SPATIAL DISTRIBUTION AND TEMPORAL ABUNDANCE VARIATIONS OF THREE IMPORTANT INSECT PESTS OF COFFEE IN KILIMANJARO REGION, TANZANIA

BY

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ABSTRACT

Studies on spatial and temporal distribution of white coffee stem borer (WCSB), antestia bug and coffee berry borer (CBB) were carried out between September 2007 and August 2008 in medium altitude (Lyamungo) and high altitude (Kilema) areas in Kilimanjaro region. Specifically, the study aimed at establishing the species composition and spatial distribution, the temporal variation in abundance, and the relative importance of three pests in coffee ecosystems. A multistage random sampling method was used to select farms in two locations where in each location, one ward was selected and within each ward three villages were chosen, and in each village fifteen farms were randomly selected for the study. In each farm, nine trees were selected to make a total sample size of 810 trees. Insects' were counted every month to establish their population dynamics. WCSB was dominant in both high and medium altitudes while antestia bugs were dominant at medium altitude and less dominant in high altitude. CBB was dominant at medium altitude and no records were noted in the high altitude. High population of antestia bug and CBB were recorded during the short and long rains when flowers and fruit developments were set. WCSB were also observed to increase gradually during short and long rains, which was established as their reproduction period. WCSB was found to be more damaging (44.8 to 67.7 %) than CBB (0 to 12.5%). The study shows that WCSB was more prevalent in the sparse shade while antestia bug and CBB were more prevalent in dense shade. Since WCSB is abundant in all locations and was the most damaging insect pest in the study area, it is recommended that more attention should be focused on management of this pest.

DECLARATION

I, **Fredrick Lugoye Kungu Magina,** do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my own original work and that has never been not concurrently being submitted for a higher degree award in any other University.

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Fredrick Lugoye Kungu Magina Date

(MSc. candidate)

The above declaration is confirmed.

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Prof. R.H. Makundi Date

(Supervisor)

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DEDICATION

This dissertation is dedicated to my mother Labi Jilala and late father Kungu Magina who took me to school and my wife Gaudensia, my children Sailine, Rozalia and Florida.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

%	Percent
ANOVA	Analysis of Variance.
CBB	Coffee berry borer
CABI	Centre for Agriculture and Bio-Science International
DS	Dense shade
EMS	Error Mean Square
EPPO	European and Mediterranean Plant Protection Organization
Fig	Figure.
Fr	Father
FAO	Food and Agricultural Organisation
g	Gram
GDP	Gross Domestic Product
IPM	Integrated Pest Management
m.a.s.l	meter above sea level
l	Litre
LSD	Least Significant Difference
n	Number of trees
P	Probability
RF	Rain fall
RH	Relative humidity
SAP	Strategic Action Plan
SAS	Statistical Analysis System
SS	Sparse shade
SUA	Sokoine University of Agriculture.

TaCRI	Tanzania Coffee Research Institute
TCB	Tanzania Coffee Board
USA	United States of America
URT	United Republic of Tanzania
WCSB	White coffee stem borer

CHAPTER ONE

1.0 BACKGROUND

1.1 Introduction

There are many coffee species, but only two are important commercially: *Coffea arabica* L, which produces Arabica coffee, and *Coffea canephora*, L that produces Robusta coffee. *C. arabica* L. is of Ethiopian origin and *C. canephora* L is native to Central Africa (Kimani *et al*., 2002; Coste, 1992).

Tanzania's economy depends to a large extent on agricultural exports which account for over 50% of its Gross Domestic Product (GDP) with coffee production being a major contributor among cash crops (TCB, 2001). The total area under coffee production in Tanzania is estimated to be 262 263 ha of which 77% is Arabica and 23% is Robusta coffee. Average yield of coffee in Africa is very low ranging from 0.3 to 0.38 tons/ha (FAO, 2006). The average coffee yields in Tanzania range from 120 to 300kg per hectare per year (URT, 1996). Low coffee productivity in Tanzania is mostly attributed to poor cultural practices, old coffee trees, low world coffee prices, frequent water stress, high incidence of insect pests and diseases and costs associated with their control (SAP, 2002; TCB, 2001).

Globally, coffee insect pests are estimated to cause losses of about 13% (Bardner, 2006). However, in Africa, yield losses can be much higher, particularly where Arabica coffee is grown. For example, in Tanzania, losses of up to 96% have been reported due to coffee berry borer infestation (Waterhouse and Norris, 1986). In addition to their impact on yield, insect pests such as antestia bugs and coffee berry borers cause indirect losses by lowering the bean and liquor qualities of Arabica coffee (Oduor and Simons, 2003).

At present, pest control measures rely mostly on the use of synthetic insecticides. However, as global coffee prices have fallen, the costs of inputs, particularly insecticides, have become increasingly prohibitive for most farmers in Africa. This, together with increasing concerns about insecticide residues polluting the environment and frequent reports of insect resistance have stimulated the development of alternative approaches for insect pest control, notably integrated pest management (IPM) (Oduor and Simons, 2003).

1.2 Problem statement and Justification

Farmers in Tanzania continue to rely on insecticides for managing insect pests of coffee in their fields. However, increasing concern about the harmful effects of insecticides both to humans and animals, pest resistance, environmental pollution and food safety is posing serious threat to the coffee farmers in terms of productivity and marketing.

Despite of growers continued using the products in their farms, but are financially unable to afford the right insecticides and application equipments. Limited knowledge on appropriate insecticides, dosage and application technique often lead to poor coverage of the target insect pests. Lack of uniformity in pesticide control measures translates to the spatial distribution of the respective insect pests. Various reviews and studies have emphasized the importance of information on the ecology and biology, particularly the knowledge of spatial and temporal distribution of insect pests in different agro-ecosystems as a prerequisite for developing sustainable pest control strategies (Koul and Cuperus, 2007; Odour and Simon, 2003; Grant and Tingle, 2002; Smith, 1996). However, there is a little information especially at the recent time in regard to major insect pests of Arabica coffee in Tanzania. In this regard, there is a need to investigate the spatial and temporal distribution of coffee insect pests and their composition in different coffee ecological zones in order to help in decision making for rational management practices.

The common varieties of Arabica coffee in Tanzania are selections from Bourbon and Kent genotypes reputed for good liquoring quality and high yielding potential source. However, these attributes are limited by insect pests particularly antestia bugs (*Antestiopsis* spp), white coffee stem borer (*Monochumus leuconotus*) and coffee berry borer (*Hypothenemus hampei*). Antestia bugs causes yield losses of 45% or more at very low population densities (2-3 bugs/tree) in the field (Lyamungu Research and Training Institute, 1997). The insects may also carry spores of the fungus *Nematospora coryli* in their proboscis, which when transmitted to the bean causes rotting and consequently loss of quality. Tampley in Wrigley (1988) estimated that an infestation of slightly over one borer per tree on 15 year-old trees caused about 8% loss of crop in Tanzania. Where the infestation was very severe (15 000 per ha), the trees could only produce a small crop about once in three years (Wrigley, 1988).

