shrubs in the farmlands dry up reducing food resources for butterflies (Pollard. 1988). There was no significant difference in diversity in season in the forest edge. This is because there is less change in forest vegetation between wet and dry season.

A high positive correlation occurred between plant species and butterfly species on the forest edge. This may be due to presence of some food plants for the developmental stages of butterflies and adequate floral resources for mature butterflies. This is in agreement with findings by Stein *et al*., (2014) that diversity richness increases with heterogeneity of the habitat in terms of available plant species. Host plants for butterflies are very important in maintaining butterfly species in a locality. *Cymothoe teita,* endemic to Taita Hills (Velzen *et al*., 2016) oviposit on *Daslepis integra,* Warb endemic to EAM (Rogers *et al*., 2008) as host plant. Both were only recorded in the forest edge. This depicts strong association between plant species and butterfly species in a locality. Similarly, *Charaxes xiphares desmondi* endemic to Taita Hills has larval food plant as Euphorbiaceae (*Drypetes*) (Larsen, 1991). Both were only recorded at the forest edge. There was no correlation between plant species and butterfly species in the farmlands. This may be due human disturbances like pesticide use which affect butterfly species composition.

3.6 Conclusion

It is evident that Ngangao forest harbors a high diversity, abundance and endemism of butterfly species. Based on this study, *Cymothoe teita* and is under threat due to deforestation and encroachment of the natural forests by farmers, therefore the survival of this species is under threat. This species, *C. teita* is therefore highly recommended for listing under the IUCN Redlist for threatened species. There is need to conserve the butterfly species found within the Ngangao forest and farmlands. The indigenous forests are key in maintenance of the high butterfly diversity recorded in this area. There is need for protection and conservation of the few remaining indigenous forests in Taita Hills, which are under threat from anthropogenic disturbances and climate change. Need for further research to determine how the anthropogenic activities on the farmlands could be affecting the diversity and abundance of these important pollinators.

CHAPTER FOUR

FARMERS' PESTICIDE USE PRACTICES AND PERCEPTION ON INSECT POLLINATORS AND POLLINATION IN TAITA HILLS, KENYA.

Abstract

Chemical pesticides are commonly used in control in pests and diseases but often at the expense of environment and biodiversity in general. Chemical use poses a threat to insect pollinators, which help in enhancing the quality and quantity of agricultural produce. Farmers' perception on insect pollinators may have influence on how they conserve them. The objective of this study was to investigate and document farmers' pesticide use practices and their perception on insect pollinators. A survey was conducted in farming villages surrounding Ngangao Forest, Taita Hills between March and April 2018. Seventy farmers were randomly sampled within ten farming villages and a written questionnaire administered to them.

It was found that 29 chemical pesticide active ingredients belonging to 14 chemical groups were used against different pests and diseases in the area. The most commonly used chemical groups were synthetic pyrethroids and organophosphate with 49.2% and 20.7% frequencies, respectively. Over 80% follow the recommended rates of chemical application as stated on the label. Farmers dispose used chemical pesticide containers in three main ways; burning 47.1%, burying 24.3%, in pit latrine 15.7% with few farmers disposing them in dustbin, leaving them in the field or disposing in nearby bushes. More than half of the farmers, 61.4% are not trained on pesticide use. Majority of the farmers 90% know about beneficial insects including insect pollinators. More than half of the farmers 62.9% were aware that insect pollinators are important in agriculture enhancing fruit, seed and pod set. This study recommends increase in farmer training in selection and safe use of chemical pesticides. There is also need for awareness creation on conservation of insect pollinators through integrated pest and pollinator

management methods (IPPM) and management of pollinator habitat through creation of hedgerows and conserving the natural forests.

Keywords: Insect pollinators, Farmers perception, Pesticides, Pollinator Conservation, Taita Hills

4.1 Introduction

Pollinating insects have been undergoing a decline in abundance, occurrence, and diversity in many parts of the world (Ollerton *et al*., 2014; Potts *et al*., 2016). The decline in pollinators is of much concern because it represents a critical ecosystem service (Garibaldi *et al*., 2013). Loss of both wild and managed pollinators may negatively affect food production as many crop types rely, at least to some extent, on pollination for the quantity and/or quality of their yield (Klein *et al*., 2007). The decline in pollinators is alarming that it raises questions regarding food security and stability of ecosystems functions (Potts *et al*., 2010). Assessment of insect pollinators at national and regional levels show high levels of threat mainly for bees and butterflies (Van Sway *et al*., 2010).

Several anthropogenic drivers are threatening the abundance, diversity and health of wild and managed pollinators, and the pollination services they provide to wild plants and crop (Vanbergen, & Insect Pollinators Initiative, 2013). The drivers for the decline in insect pollinators worldwide include habitat transformation or fragmentation (Kennedy *et al*., 2013), loss of diversity and abundance of floral resources (Kremen *et al.,* 2007), inappropriate use of pesticides (Pettis *et al.,* 2013) and climate change (Schweiger *et al.,* 2010).

The risk to pollinators from pesticides arises through a combination of toxicity and the level of exposure (Potts *et al.,* 2016). The magnitude of risk of pollinators from pesticides depends on chemical compounds used and scale of land management. Under controlled environments, pesticides like neonicotinoid exhibit a broad range of lethal and sublethal effects on insect pollinators (van der Sluijs *et al.*, 2015; Godfray *et al.*, 2015). Depending on the concentration of pesticides exposed to pollinators, pesticides may reduce pollination service provided by the pollinators (Stanley et al., 2015). According to Rundlöf *et al.* (2015) actual field exposure of wild pollinators to a neonicotinoid resulted to their reduced survival and reproduction.

Pollinators exposure to pesticides can be lessened through various methods including adoption of alternative forms to pest control, reduction in chemical pesticide use and adopting pesticide application practices which safeguard pollinators (Johansen *et al.*, 2013). Integrated pest management practices can also help in minimizing pesticide exposure (Ekström & Ekbom, 2011). Traninig of farmers on safe use of pesticides and reduction of pesticide use in agricultural setting can protect the pollinators from pesticide exposure (Waddington *et al.*, 2014).

Despite the important role of insect pollinators in agricultural production and the continued use of pesticides by small-scale farmers, there is inadequate information on farmers' pesticide use practices, which might pose a threat to the pollinators. There is also limited information on farmers' perception on insect pollinators and pollination services. The objective of this study was to document farmer' pesticide use practices and their perception on insect pollinators and pollination service in Taita Hills.

4.2 Materials and Methods

4.2.1 Description of the study site

The study was conducted in Taita Hills, in farming villages adjacent to Ngangao Forest. The forest is an indigenous cloud forest within Taita Hills which is placed 03025'S, 38020'E.). It lies 10 Km from Wundanyi town with an altitude ranging from 1700 m to 1900 m a.s.l. The study area has two distinct rain seasons, short rain season and long rain season (Odanga, 2017).