In South Africa, moderately infested coffee plantations with white stem borer were found to yield up to 65% less than unaffected fields when not properly treated during the early phase of infestation (Schoeman, 1998). Waterhouse and Norris (1986) reported that losses of up to 96% were caused by coffee berry borer in Tanzania. There is little information on temporal and spatial distribution of these insect pests especially, which limits the need to design an effective management strategy (Koul and Cuperus, 2007; Grant and Tingle, 2002; Smith, 1996). For this reason, the current study aimed at investigating spatial and temporal distribution of the three most important insect pests in Arabica coffee ecosystems in Kilimanjaro region. Further, it intended at providing a useful basis for decision making in rational management practices. The results from this study will be useful for research institutes, decision makers and farmers in ensuring proper management of coffee insect pests.

1.3 Objectives

1.3.1 Overall objective

To investigate spatial and temporal distribution of the three most important insect pests of coffee in Kilimanjaro region, northern Tanzania.

1.3.2 Specific objectives

a) To establish the spatial distribution and abundance of the three pests.

b) To establish the temporal variation in abundance.

c) To investigate the damage levels caused by the three major insect pest species in coffee ecosystems.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Insect pests of coffee

Coffee is indigenous to Africa and so are most of its major insect pests. Over 900 species of insects have been reported to feed on coffee in the world (Kimani *et al*., 2002; Hillocks, 2001). However, fewer than 20 of the arthropod insect pests constitute major constraints to coffee production (Odour and Simons, 2003). In terms of economic importance, there are five coffee insect pests that are particularly important on Arabica coffee in East Africa. These include antestia bugs (*Antestiopsis* spp), coffee berry borer (*Hypothenemus hampei* Ferrari*)* and green scales (*Coccus* spp, De Lotto), Kenyan mealybugs (*Planococus kenyae* Le Pelley) (Mbugua, 1995) and coffee leaf miners (*Leucoptera meyricki* Ghesquiere and *L. caffeine* Washbourn). Other coffee insect pests of minor importance are thrips (*Diarthrothrips coffeae* Will), yellow-headed borer (*Dirphya nigricornis* Ol) and berry moth (*Prophantis smaragdina* Battl). In Tanzania, coffee insect pests of economical importance include white coffee stem borer (*Monochumus leuconatus* Pascoe*)*, antestia bugs (*Antestiopsis* spp), coffee berry borer (*Hypothenemus hampei* Ferrari*)*, and coffee leaf miner (*Leucoptera* spp.). Other coffee insect pests of minor importance are green scales (*Coccus alpinus* De Lotto and *Coccus viridis* Green), mealy bugs (*Planococcus kenyae* Le Pelley), yellow-headed borers (*Dirphya nigricornis* Olivier), and coffee berry months (*Prophantis smaragdina* Butler) (TaCRI, 2007; Magina, 2005).

2.2 White coffee stem borer (*Monochumus leuconatus* Pascoe) (Coleoptera, Cerambycidae)

2.2.1 Description, life history and type of damage

White coffee stem borer is endemic to East and Central Africa, where it is also found infesting wild coffee in natural forests, and has spread to become a major coffee pest throughout the world. The only known species of coffee varieties infested by the pest includes: *Coffee arabica*, *C. liberica*, *C. eugenioides* and *Lachnastoma khasianum*, however the insect is a very severe pest of *C. arabica* (Wrigley, 1988; Le Pelley, 1968; Mcnutt, 1967). A number of wild *Rubiaceae* and shrubs are recorded as alternative host plants. These include: *Oxycanthus speciosus, Randia* spp., *Vangueria* spp., *Pavetta oliveriana* and *Rytigynia schumanii*, but they are much less heavily infested than neglected coffee trees (Le Pelley, 1968; Davies, 1937). The distribution of the pest is confined to East Africa (CABI/EPPO, 2005; Bohlen, 1978). Coste (1968) considers this is because it prefers the higher and drier regions of Africa rather than the west coast. In the past, the pest was known as *Anthores leuconutus,* but Duffy (1957) pointed out that the larvae of the two genera are distinct with *Anthores* having 2-segmented larvae and *Monochamus* 3-segmented. The pest is particularly widespread in the high altitudes regions in East Africa (Coste, 1992).

In Kenya, the pest has been recorded attacking coffee at an altitude up to 1615.4 m .a s. l (5,300ft) (Knight, 1939). Also Wrigley (1988) in Kenya noted that the pest is severe on Arabica coffee grown at lower altitudes (below 1500 m.a.s.l). The pest is also found in southern parts of Africa. The larvae feed on the bark and finally bore into the coffee stem, weakening the plant and causing yellowing of the foliage. Infested trees that are less than two years old are inevitably killed; while a high percentage of old trees also succumb. Weak trees on impoverished soils are the most susceptible to attack, and injury is therefore more frequent at low altitudes than at higher ones where the soil is richer (Knight, 1939). Routine crop losses of greater than 5% have been attributed to stem borers in Africa. Cumulative yield losses of up to 25% in South Africa (Schoeman, 1998) and incidences of up to 80% on small-scale-farms in the northern Malawi have been reported (Oduor and Simons, 2003). In Southern Africa, it has been observed that moderately infested coffee plantations may yield up to 65% below normal production of unaffected field if not properly treated during the early stage of infestation. The borer will ultimately destroy the entire plantation (Schoeman, 1998).

Females lay and insert eggs beneath the bark of the tree, usually within 0.5m from the ground. A female beetle has been observed to lay 30-40 eggs at a time. They require about 3 weeks (21 days) to hatch. The young larvae bore just under the bark of the tree downwards from the point of insertion of the egg. Early stages of larvae development are causing the most serious damage, in the form of ring barking. However, complete ring barking does not always occur. Those larvae hatched near ground level girdle the trunk, burrow downwards into the roots, but those higher up girdle the trunk, and continue to move downwards under the bark, usually penetrate the wood of the tree at the junction of a lateral root within the stem of the tree (Le Pelley, 1968). Male and female beetles were found in about equal numbers in the field, but males emerged from the trees slightly earlier than females. At the warmer, lower altitudes, the larvae are found mostly in the base of the stem and main root system, but at higher, colder altitudes, and also in heavy shade, more live well above ground level (Mcnutt, 1967). The later instars bore in the wood cylinder. There are seven larval instar stages, which last one to two years. The average length of the insect’s development is 16 - 20 months. The larvae pupate within the tree, pupal stage lasts 4 - 5 weeks, and the adult remains within the tree for a further 2 weeks (Le Pelley, 1968). Adult beetles are about 21 - 29 mm long, grayish in colour with a dark head and thorax and with dark markings near the end of the wing cases. At the beginning of the rains they emerge from the trunk by cutting circular holes to the exterior which are about 8 mm in diameter. The beetles do little damage and feed only on the bark of the branches. The life cycle from egg to adult is about 12-25 months and most individuals requiring 16-20 months, where the mean life-cycle last for 18 months (Mcnutt, 1967; Le Pelley, 1968). Adults from eggs laid during the long rains (April-June) of one year will thus mostly emerge during the short rains (November-January) at the end of the following year, with some appearing during the preceding and some during the ensuing rains (Mcnutt, 1967). The length of the life of the adult beetle is not precisely known.

2.3 Antestia bugs, *Antestiopsis* spp (Heteroptera, Pentatomidae)

2.3.1 Description, life history and damage caused

The antestia bugs consist of a species complex, which includes *Antestiopsis orbitalis benchuana* (Kirk), *Antestiopsis orbitalis intricate* (Ghesquire and Carayon) and *Antestipsis facetoides* Greath. (Oduor and Simons, 2003). Of these, the two most important are *A.o. intricate* in West and Central Africa and *A.o. orbitalis* an important species in Southern and East Africa. It causes a considerable damage in East Africa (Kenya, Uganda and Tanzania). Two other antestia bug species, *A. orbitalis ghesquieri* and *A. facetoides* are found in Tanzania. They are the most destructive pests of Arabica coffee, but do not affect Robusta coffee (Bohlen, 1978). Damage is caused both by nymphs (at all stages) and adults. The nymphs and adults pierce and suck flower buds and green coffee berries, causing premature loss of flowers and berries, and sometimes affect the growth of the plant (Coste, 1992; Le Pelley, 1968). More mature nymphs and adults pierce the young berries causing one or both of the ovaries of the fruits to abort.

The pest normally feeds on red berries, large green berries, small green berries, green shoots then flower buds while leaves are seldom fed on in the presence of other foods. The most suitable food is the full sized green berries (Le Pelley, 1968). Harvest losses can be very high (fruits are either atrophied, or have empty loculi). The growth problem caused by the damage to the buds and young shoots provoke a characteristic proliferation of branches (witches broom) with progressive degeneration, which also adversely affects productivity (Coste, 1992). The percentage of infested beans is very variable, from 32% or more without treatment (CABI, 2007). Presence of a very small population (2 - 3 bugs/tree) in the field can cause up to 45% crop losses (Lyamungu Research and Training Institute, 1997). The insect may also transmit spores of the fungus *Nematospora coryli* through its proboscis which causes rotting of the coffee endosperm and thus lower the quality (Le Pelley, 1968). One estimate puts the damage to berries caused by one Antestia bug per tree throughout the year at 9 to 16% (Robinson, 1964). Infestation often leads to berry drop, with surviving berries producing cracked beans on ripening (zebra or ragged beans). In the Great Lakes area of East Africa, Arabica coffee can develop an undesirable taste known as ‘peasy gout de pomme de terre (GPDT)’ or erbsig. The taste is due to a bacterium belonging to the family of Enterobacteriaceae which has not yet been fully identified. This also reduces the quality of the commercial coffee (CABI, 2007).

Other research findings from other countries like Ethiopia have reported that the population of this insect starts to build up in March and reaches a peak around May-June although slight variations have been observed in various coffee growing areas due to differences in flowering and fruit setting (Abebe, 1987). Also report from Uganda by McNutt (1979) indicated that the crop loss without spraying with chemicals and the mean number of pentatomids/100 trees a year was 20, 36 and 51% at a mean population of 0.5, 1 and 2 pentatomids /tree, respectively. The percentage losses in yield were most closely related to populations in January-March (when the flowers were setting) and April-June (when the fruits grew rapidly). Normally the pest is known to increase in the period of flowering and fruit formation. The adults and nymphs suck on green berries and after the harvest on different parts of the trees. However, the main damage is caused by secondary infestations of the berries with the fungus *Nematospora spp* that destroys the seeds. Serious damage is likely to occur if sucking on the buds causes them to drop (Jansen, 2005).

The adult is about 7 mm long. Its body is brown or bronze with yellow-orange pattern. The eggs are whitish in colour, usually laid on the underside of the leaves, (but can sometimes be found on the stems and the fruits) in an average batch of 12 to 15 eggs, arranged in rows (CABI, 2007; Coste, 1992; Le Pelley, 1968). The incubation period is linked to relative humidity: 9 days at 68% RH, 11 days at 76% RH and 12 days at 81% RH. The five larval stages last 8-9, 12-15, 11-13, 11-15 and 17-21 days, respectively. The average length of the development period is 70-80 days; adult males live 50 days and females 76 days. The period of maturation of the females (between emergence and the first laying) is 17-19 days. Females lay an average of 156 eggs. Egg laying requires between 35 and 40 minutes. The average duration of the complete female cycle (from egg to first laying) is 95 days. Therefore, there could be 3.8 generations per year. The newly emerged nymph is about 1 mm length. There are 5 nymphal stages and the last one gives rise to adult bug. The whole life cycle may be noticeably shorter in hot areas. For example, the life cycle requires about eight weeks to completion in hot weather and up to four months in cold weather (Robinson, 1964). Larvae do not feed during the first stage. The larvae of the second stage move actively. From the third stage onwards, feeding is the priority and movement is less (CABI, 2007). The fifth stages of nymphal instars resemble the adults in colour, but have a more rounded shape and lack functional wings. The adult insect is generally dark brown, orange and white. Some types are much more brightly coloured than others. The body length is about 6 mm, and the legs and antennae are easily visible. Adults can live 3 - 4 months (Le Pelley, 1968). The adult antestia bug is presented in Plate 1.

Plate 1: Antestia bug (*Antestiopsis orbitalis* Westwood) on the large green coffee berry clusters © Benard Bouyjou (CABI, 2007)

2.4 Coffee berry borer (*Hypothenemus hampei* Ferrari) (Coleoptera: Scolytidae).

2.4.1 Description, life history and type of damage caused

The coffee berry borer is a serious pest of coffee in many of the major coffee-producing countries. The pest is endemic to East and Central Africa where it is also found attacking wild coffee in natural forests and has spread to become a major pest of coffee throughout the world (Le Pelley, 1968). It is serious pest of Robusta and Arabica coffee grown at low altitude agro-ecological zones. In Tanzania, this pest was formerly confined to the West Lake Region but since 1969, it is also found in Kilimanjaro region (Bohlen, 1978).

Crop losses caused by this pest can be severe, ranging from 50-100% of berries attacked if no control measures are applied (Le Pelley, 1968; Magina *et al*., 2005). By harvest time, the borer has usually not had time to infest both cotyledons of the berry, so that even 100% attack of berries is unlikely to cause more than 50% perforated coffee beans. The female attacks developing coffee berries from about 8 weeks after flowering up to harvest time (32+ weeks). It shows a marked preference for older berries if they are available. When berries of different maturity are present on the same branch, there is a strong selection for mature berries with over 25% dry matter content (CABI, 2007).

In coffee plantations, attack is frequently aggregated towards a part of a field, often where there is shade or higher humidity or a border. If the infestation is not controlled, attack becomes general over the entire plot (CABI, 2007). The adults and larvae bore into the beans and feed on the endosperm, giving the bean a characteristic blue-green stain. Damaged cherries are retained on the trees until harvest, making them of low commercial value by reducing weight of the bean and downgrading the quality affecting the flavour of the coffee (Baker *et al.*, 2002; Le Pelley, 1968). This amount of damage, however, will produce poor quality coffee, which is difficult to market. Heavy infestation usually leads to berry drop. *H. hampei* may be a vector of the fungus *Aspergillus ochraceus*, which produces Ochratoxin “A” (Oduor and Simons, 2003). The rate of infestation tends to vary with altitude, more severe in low altitude than at higher altitude areas. For example, in Ivory Coast losses ranging 20-80% have been observed. In Malaysia, losses were about 50-80% (Murphy and Moore, 1990). Waterhouse and Norris (1986) reported that losses of up to 96% were caused by coffee berry borer in coffee in Bukoba, Tanzania.