The mean annual rainfall in Taita Hills is about 1500ml and the mean temperature is 25^0C. The forest is surrounded by small-scale farms where intensive cultivation is practiced. Both rains fed agriculture and small-scale irrigation carried out. The neighboring farms receive ecosystem services provided by the forest like pollination service. Farmers were sampled from a total of 10 villages; Maghimbinyi, Kimanghachugu, Marumange, Kishenyi, Mashighi, Matasenyi, Mraru, Mchonyi, Kitumbi and Kichi-Kirema (Figure 5)

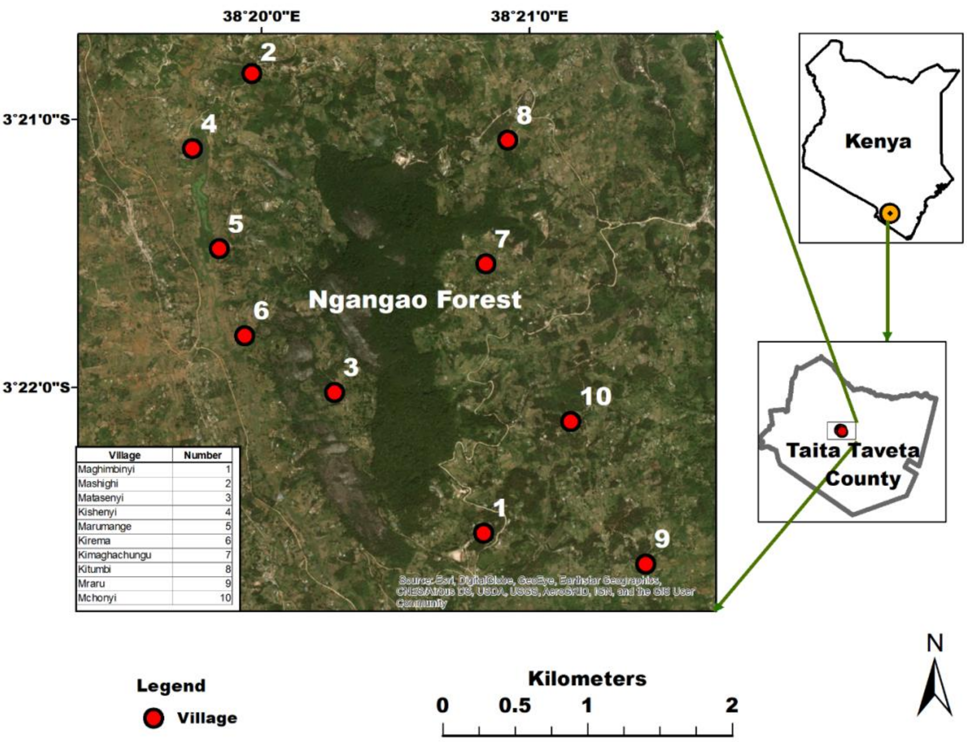

Figure 4. 1**: Sampled villages adjacent to Ngangao Forest, Taita Hills (Developed using ArcGIS, ILRI database)**

4.2.2 Sampling and data collection

Data was collected in March and April 2018. The target group was farmers practicing crop farming, both rains fed or in irrigation set up in the villages adjacent to Ngangao forest. To test the validity and reliability of the information collected, the questionnaire was pre-tested with 10 farmers who were farmers in the study area and were not included in the main data collection. The pre-test further helped in refining the questions to ensure uniformity in understanding by all respondents. Seventy respondents (farmers) were determined using Single population Proportion Formula in the survey study area. A total of 10 villages adjacent to Ngangao forest were sampled and 7 farmers were randomly selected from each village. The interviews were conducted face to face by the researcher and assisted by a member of the local community who had been trained on the concepts and contents of the questionnaire. The questionnaire was facilitated in both English and the local language. In each case, consent was first sought to participate in the survey from the respondents and then provided the explanation for the purpose of the survey which was to investigate farmers' pesticide practices and their perception on insect pollinators and pollination. After developing a rapport with the respondent, each interview took about 20 minutes to complete allowing ample time to express their true experience on chemical pesticide use practices, awareness on insect pollinators and pollinations services and conservation of insect pollinators.

4.3 Data analysis

Data from the questionnaires filled during the interview were checked to ensure completeness, then coded and entered into spreadsheet using Statistical Package for Social Sciences (SPSS) software version 22. Descriptive statistics such as frequency distributions, means, and percentages were analyzed.

4.4 Results

4.4.1 Demographic information

All the targeted farmers (70) responded to the structured questionnaires during the survey. Male respondents were dominant gender (82.9%; n=58). About 38.6% (n=27) of respondents were aged 35-45 years old followed by the age group 25-35 years with 28.6% (n=20). About 1.4% of the respondents were less than 25 years of age. Overall, the level of education was high with more than 50% having secondary and post-secondary education and only less than 3% had no formal education. The main occupation of the respondents was farming (92.9%; n=65) who inherited (81.4%) the land from the forefathers (Table 4.1). Land size in the study area is small scale. The average land size owned by the farmers is 1.84 acres (Standard deviation 1.4) while the maximum land size is 6.7 acres and the minimum at 0.25 acres.

Table 4. 1**: Socio-demographic characteristics of surveyed farmers in Taita Hills**

Variable	Frequency (No)	Frequency (%)
Gender		
Male	58	82.9
Female	12	17.1
Age		
Less 25 years	1	1.4
25-35 years	20	28.6
36-45 years	27	38.6
46-55 years	13	18.6
>55 years	9	12.9
Marital status		
Single	10	14.3
Married	58	82.9
Divorced	1	1.4
Widowed	1	1.4
Level of education		
No formal education	2	2.9
Primary education	32	45.7
Secondary education	31	44.3
Post secondary education	5	7.1
Occupation		
Farming activities	65	92.9
Off farm activities	4	5.7
Business	1	1.4
Land ownership		
Purchased	6	8.6
Inheritance	57	81.4
Rented	7	10.0

4.4.2 Crops grown by farmers and their pests

Farmers in Taita Hills carry out small-scale farming for subsistence use and for sale. The crops are grown in mixed farming systems. The common grown food crops in the area are 17 with Maize 80%, Kales 75.7%, cabbage 52.9 %, and common beans 50% as the commonly grown (Table 4.2). The average number of crops grown per farmer is six crops per season in the field mixed within the small pieces of land.