Each female lays 30-60 eggs in batches of 80-120 in chambers dug out in the hardened maturing bean, over a period of 3-7 weeks; the incestuous mating occurs between daughter and flightless brother; the eggs hatch in 8-9 days. The larvae are legless, white with brownish heads. They feed by tunneling in the tissues of the beans. Due to the long egg laying period, larvae in all stages of development may be found within the same bean. The male larva develops through two instars in 15 days; the female through 3 instars in 19 days. The naked pupal stage is passed in 7-8 days in the larval galleries (Le Pelley, 1968). Up to three generations are possible inside the berry though it is likely that the first two generations are the most important. In old dry berries left after harvest, it is not uncommon to find more than 100 individuals. It is frequently stated that the borer goes through eight or more generations per year, but with the often slow start to attack and the possible long wait in an old berry before emerging, it is unlikely that many borers give rise to more than five generations per year.

Fallen berries in dry conditions can build up large numbers of adults which are triggered to emerge by high humidity (>90% RH) that occurs after rains (CABI, 2007). The adult female is about 2.5 mm long, and the male about 1.6 mm. The females are much more numerous than male (sex ratio is about 10:1) and are responsible for the distribution of the species by short flights to neighboring trees. The males are incapable of flight and remain in the berry fertilizing females of the same brood; the egg-laying female may make a number of tunnels in different berries that are not suitable for breeding purposes and will then abandon them (Le Pelley, 1968). The adult coffee berry borer is shown in Plate 2.

Plate 2: Adult coffee berry borer (*Hypothenemus hampei* Ferrari) © Georg Goergen (CABI, 2007)

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Description and location of the study area

The study was conducted in Hai and Moshi Rural districts in Kilimanjaro region, in two wards, namely, Machame East (Hai district) located at medium altitude (1200-1600 m. a. s. l.) and Kilema north (Moshi Rural district) located at high altitude (1600-2100 m a. s. l.) areas (Fig. 1). The sites were selected in areas where weather data had been recorded for a long time and included relative humidity, rainfall and temperature, which were important parameters for the study.

Hai and Moshi Rural districts are located between latitudes 3˚00` and 3˚15` S and longitudes 37˚00` and 37˚45’E and have a bimodal rainfall pattern (long and short rain seasons). The long rains or *Masika* typically occur from February to May, while the shorter rains or *Vuli* occur during November and December. Precipitation varies from 2000 mm per year in the rainfall belt to less than 100 mm per year in the summit zone. Weather condition near the base of the mountain tend to be tropical to semi temperate and the lower plains are hotter and dry with average temperature of around 40˚C (Indigo guide, 2008).

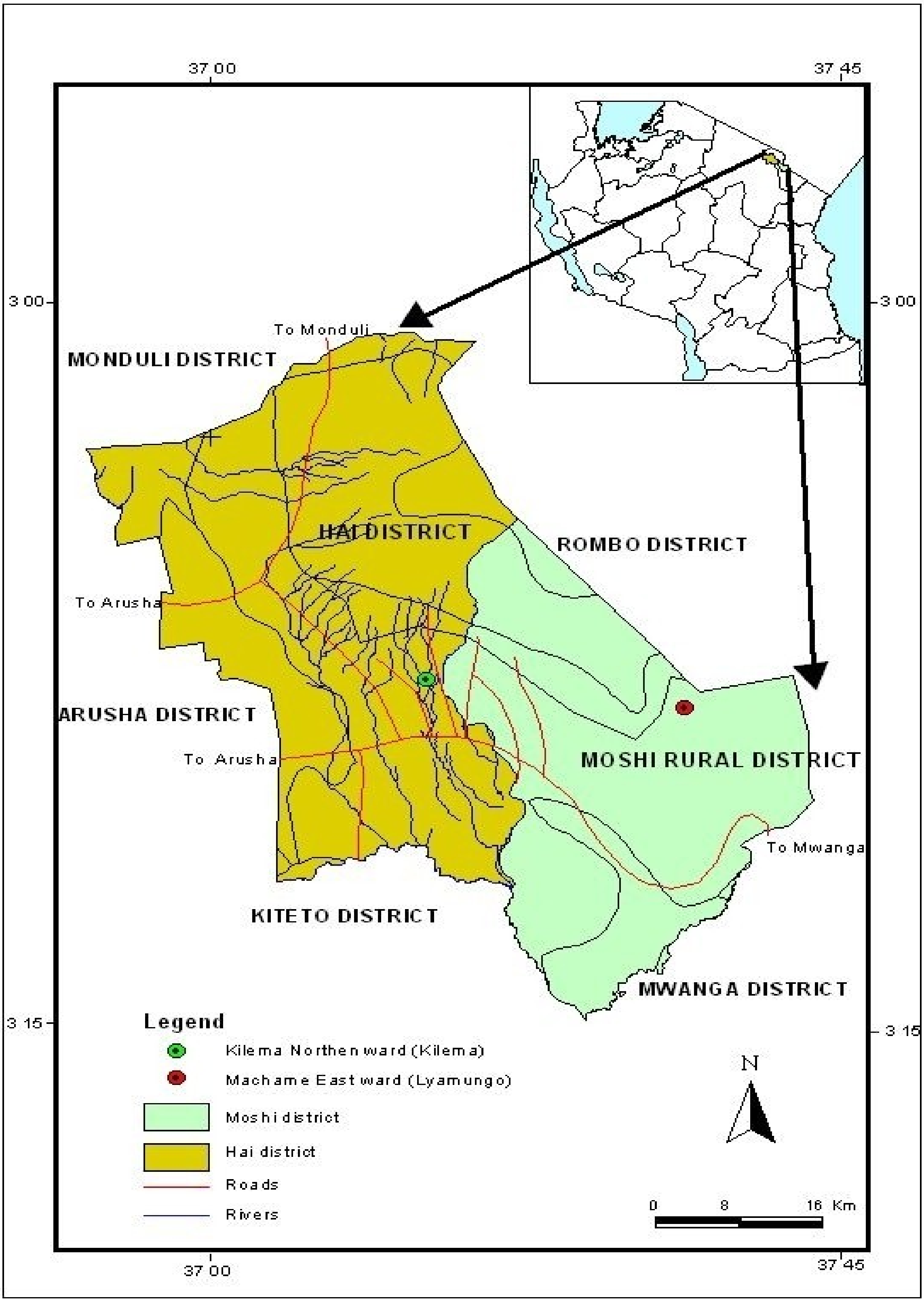


Figure 1: Map of Moshi rural and Hai districts indicating a study area

3.2 Experimental design

A split-split plot design was used, involving 3 factors: Factor A: Altitude: (high and medium), Factor B: Seasons (wet and dry) and Factor C: micro-climate (sparse shade and dense shade). The main plot was altitude (high and medium), sub plot was seasonality (dry and wet seasons) and sub-sub plot was microclimate (dense and sparse shade).

3.3 Sampling technique and sample size

Multi-stage sampling techniques were used as described by Kothari (2004). At each location, one ward was selected and within wards three villages were chosen. Fifteen farms were selected for the study in each village. In each farm, nine trees were randomly selected for determination of insect pest infestation. The sample units were nine trees per farm. A total of 15 coffee farms/village were sampled, nested in two microclimates: sparse and dense shade and two agro-ecological areas, namely medium altitude (1200-1600 m. a. s. l) and high altitude (1600-2100 m. a. s. l) (Table 1).

Table 1: Summary of the sampling protocol in two districts

	No. of wards	No of villages/ward (replicates)	No of farms per village	No. of sampled trees/farm	Total no. of samples collected
Moshi Rural	1	3	15	9	405
Hai	1	3	15	9	405
Totals	**2**	**6**	**30**	**18**	**810**

The total sample size was 810 trees (2 ward x 3 villages x 15 farms/villages x 9 trees per farm). Data for pest infestation were collected from unsprayed coffee farms in the sparse and dense shade. Geographical Positioning System (GPS) was used to mark the geo reference of each sampled farm

The farms were divided into equal grids. Sampling was carried out at certain grid points determined using horizontal and vertical transects (Lyons, 2000). The nearest coffee tree to the point at which the 2 transects crossed was sampled. Therefore, in every farm, a total of 9 sampling points were earmarked regardless of the size of the farm. There were 5 transects (Y-axes) X 5 transects (X-axes) for each field. The length of transects varied depending on the size of the farm. The edge or periphery of the farms (first transect) was not sampled and was regarded as a guard row.

3.4 Data collection

Data collected were: total number of the three coffee insect pest species (white coffee stem borer, antestia bug and coffee berry borer) per tree, coffee ecosystem, fruit phenology (at flowering stage, young berries, mature berries, ripe and overripe berries). These data were correlated with the insect pest population abundance and infestation/damage levels.

Collection of data on number of insect pests was done on monthly basis (four weeks) to allow for changes in life cycles for some of the insect pest species. Fruits phenology (young fruits, mature green, ripe and over-ripe stages) was also recorded during the study period. Data collection covered both dry (January - March 2008 and September-October 2007) as well as wet seasons: Short rains fall from November December and long rains from mid February to May.

Three factors, namely location/altitudes (2 levels: high and medium altitudes), season (2 levels: dry and wet) and micro-climate (two levels: sparse and dense shades) were assessed to establish their influence on spatial and temporal distribution and abundance of the three coffee pests. Separation of farms under dense and sparse shades were determined in the field using Light Intensity Meter (Digital Luxmeter, type: XL-101) in each coffee tree. The Light Intensity Meter instrument is presented in Plate 3 and measuring of light intensity in the field is presented in plate 4.

Plate 3: Light Intensity Meter (Digital Luxmeter, type: XL-101)

Plate 4: Counting of insect pests and measuring light intensity by use of Light Intensity Meter

3.5 Insect pest counts and damage assessment

Counts of WCSB, antestia bug and CBB were studied at monthly interval (four weeks) for one year (September, 2007 to August, 2008) to find out if there were any differences between two locations (medium and high altitudes) in Hai and Moshi Rural districts. Assessment of the number of each pest type was carried out as described below:

3.5.1 Antestia bug (*Antestiopsis* spp)

Careful observation of the tree from all angles for the presence of the pest without disturbing the tree canopy was done. For the case of heavy canopy of coffee the knockdown approach for pests by spraying with a mixture of Pyrethrum extracts and Kerosene oil (10g: 2 l) was done (CABI, 2005; Mcharo, 1980) (Plate 5). The total number of adult antestia bug and nymphs was recorded in a modified standard sheet described by Kyamanywa (2006) (Appendix 11). Also the total number of berries was counted per each sampled coffee tree. Damage assessments due to Antestia bugs can be determined using the following formula:

$$\text{Percentage damage by antestia bug} = \frac{\textit{Number of damaged cherries by antestia bug}}{\textit{Total number of cherries in a coffee plant}} \text{x100}$$

The damage caused by antestia bug was not determined in the field due to the fact that the main damage after infestation by the pest is caused by secondary infection of the berries with the fungus *Nematospora* spp that destroys the seeds (Jansen, 2005). Hence in order to estimate the damage caused by this pest all the berries must be assessed to establish the ac ... was not co ... Thus, no da

1 2

Plate 5: Counting of antestia bug (2) after knock down by Pyrethrum extracts (1)

3.5.2 Coffee berry borer (*Hypothenemus hampei* Ferrari)

In each tree, a primary branch bearing coffee berries was randomly selected in the middle third of the bearing head. In each sampled primary branch, two medial berry clusters were recorded for the presence of the pest in a modified standard sheet described by Kyamanywa (2006) (Appendix 11). The number of bored berries and total number of berries were recorded.

Damage assessments were determined using the following formula:

$$\text{Percentage damage by CBB} = \frac{\text{Berries damaged by CBB in a cluster}}{\text{Total berries (healthy and infected) in a cluster}} \text{x100}$$

3.5.3 White coffee stem borer (*Monochumus leuconatus* Pascoe)

The lower trunk, up to 0.6 m above the collar level was closely examined for any signs of stem girdling or boring by white coffee stem borer. The numbers of trunks for each coffee bush, number of insects per coffee tree represented by the number of bores per coffee tree were recorded for the presence of the pest in a modified standard sheet described by Kyamanywa (2006) (Appendix 11). Damage assessments were determined using the following formula:

Percentage damage by WCSB = $\frac{Coffee\ trees\ damaged}{Total\ No.\ of\ trees\ (heathy\ and\ infected)}\ x\ 100$

3.7 Data analysis

Analysis of variance was done by SAS (2007) using the general linear model (GLM) below. The treatment mean of insect pests between high and medium altitudes, wet and dry seasons and dense shade and sparse shade were compared by t-test as described by Zar (1999) to determine any significant differences between the treatments.

Yijk = **μ** + **A**i +ei + **S**j + (**AS)** ij + ej + **M**k + (**MA**) jk + (**MS**) jk + (**MAS**) ijk + **e**ijk.

Where by

Yijk = response of values investigated (insect population abundance)

μ = General mean common to all observations,

Ai = effect caused by altitudes,

ei = random effect (error) due to altitude,

Sj = effect caused by seasons,

ASij = effect caused by interaction between altitude and season,

ej random effect (error) due to season

Mk = effect caused by microclimate,

(MA) ilk = effect caused by interaction between altitude and microclimate,

(SM) jk = effect caused by interaction between season and microclimate,

(MAS) ijk = effect caused by interaction between microclimate, altitude and season and

eijk = random effect (error) specific to each treatment in the experiment.

The variation in mean values was tested using Least Significant Differences (LSD)

Species diversity and distribution were determined using Shannon-Wenner and Jaccard (1901) index functions. These are the measures of species diversity which are based on information theory. The Shannon diversity index [H] is commonly used to characterize species diversity in a community, whereby it measures both abundance and evenness of the species present in a certain community.

Shannon-Wenner index for diversity (H),

$$H = -\sum_{i=1}^{n} Pi \ln Pi ,$$

Where, H = Shannon diversity index

Pi = No. of individual of one species /Total no. of individuals in the sample

The Jacard index, also known as the Jaccard similarity coefficient was used to compare the similarity and diversity of sample sets of insects in a community. The Jaccard coefficient is defined as the size of the intersection divided by the size of the union of the sample sets.

$$\text{Jaccard } (S_{ij}) = \frac{a}{a+b+c}$$

Where:

S_{ij} = the similarity Jaccard index between “i” and “j” altitudes

a = is the distribution of species present in both “i” and “j” altitudes

b = is the number of species present in “i” but not in “j”

c = the number. of species present in “j” but not in “i”

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Species composition, spatial distribution and abundance of WCSB, antestia bug and CBB

Results of species composition are presented in Fig. 2, 3 and 4. A total of 19 243 insect were counted: 14995 (78%) were WCSB; 3225 (17%) antestia bug; and 1023 (5%) CBB. The number of individuals counted varied within and between altitudes and also in different microclimates (sparse and dense shade) across the study area. There were more pest populations at the medium altitude (Lyamungo, 1600 to 2100 m a. s. l.) relative to high altitude agro-ecological zone (Kilema, 1200 to1600 m. a. s. l.) (Appendix 2). In the medium altitude there were more antestia bug (46%) followed by WCSB (45%) and CBB (9%) (Fig 3). In the high altitude there were more WCSB (99%) followed by antestia bugs (1%). However, no CBB were found (Fig 4).