Table 4. 2**: Crops grown by farmers adjacent to Ngangao forest, Taita Hills**

Crop	Scientific name	Frequency (No)n=70	Frequency (%)
Maize	*Zea mays*	56	80
Kales	*Brassicae*	57	75.7
Cabbage	*Brassicae*	37	52.9
Common Beans	*Phaseolus vulgaris L.*	35	50
Tomatoes	*Solanum lycopersicum*	32	45.7
Spinach	*Spinacia oleracea*	29	41.4
French beans	*Phaseolus vulgaris*	27	38.6
Courgettes	*Cucurbita sp*	22	31.4
Lettuce	*Lactuca sativa*	15	21.4
Cucumber	*Cucumis sativus*	14	20
African Nightshade	*Solanum sp*	14	20
Potatoes	*Solanum tuberosum*	10	14.3
Chillies	*Capsicum sp*	9	12.9
Cauliflower	*Brassica sp*	8	11.4
Onions	*Allium cepa*	7	10
Snow Peas	*Pisum sativum*	7	10
Macadamia	*Macadamia integrifolia*	6	8.6

Different insect pests affect crops in Taita Hills. Based on the total farmer respondents (n=70), 92.5 % recorded that aphids are a major pest to their crops. Other insect pests encountered by farmers included whiteflies 80%, fall armyworm 64.3 %, cutworm 62.9 %, *Tuta absoluta* 32.9%, beetles 31.4%, and diamondback moth 25.7% (Table 4.3). Infestation of crops by insect pests in Taita Hills is a problem as all the respondents reported presence of insect pests in their farms. More than 90% of respondents observed insect pests attacking their crops more than once every crop season.

Table 4. 3**: Insect pests frequently observed by farmers infesting their crops**

Pest	Frequency (No)	Frequency (%)
Aphids	65	92.5
Whiteflies	56	80
Fall Armyworm	45	64.3
Cutworm	44	62.9
Tuta Absoluta	23	32.9
Beetles	22	31.4
Diamondback moth	18	25.7
Grasshoppers	9	12.9
Spider mites	7	10
Leaf miners	4	5.7
Thrips	2	2.9

4.4.3 Chemical use practices by farmers

All the farmers in Taita Hills use chemical pesticides to manage pests in their farms. Different chemicals in different chemical groups were used and at different rates. A total of 29 active ingredients were recorded belonging to 14 chemical groups were recorded. The chemicals recorded were of different WHO class. The highly common chemical active ingredients were Labda-Cyhalothrin (77.1%), Alpha-Cypermethrin (70%), Chloropyriphos 62.9% and Cypermethrin 62.9%. Synthetic pyrethroid and organophosphates were the highly used chemical groups. (Table 4.4)

Table 4. 4**: List of chemical active ingredients used by farmers with their chemical group, WHO class and percentage frequencies**

S/N	Active ingredient	Chemical group	WHO class	% Frequency
1	LabdaCyhalothrin	Synthetic Pyrethroid	II	77.1
2	AlphaCypermethrin	Synthetic Pyrethroid	II	70
3	Chloropyriphos	Organophosphates	II	62.9
4	Cypermethrin	Synthetic Pyrethroid	II	62.9
5	Mancozeb	Dithio carbamate	III	31.4
6	Diazinon	Organophosphates	I	27.1
7	Emmamectin_Benzoate	Avermectin	II	25.7
8	Metalaxyl	Acylalamines	III	14.3
9	Flubendiamide	Flubediamide	II	11.4
10	Deltamethrin	Synthetic Pyrethroid	II	10
11	Propineb	Dithio carbamate	II	8.6
12	Abamectin	Avermectin	II	7.1
13	Azoxystrobin	methoxy-acrylates	II	5.7
14	Chlorantraniliprole	Chlorantraniliprole	U	5.7
15	Cymoxanil	cyanoacetamide-oxime	III	4.3
16	Oxymatrine	Oxymatrine	U	4.3
17	Thiamethoxam	Neonicotinoid	II	4.3
18	Acetamiprid	Neonicotinoid	II	2.9
19	BetaCyfluthrin	Synthetic Pyrethroid	II	2.9
20	Difenoconazole	Triazoles	II	2.9
21	Triadimefon	Triazoles	III	2.9
22	Carbendazim	Benzimidazoles	III	1.4
23	Ethoprophos	Organophosphates	II	1.4
24	Flusilazole	Triazoles	III	1.4
25	Lufenuron	Benzoylureas	II	1.4
26	Methomyl	Carbamates	I	1.4
27	Permethrin	Synthetic Pyrethroid	II	1.4
28	Triazophos	Organophosphates	II	1.4
29	Trichlorfon	Organophosphates	II	1.4

The chemicals used by farmers belonged to different WHO classes. WHO class II had the highest number of chemical groups and percentage usage by farmers with 19 chemical groups and 79.3 % usage by the farmers. WHO class I had 2 chemical groups with 6.3% usage, WHO class III had 6 chemical groups with 12.2% usage by farmers while WHO class U, had 2 chemical groups with 2.2% farmer usage (Figure 4.2)

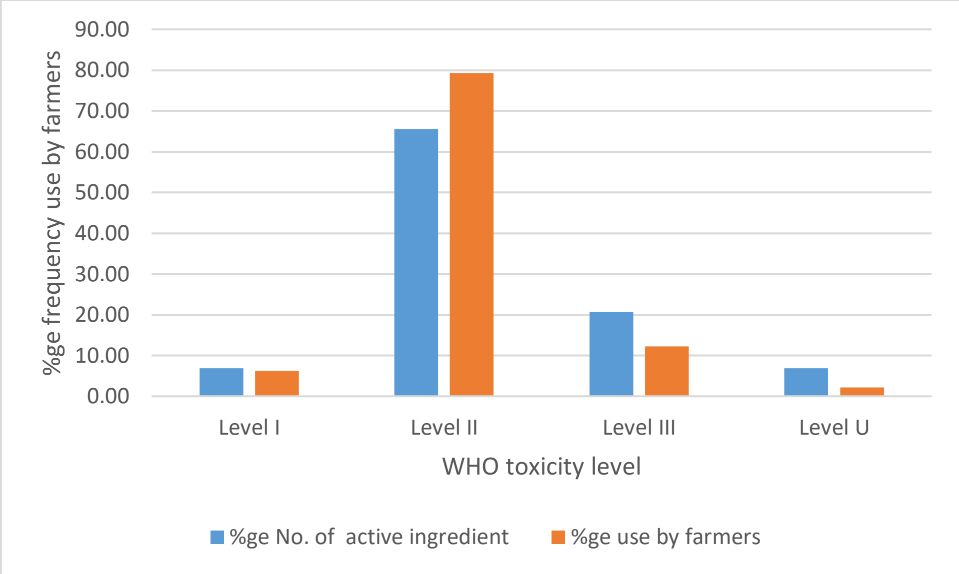

Figure 4. 2**: WHO classifications of chemicals pesticides used by farmers**

The frequency of chemical pesticide use varied significantly among the respondents. More than 50% of farmers applied chemicals more than thrice in their crops per season. This significantly varied with the lower number (4%) of the farmers' who applied chemicals only once per season (Figure 4.3)