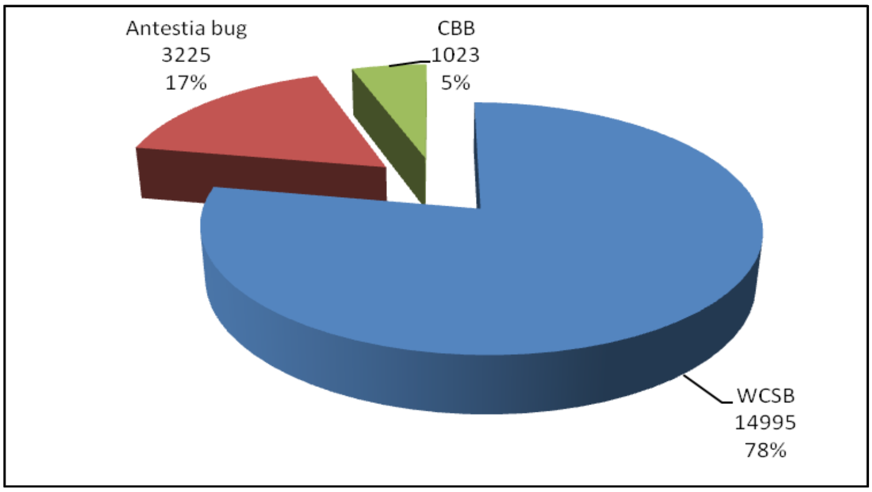


Figure 2: The proportional composition of each species of coffee pests in the study area

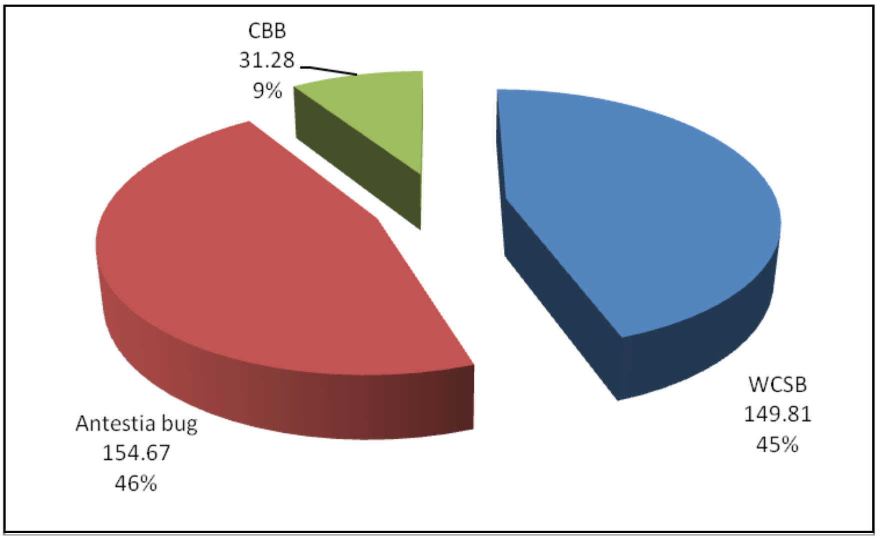


Figure 3: Mean number of WCSB, antestia bugs and CBB at medium altitude (Lyamungo)

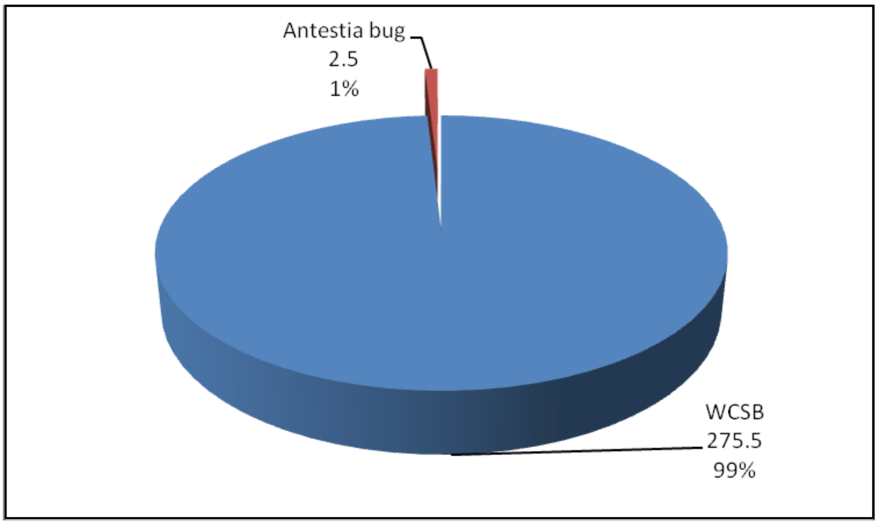


Figure 4: Mean number of WCSB and antestia bug at high altitude (Kilema)

4.1.1 Identification of farms under dense and sparse shades

The measurement of light intensity for nine coffee trees per farm was taken at the upper part of coffee trees by use of Light Intensity Meter (Digital Luxmeter, type: XL-101) and the averages were calculated to determine the mean light intensity for coffee farms under two microclimates (dense and sparse shade). Farms under dense shade microclimate were classified to be under mean light intensity between 20 and 40 Lux and those under sparse shade between 41 and 100 Lux. There were 45 farms under dense shade and 45 farms under sparse shade (Appendix 12).

4.1.2 Population abundance of insect pests between locations

Results of the population abundance of the three important coffee insect pests are presented in Fig. 5. Results in Fig. 5 show that WCSB was significantly more abundant at high altitude agro-ecological zones as compared to medium elevation areas ($P \leq 0.05$). On the other hand the population abundance of antestia bug was significantly higher at medium altitude than at high altitude areas ($P \leq 0.05$). However, no CBB were found at the high elevations and relatively lowest population abundance was observed at medium agro-ecological zone as compared to other coffee insect pests investigated.

4.1.2.1 Population abundance of WCSB between high and medium altitudes

The abundance of insect pests in the two locations under dense and sparse shade is presented in Table 2. The study found highly significant differences in population abundance of WCSB at high and medium altitudes ($P \leq 0.05$). These results support the earlier findings reported by CABI (2007) that the pest is abundant at high altitudes in East Africa.

Le Pelley (1968) and Wrigley (1988) in Kenya reported that high prevalence of the pest was found at low altitudes (below 1500 m a s l) compared to high altitude. Knight (1939) in Kenya also recorded the pest attacking coffee at an altitude up to 1615.4 m .a s. l. This observation may be due to changes in environmental conditions particularly temperature (global climatic change) which may have important consequences on spatial distribution and population abundance (Fernani *et al.,* 2008; Makundi, 2007; Stambuli, 1988). Most studies have concluded that insect pests will generally become more abundant as temperatures increase, through a number of inter-related processes; including range extensions and phenological changes, as well as increased rates of population development, growth, migration and over-wintering. Migrant pests are expected to respond more quickly to climate change and may be able to colonize newly available crops/habitats (Cannon, 1998).