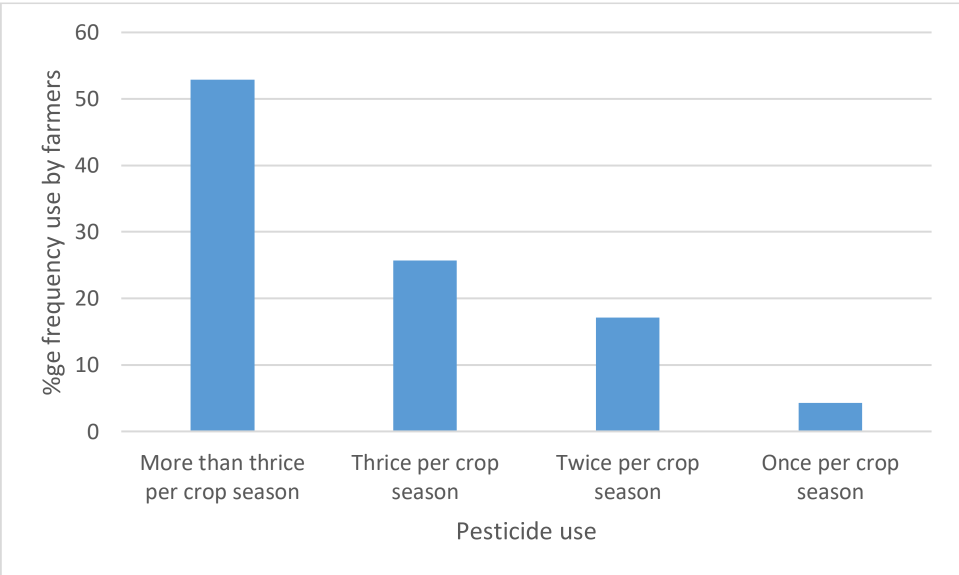

Figure 4. 3**: Frequency of chemical pesticides usage by farmers in a season**

Most of the farmers spray chemicals early morning and late evening 81.4%, with 14.3% spraying anytime of the day while 4.3% of the farmers sprayed mid of the day. The weather condition at which the farmers spray chemicals mainly was when the weather is cold and calm 95.7%.

All the farmers sampled were in a position to get information on the recommended amount of chemical use. 80% of the farmers get the recommended rate of chemical use by reading from the labels (Figure 4.4)

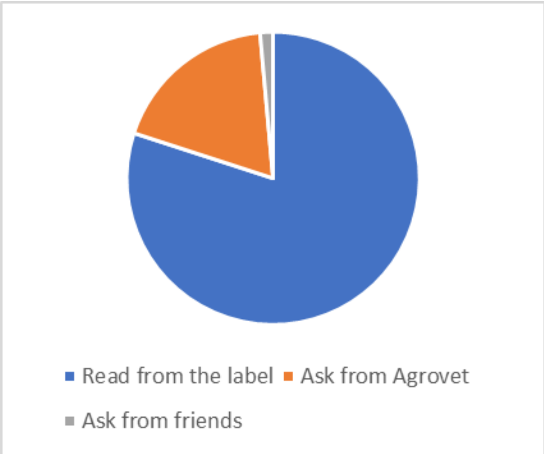

Figure 4. 4**: Ways in which farmers know the recommended rate for chemical pesticides application.**

Farmers dispose used pesticide containers in different ways. The most commonly used method of disposal of used pesticide containers is through burning 47.1%. Other methods used by the farmers included burying (24.3%), throwing into pit latrines (15.7%), placing them in dustbins (5.7%), leaving in the farm (4.3%) and disposing them in the nearby bushes (2.9%) (Figure 4.5). More than half of the farmers surveyed were not trained on pesticide use (61.4%).

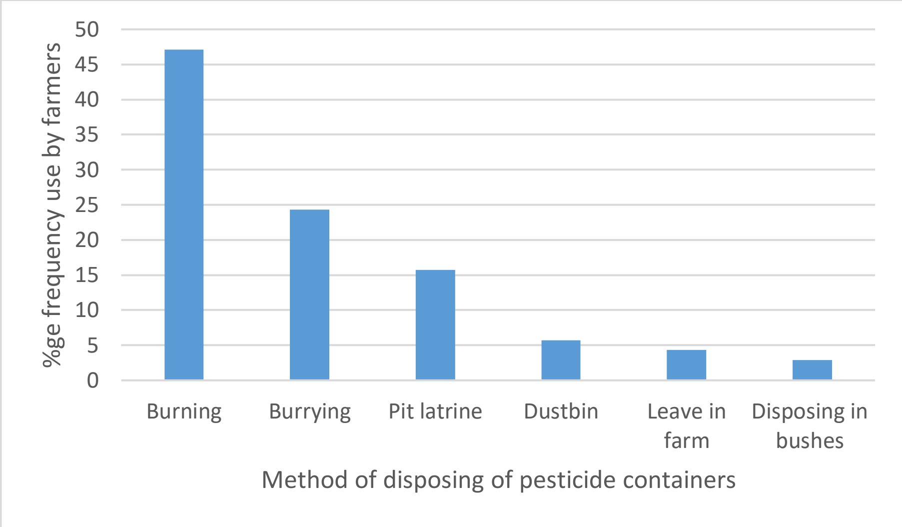

Figure 4. 5**: Methods of disposing of empty pesticide containers in Taita Hills**

4.4.4 Farmers' perception on insect pollinators and pollination

More than 90% of the farmers in the research area were aware of beneficial insects and they were also aware of the effects of pesticides to beneficial insects (Figure 4.6). Similarly, farmers awareness on some of the beneficial insects are pollinators followed the same trend, with more than 90% of farmers in the study area being aware that some beneficial insects carry out pollination service (Figure 4.6).

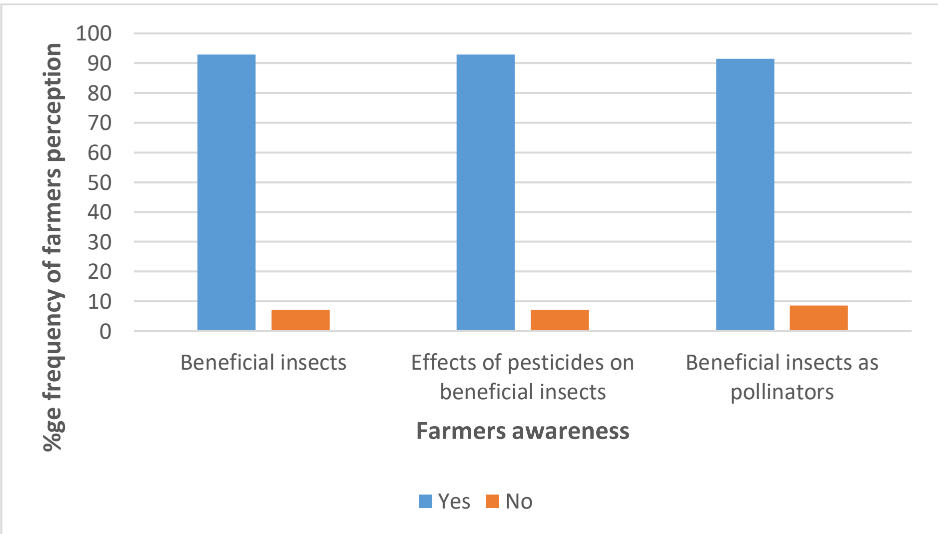

Figure 4. 6**: Farmers' awareness on beneficial insects, and the effects of pesticide use on beneficial insects.**

Farmers were aware that different insect visit flowers of different crops in their farms. The most common flower visitor observed by the farmers were the bees with 98.6% of the farmers observing bees visiting flowers in the field. Other flower visitors observed by farmers visiting their crops are butterflies (77.1%), Wasps (44.3%), ants (28.6%), Flies (20%), carpenter bees (5.7%) and ladybird (5.7%) (Figure 4.7).

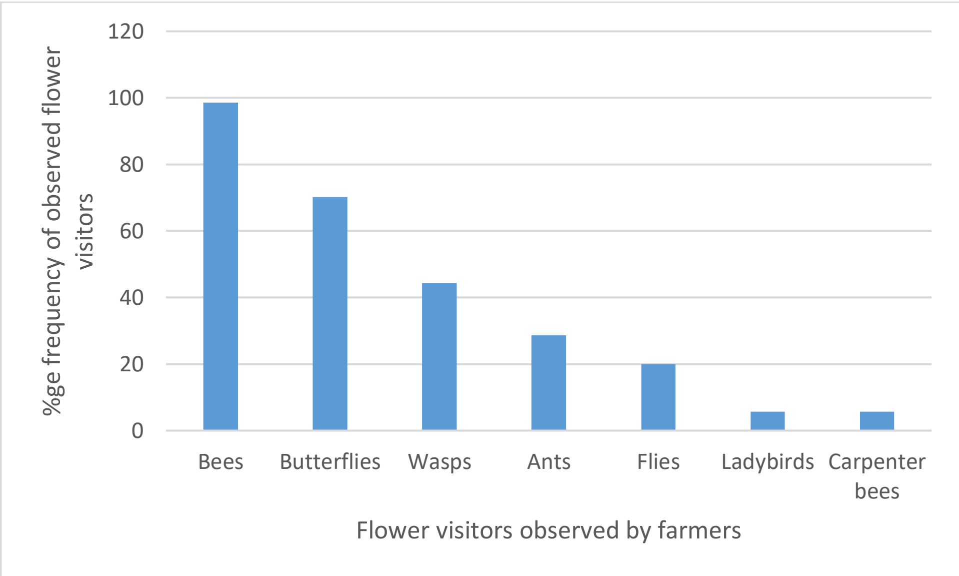

Figure 4. 7**: Insect flower visitors of the crops in the farmers' field as observed by farmers.**

The most visited crops by the insect flower visitors observed by the farmers were tomatoes (52.9%), beans (50%), Courgette (40%), French beans (37.7%), maize (28.6 %) Cucumber (25.7%) Potatoes (12.9%) and Capsicum (8.6%) (Figure 4.8)

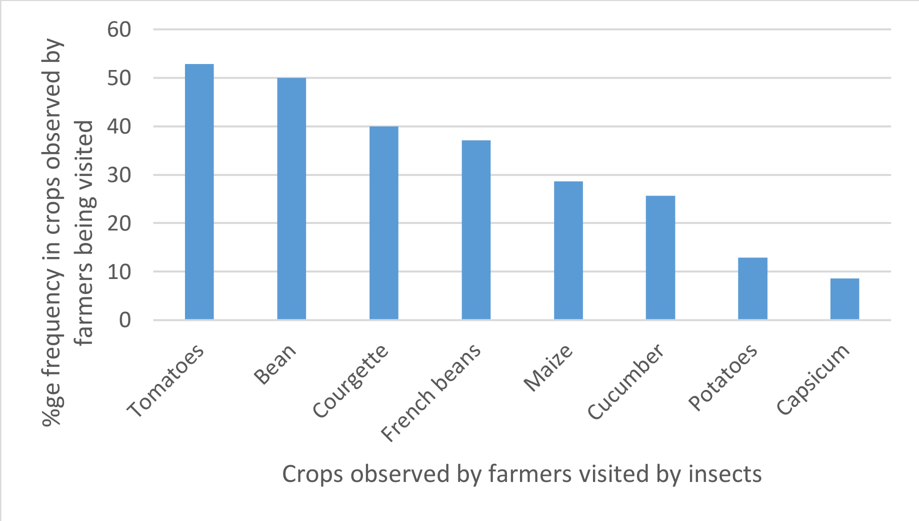

Figure 4. 8**: Crops mostly visited by insect flower visitors as observed by farmers**

Farmers' in the study area were aware of the role of insect pollinators in agriculture. About 63% of the farmers were aware of the role of insect pollinators in agriculture. Thirty four percent were not sure whether insect pollinators have a role in agriculture and 2.9% of the farmers perceived that insect pollinators play no role in agriculture (Figure 4.9). Similarly, farmers' knowledge on contribution of insect pollinators in fruit, seed and pod set followed the same trade with 62.9% agreeing, 34.3% not sure and 2.9% disagreeing (Figure 4.9).