Other factors which may contribute to increasing abundance of the pest at the study area may be the differences in coffee management practices prevailing in the two locations. It has been reported that the number of arthropods was higher in abandoned than managed coffee farms and higher in the edge than in the centre of the abandoned agro forestry/farms (Jansen, 2005; Sreedharan, *et al.*, 2005). Richter *et al.* (2007) and Sreedharan *et al.* (2005) reported that in order to fight and minimize stem borers in coffee fields, it is important to maintain optimal shade, plant protection measures like tracing and uprooting, back scrubbing and spraying with recommended insecticide. Negligence in management of coffee farms is a typical situation of farmers in the study area which is associated with low prices of coffee in the market, high price of inputs and other costs associated with management practices.

4.1.3 *Population abundance of WCSB, antestia bug and CBB in relation to* microclimate

The comparison of population abundance in relation to microclimate is presented in Table 2. The results show that the population of WCSB was significantly higher in sparse shade (20.655) as compared to dense shade (10.552) in the two agro-ecological zones. However, the population abundance of antestia bug was significantly higher in the dense shade microclimate (9.036) than sparse shade (4.544) microclimate (P≤0.05). CBB was only found at medium altitude although statistically there were no significant differences between the two locations (P≤0.05). These results show that shading has some effects on the population abundance of different coffee insect pests.

Table 2: Mean numbers of insect pests at two locations (Lyamungo and Kilema) in farms with sparse and dense shade

Location	Dense shade			Sparse shade		
	WCSB	**Antestia bug**	**CBB**	**WCSB**	**Antestia bug**	**CBB**
Lyamungo	10.552b	9.036a	2.975a	20.655a	4.544b	2.550b
Kilema	17.788b	1.228a	N/A	23.475a	0.255b	N/A
Total	**28.340**	**10.254**	**2.975**	**54.120**	**4.799**	**2.550**

Means in a column followed with the same letter are not significantly different (P≤0.05). Means separations are compared within the locations.

4.1.3.1 Population abundance of WCSB under shade conditions in high and medium altitudes

These results indicated that population abundance of WCSB is significantly low in dense shade as compared to sparse shade in the two agro-ecological zones (Table 3). These results are similar to those reported by Le Pelley (1968) in Kenya that well- shaded coffee plantations have less WCSB incidence as compared to less shaded plantations, although this report did not quantify the level of shade in the respective locations reported. Caresche

(1938), Subraman (1934) and Mayne *et al.* (1933) reported that the beetle is active and oviposits freely in bright sunshine in Mysore (India) and Vietnam where shade is recommended both for young and old coffee trees in coffee plantations. The beneficial influence of shade is even experienced when it is provided by the leaves. Also it has been reported that management of *Hemileia* spp in coffee farms by the application of Bordeaux (fungicide), which increases the health of growing shoot and leaf and facilitates development of shade microclimate, resulted in a decrease of WCSB infestation compared to unsprayed areas (Caresche, 1938).

Table 3: Mean population abundance of WCSB, antestia bug and CBB at Lyamungu and Kilema in sparse and dense shade within lcations

Location	**Lyamungu**			**Kilema**		
	WCSB	**Antestia bug**	**CBB**	**WCSB**	**Antestia bug**	**CBB**
Sparse shade	20.655a	4.544b	2.550b	23.475a	0.255b	N/A
Dense shade	10.552b	9.036a	2.975a	17.788b	1.228a	N/A
Total	**30.207**	**13.590**	**4.525**	**41.263**	**1.483**	**-**

Means in a column followed with the same letter are not significantly different (P≤0.05). Means separations are compared within columns.

4.1.3.2 Population abundance of antestia bug under shade conditions in high and medium altitudes

The population of antestia bug for the two locations indicated highly significant differences in insect pest abundance between the medium and high altitudes (Table 2). Shading of coffee was also observed to have some effects on population abundance of antestia bugs. The results from this study are in agreement with previous findings by Canon (1998) in United Kingdom (UK) who reported that the impact of insect abundance changes on agricultural systems in high altitude regions are predicted to be less severe than in medium low altitude regions.

The results in Table 2 revealed that shading of coffee has some effects on population abundance of antestia bug both at high and medium altitudes. In the high altitude areas, there is a significantly higher population ($P \leq 0.05$) of the pest in dense than sparse shade farms (Table 2). Also in the medium altitude areas the population abundance was lower in sparse compared with dense shade. These observations are similar to those given by Hargreaves in Le Pelley (1968) that shade microclimate is responsible for increase in population of the antestia bug and hence higher population on coffee plantations. However Kirkpatrick, in Le Pelley (1968) observed that there are highly significant differences of pest abundance in dense shade compared to sparse shade in the medium altitude, where as the reverse are true at the high altitude. Higher elevations are cold at night while the lower altitudes are characterized by high temperatures. In the medium elevation, the insect thrives better in unshaded plantations.

4.1.3.3 Population abundance of CBB under shade conditions in high and medium altitudes

The population abundance of CBB at the two locations indicated highly significant differences in the medium compared to high altitudes (Table 2). Jansen (2005) reported that low temperatures and relative humidity under 50% in areas above 1500 m in the tropical belt are limiting factors for development. The pest is probably not adapted to high elevations where the weather conditions are cold, as is the case for Kilema. A study by Wrigley (1988) in Uganda indicated that the lower the altitude the more severe is the pest, and also that the pest is seldom serious over 1340m (4500ft), rare at 1525m, and has not been found at 1680m. Similarly, other reports by Le Pelley (1968) and Bohlen (1978) indicated that the pest is a problem in Arabica coffee at low altitude ecological zones where temperatures are high.

The population abundance of CBB was slightly higher in the dense compared to sparse shade. There was a significant difference ($P \leq 0.05$) in both microclimates. However, the pest was not found in high altitude agro-ecological zone.

4.1.4 Population abundance of WCSB, antestia bug and CBB within locations in two ecological zones

Results for the population abundance of WCSB, antestia bug and CBB within locations are presented in Fig. 5, 6 and 7 respectively. The results in Fig. 5 indicate a high abundance of WCSB in sparse shade as compared to dense shade in both Kilema and Lyamungo. Under sparse shade the mean number of WCSB was 20.65 for Lyamungo and 23.47 for Kilema while under dense shade the mean number of WCSB was 10.55 and 17.78 for Lyamungo and Kilema, respectively. On the other hand, the population abundance of antestia bug was higher in the dense shade compared to sparse shade in two locations (Fig. 6). Under sparse shade the mean number of antestia bugs was 4.54 for Lyamungo and 0.26 for Kilema while under dense shade the mean number of antestia bugs was 9.04 and 1.23 for Lyamungo and Kilema, respectively. CBB which was prevalent in medium altitude only (Lyamungo) has high population abundance in dense shade compared to sparse shade (Fig. 7). Results in Fig. 8 indicate that the mean number of CBB for Lyamungo under dense shade and sparse shade were 2.97 and 2.55 respectively.