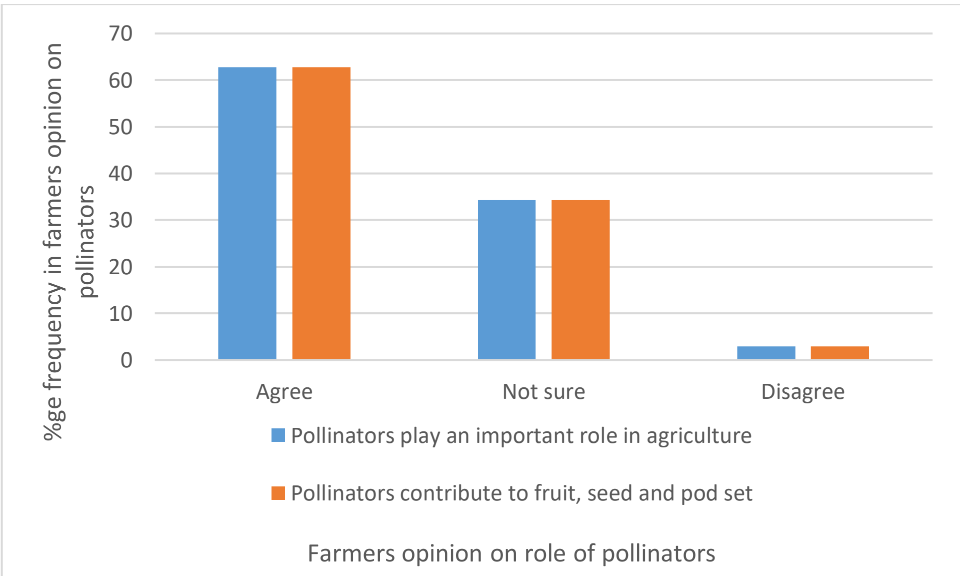

Figure 4. 9**: Farmers' knowledge on the role of pollinators in agriculture and insect pollinator contribution to fruit, seed and pod set.**

4.4.5 Conservation of insect pollinators by farmers

Most farmers in the study area conserve and protect insect pollinators (84.3%, n=59) with a few farmers not conserving and protecting the pollinators (15.7%, n=11). The farmers use different methods in conservation and protection of pollinators by spraying chemicals early morning when pollinators are not foraging (84.7%), agricultural intensification (74.6%), managing pollinator habitat (28.8%) and use of alternatives to chemical pesticide such as natural pest control products, bio-pesticides and cultural control (25.4%) (Figure 4.10).

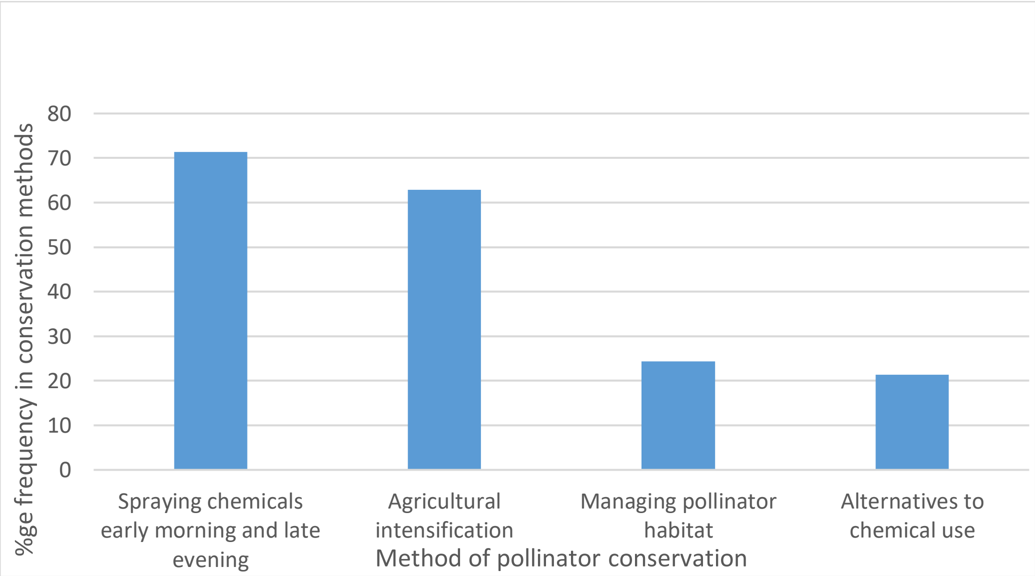

Figure 4. 10**: Methods used by farmers to conserve and protect insect pollinators**

4.5 Discussion

Agriculture in Taita Hills is intensive small-scale subsistence farming. This is due to small pieces of land each farmer owns with the average land size owned by a farmer being 1.84 acres. This is in agreement with Maeda *et al*., (2010) on land use patterns in Taita Hills. The most commonly grown crops are maize, kales, cabbages and common beans. Agricultural intensification is highly carried out in Taita Hills with an average of six crops grown by each farmer per season. Horticultural crops are the main crops grown by the farmers as majority of the crops are vegetable crops. Insect pests are a major threat to farmers in the area. The major pests observed by farmers infesting their crops were aphids (*Aphidoidea*), whiteflies (*Aleyrodidae*), fall armyworm (*Spodoptera frugiperda*) and cutworms (*Agrotis sp*). Aphids (*Aphidoidea*), whiteflies (*Aleyrodidae*) are major pests of brassica family and are highly grown by the farmers (Flint, 2018). Fall armyworm is a current pest of maize and it has a widespread distribution within Kenya (Early *et al*., 2018).

Farmers in Taita Hills use chemical pesticides in management of pests that pose a threat to non-target organisms like pollinators and the environment. Twenty-nine active ingredients belonging to different chemical groups were recorded. The most common used chemical groups are synthetic pyrethroids, organophosphates, dithio carbamates and neonicotinoids. Synthetic pyrethroids exposure to bees has been demonstrated to have negative effects on their movement and interaction (Ingram *et al*., 2015). Neonicotinoid have been reported to pose an enormous threat to pollinators like bees (Stanley *et al*., 2015; Woodcock *et al*., 2017; Mitchell *et al*., 2017). These pesticides pose a threat to food security in the future due to reduction in insect pollinators that improve yield and quality of agricultural produce (Potts *et al*., 2010).

The pesticides used by the farmers belong to different WHO classes. The highest number of the pesticides belonged to WHO class II followed by WHO III class, a few in WHO I and U. Pesticides belonging to WHO class I and II are likely to pose a health threat to the farmers and the environment inclusive of insect pollinators due to their high toxicity levels (Van Scoy *et al*., 2013). Some chemicals belonging to these WHO classes have been banned from use in agricultural production by various governments. This is because pesticide corporations use trade negotiations to avoid bans (Rosenthal, 2005). Class II pesticides which were highly used by the farmers also pose a threat to the environment and the user due to poisoning. Low use of WHO U class might be because they are expensive and the farmers are resource poor. There is need to adopt environmentally safe pesticides with least toxicity levels like Class U which involves the bio pesticides to protect the environment and pollinators.

Farmers in the study area apply high volumes of pesticides, majority of farmers doing more than three pesticide applications per season. High pesticide loads are known to cause decline in pollinator diversity (Brittain *et al*., 2010). Time for chemical application is very important as it reduces insect pollinator exposure during foraging hours. Pesticide application early morning and late evening is encouraged as the pollinators and other beneficial arthropods are less active. Application of chemical pesticides during calm whether also reduces chemical drift to beneficial arthropods like pollinators and predators (Otto *et al*., 2009). The rate of application is very important in pesticide use. Majority of the farmers have the capacity to read, hence they determine the right rates of application by reading the label. Disposal of used pesticide containers is crucial in pollinator conservation. Farmers do not have good disposal systems for used pesticides containers hence chemical traces in the containers may end up into water bodies or be exposed to beneficial arthropods concurring with findings of Damalas *et al*. (2008). From the study, it was established that more than half of the farmers have not received any form of training of pesticide use. Training farmers on pesticide selection and safe use is key in environmental conservation (Damalas & Koutroubas, 2017).

Farmers' perception on insect pollinators and pollinations is crucial in conservation of insect pollinators. More than 90% of the farmers in the study were aware of beneficial insects, and insect pollinators contrary to findings of Misganaw *et al*. (2017) in Ethiopia where majority of respondents were not aware of pollination and importance of insect pollinators. Most of the respondents identified bees as the most common flower visitor and it concurs with Misganaw *et al*. (2017) that recorded bees as common flower visitor. Commonly visited crops by insects' pollinators were tomatoes, beans and courgette. This implies that farmers are familiar with bee's dues to frequent visits to crops and other plants.

Above half of the respondents stated that they know the importance of insect pollinators in agriculture and their contribution to fruit, seed and pod set. This was contrary to Munyuli (2011) who reported that majority of the farmers surveyed in Central Uganda did not know the role played by honeybees in coffee yield increase. This may be due to a lot research done in the area over the last years in other fields aiming at conservation of the few indigenous forest fragments and probably there is no much research in Uganda on the same.

Majority of the respondents' conserve and protect insect pollinators in their fields whereas few farmers' do not conserve and protect them. The farmers in their fields undertake different methods of conservation measures. Timing of chemical pesticide application, whereby farmers spray them early morning and late evening is the commonly used intervention to conserve the insect pollinators. This is because the pollinators are less active during early morning and late in the evening therefore reducing the chances of pesticide exposure. The respondents also do agricultural intensification as measure to enhance insect pollinator diversity. The average number of crops grown by each farmer is six crops; therefore, there are diverse floral resources for visitation by the insect pollinators (Tscharntke *et al*., 2012). Less than half of the farmers manage insect pollinator habitats. The pollinator habitat includes fields planted with temporary flowering cover crops, field borders with perennial or annual flowering species, hedgerows comprising prolifically flowering shrubs and grass buffer strips. Managing pollinator habitat increases the ecological fitness of pollinator populations through enhanced larval and adult nutrition (Wratten *et al*., 2012). Use of alternatives to chemical pesticide use is least used by the farmers. This indicates there is over reliance of pesticides in the management of crop pests. There is need for farmer training to promote integrated pest and pollinator management (IPPM) strategies to reduce over reliance on chemical pesticides in the management of crop pests (Meissle *et al*., 2010).

4.6 Conclusion

Chemical pesticides are highly used by all farmers surveyed in the study. Farmers use different active ingredients belonging to different chemical groups with synthetic pyrethroid being the most commonly used chemical group. Farmer's disposal of empty pesticide containers may end up harming the environment. Few farmers have been trained on pesticide use in the study area. There is need for farmer training on best safe pesticides for use, which are environmentally friendly and safe use of the pesticides.

Most of the farmers are aware of beneficial insects and some beneficial insects are pollinators. Farmers observed honeybees as the most common flower visitor in their crops. Most of the farmers are aware of the role played by pollinators in agriculture but some of the farmers are not sure whether the insect pollinators are important in agriculture. Therefore, there is need for more farmer training on the role played by insect pollinators in agricultural production. Agricultural intensification and spraying chemicals early morning and late evening are the common methods used by farmers to conserve insect pollinators. There is need to create more awareness on the need to adopt other pollinator conservations methods like managing pollinator habitats and adopting chemical pesticide alternatives.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 General discussion

This study assessed butterfly diversity and abundance along Ngangao forest edge and the adjoining farmlands. The study was focused on butterflies because they provide pollination services and more research has been done on bees as pollinators. Ngangao forest being one of the few remaining indigenous cloud forests of Taita Hills, it harbors a high diversity of butterfly species compared to other forests in the coastal region (Ayiemba, 1995; Rogo *et al*., 2001; Chiawo *et al*., 2011). The forest edge recorded higher butterfly species richness and abundance compared to the adjoining farmlands. This shows that some butterflies might be only restricted to the forest habitat with limitations in habitat range. The indigenous forests are important for the maintenance of butterfly species and abundance and their survival.

Taita Hills are characterized by high endemism in both flora and fauna. Three butterfly species endemics to Taita Hills, namely; *Papilio desmondi teita*, *Cymothoe teita* and *Charaxes xiphares desmondi* were recorded in Ngangao forest. From the study, two of these species, *Cymothoe teita* and *Charaxes xiphares desmondi* were found to be restricted in the forest and the forest edges. This implies that degradation of the few remaining indigenous forests threaten this endemic species. *Papilio desmondi teita* was recorded to occur in both the forest edge and in considerably high numbers. Endemic *Cymothoe teita* may be endangered as it only survives in the indigenous forests of Taita Hills, (Larsen,1991) reported this threat earlier.

Butterflies interact with plant species for their existence and survival since the plants act as the food resources for both adult and the larval stages of butterflies (Stein *et al*., 2014). A high positive correlation occurred between plant species and butterfly species on the forest edge.

Lack of correlation between plant species and butterfly species in the farmland may be due to disturbances that play a role in reducing composition of butterfly species diversity.

Pesticide use in Taita Hills is high with nearly all farmers applying pesticides in their farms. Intensive farming and high incidence of pests and diseases in the area may attribute the high chemical use by farmers. Commonly used chemical groups were synthetic pyrethroids and organophosphates, which have a negative impact on insect pollinators and environment in general (Ingram *et al*., 2015). Chemical pesticides belonging to WHO class I are in use in agricultural production by the farmers posing a great threat to them and the environment.

Proper disposal of used pesticide containers is an important aspect in protection of insect pollinators and the environment (Damalas *et al*., 2008). Farmers dispose used pesticide containers differently including burning, burying, disposing in pit latrines, putting them in the dustbin, leaving them in the farm and disposing them in nearby bushes. When pesticide containers when left on the field or disposed on bushes and forests, the pollinators may be exposed to the chemical traces hence harming them. Farmers know the recommended rate of pesticide use by reading from the label because majority of the farmers are literate. Farmer training on safe pesticide use is important in safeguarding insect pollinators and the environment.

Farmers' perception and awareness is key in conservation and protection of insect pollinators and the environment. Majority of the farmers from the study area were aware of insect pollinators and the role played by pollinators in agricultural production. The farming practice conserve insect pollinators although not intentional.

5.2 Conclusion

Ngangao forest harbors a higher diversity, abundance and endemism of butterfly species compared to the farmlands. The indigenous forests are key in conservation and protection butterfly species. The farmlands also recorded a high butterfly species diversity which could be playing an important role in crop pollination.

Chemical pesticides are highly used by the farmers surveyed in the study area. Synthetic pyrethroids are the most commonly used chemical group by farmers. These have been reported to affect pollinators. Methods used by farmers to dispose empty pesticide containers may end up harming the pollinators and the environment. Most of the farmers are aware of beneficial insects and some beneficial insects are pollinators. However, there is need to create more awareness on the need to adopt pollinator conservations methods like managing pollinator habitats and adopting integrated pest and pollinator management strategies.

5.3 Recommendations

1. Listing of *Cymothoe teita* (Teita Glider) Van Someren, as an endangered species in IUCN Red list as it won't survive destruction the few remaining indigenous forests
2. Listing *Cymothoe teita*, *Charaxes xiphares desmondi* and *Papilio desmondi teita* as flagship species for conservation action of Taita forest
3. There is need to conserve indigenous forest fragments in Taita Hills to protect the high diversity of flora and fauna
4. There is need for farmers to adopt environmentally friendly chemical pesticides especially bio-pesticides to conserve pollinators.
5. Further studies to determine butterfly distribution and composition on other indigenous forest fragments of Taita Hills
6. Further research on the interaction between butterfly species and plant species to establish the interdependence between them

7. Further research to determine butterfly diversity composition along attitudinal gradient in Taita hills

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LIST OF APPENDICES

APPENDIX 1**: STUDY SURVEY QUESTIONNAIRE: FARMERS' PESTICIDE USE PRACTICES AND PERCEPTION ON INSECT POLLINATORS IN TAITA HILLS, KENYA**

NATIONAL MUSEUMS OF KENYA

WHERE HERITAGE LIVES ON

Farmers' pesticide use practices and perception on insect pollinators in Taita Hills, Kenya

Questionnaire No:			

SURVEY QUALITY CONTROL

Part I. IDENTIFICATION OF PARTICULARS

Name of the interviewer …………………………………………………………………

Date of the interview……………………………………………………………..

Name of County………………………………………………………………

Name of the Sub-county……………………………………………………..…

Name of Division………………………………………………………………

Name of the Location……………………………………………………

Name of Sub-Location………………………………...

Name of the village……………………………………………………………..

SECTION A. DEMOGRAPHIC INFORMATION

1. Name of the respondent ………………………………………………….
2. Age of the respondent ……………………….. years
3. Sex of the respondent [1] Male ☐ [2] Female ☐
4. Marital Status: [1] Single ☐ [2] Married ☐ [3] Divorced ☐ [4] Widowed ☐
5. Highest level of education

   [1] No formal education ☐ [2] Primary education ☐ [3] Secondary education ☐

   [4] Post-secondary education ☐
6. What is the main source(s) of income?

   [1] Farming activities ☐ [2] Off-farm activities ☐ [3] Family remittance ☐

   [4] Business ☐
7. What is the total land size owned by the household? …………….acres.
8. What is the type of land ownership by a household? ...…………….

   [1]Purchased ☐ [2] Inherited ☐ [3] Rented ☐ [4] others, specify............... ☐

SECTION B. FARMERS' PESTICIDE USE

9. Which crops do you grow on your farm?

   a) ………………………. ………………b) ……………………………………..
   c)………………………………………… d)…………………………………….

   e) …………………………………………f)………………………………….

10. What are the major pests you find in your farm?
    A) ………...………………………….B)……………………………………

    C)…………………………………… D)……………………………………..

    E)…………………………………… F)……………………………………
11. How frequently are your crops being affected by pests?
    1. Once every crop
    2. More than once every crop
    3. None

12. Do you use chemical pesticides to control these pests?

[i] Yes [ii] No

13. Which pesticides do you use?

1)…………………………………2)……………………………………

3)…………………………………4)……..………………………………..

5)…………………………………6)…………..……………………………

14. How frequently do you use pesticides on your farm?

a) Once in crop season
b) Twice in crop season
c) Thrice in crop season
d) More than thrice

15. How do you know the recommended rate of pesticides application?

a. I read from the label
b. I ask my friends
c. I ask from the agrovet
d. I don't know

16. At what period of the day do you spray the pesticides on your farm?

a) Early morning
b) Late in the evening
c) Mid of the day
d) Anytime

17. Under what weather conditions do you spray?

a) Low temperatures and calm wind
b) High temperature and windy
c) Windy and raining

18. How do you dispose of old and empty pesticide containers?

a) I leave them in the farm
b) I bury them
c) Dispose of them in nearby bushes or forest

d) Burn then
e) Put in dustbin
f) Put in pit latrines

19. Have you undergone any training on pesticide use?
    1. Yes
    2. No

SECTION C. FARMERS PERCEPTION OF POLLINATORS AND POLLINATION

20. Are you aware of beneficial insects?

    [1] Yes [2] No

21. Do you know inappropriate use of pesticides can be harmful to these beneficial insects?

    [1] Yes [2] No

22. Are you aware that some of these beneficial insects are pollinators?

    [1] Yes [2] No

23. What type of insect pollinators do you observe in your farm?

    [a] ……………………………………[b]……………………………..

    [c] ……………………………………[d]…………………………….
    [e]…………………………………….[f]…………………………….

24. Which crops do the pollinators visit most on your farm?

    a) ………………………………….[b]………………………………
    c)…………………………………[d]………………....................

    f)………………………………….[g]…………………………….

25. In a scale of 1-3, do you agree that pollinators play an important role in agriculture?

    [1] Agree [2] Not sure [3] Disagree

26. In a scale of 1-3, do you agree that pollinators play an important role in fruit, seed and pod set?

[1] Agree [2] Not sure [3] Disagree

27. Do you protect and conserve the pollinators?

[1] Yes [2] No

28. Which methods do you use to protect and conserve the pollinators?

A. Agricultural intensification
B. Use of alternatives to chemical pest control
C. Spraying chemicals early morning or late in evening
D. Managing pollinator habitat

29. If no, are you willing to start protecting and conserving them?

[1] Yes [2] No

39. If yes, How?

A. Agricultural intensification
B. Use of alternatives to chemical pest control
C. Spraying chemicals early morning and late in evening
D. Managing pollinator habitat