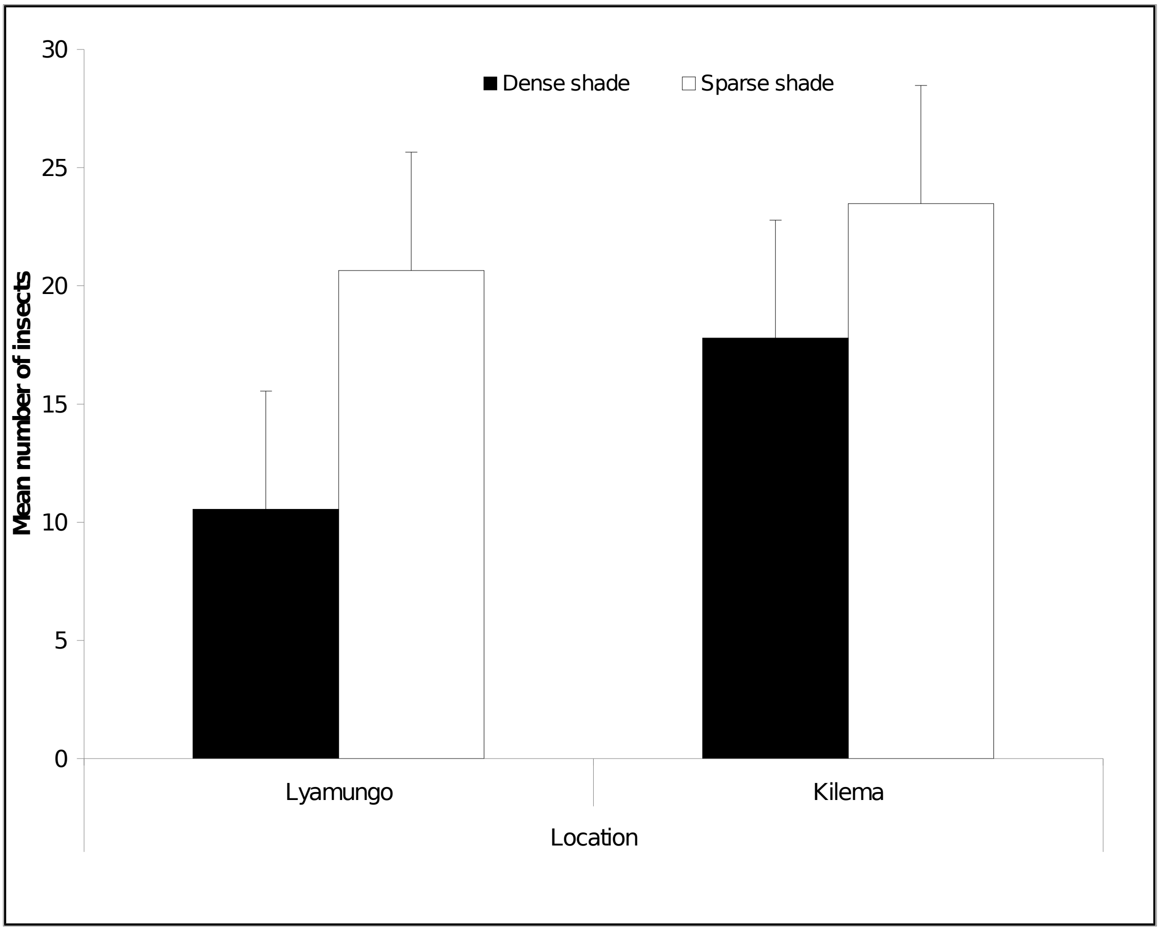


Figure 5: Population abundance of WCSB between locations and microclimates

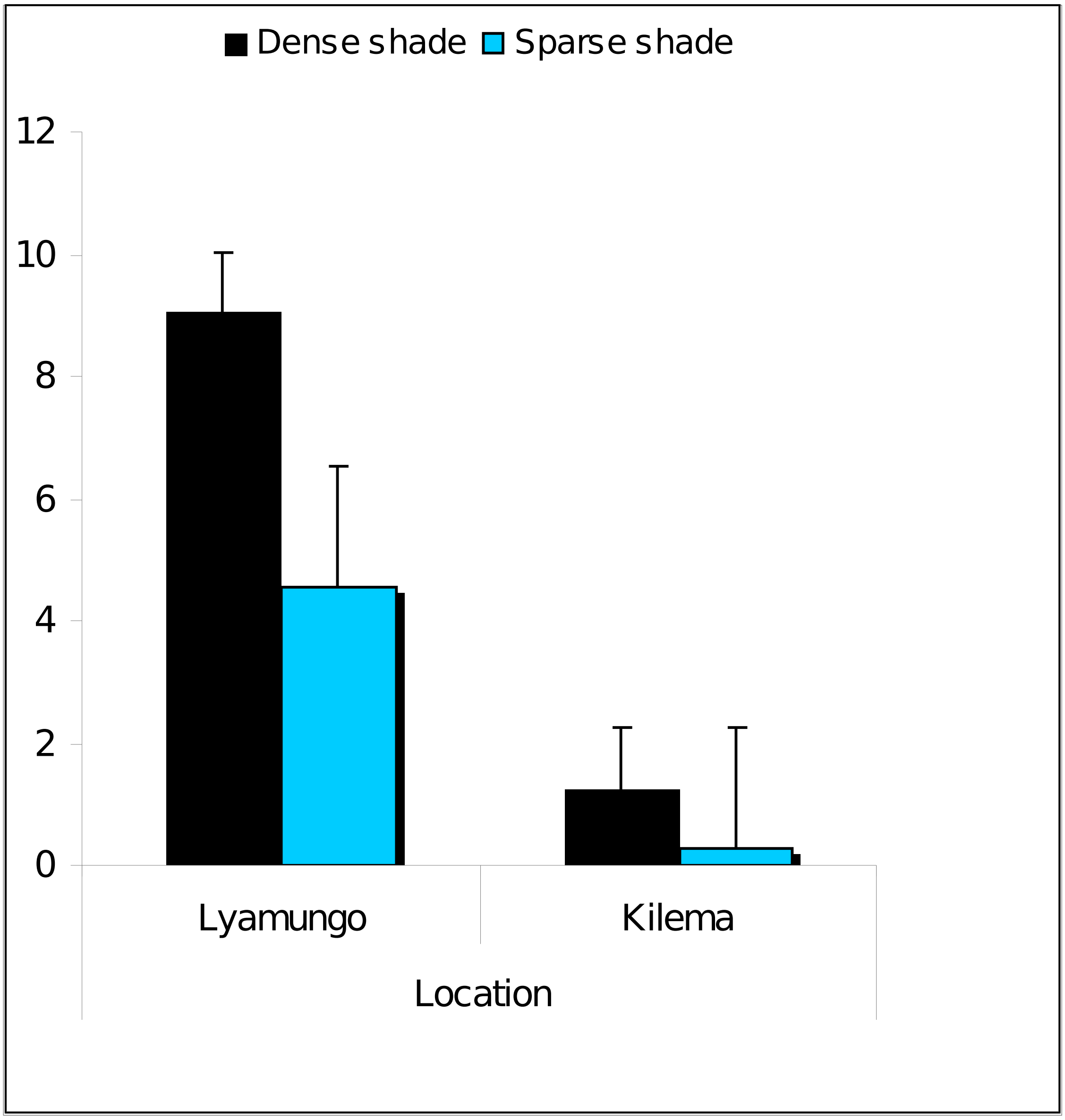


Figure 6: Population abundance of antestia bug between locations and microclimate

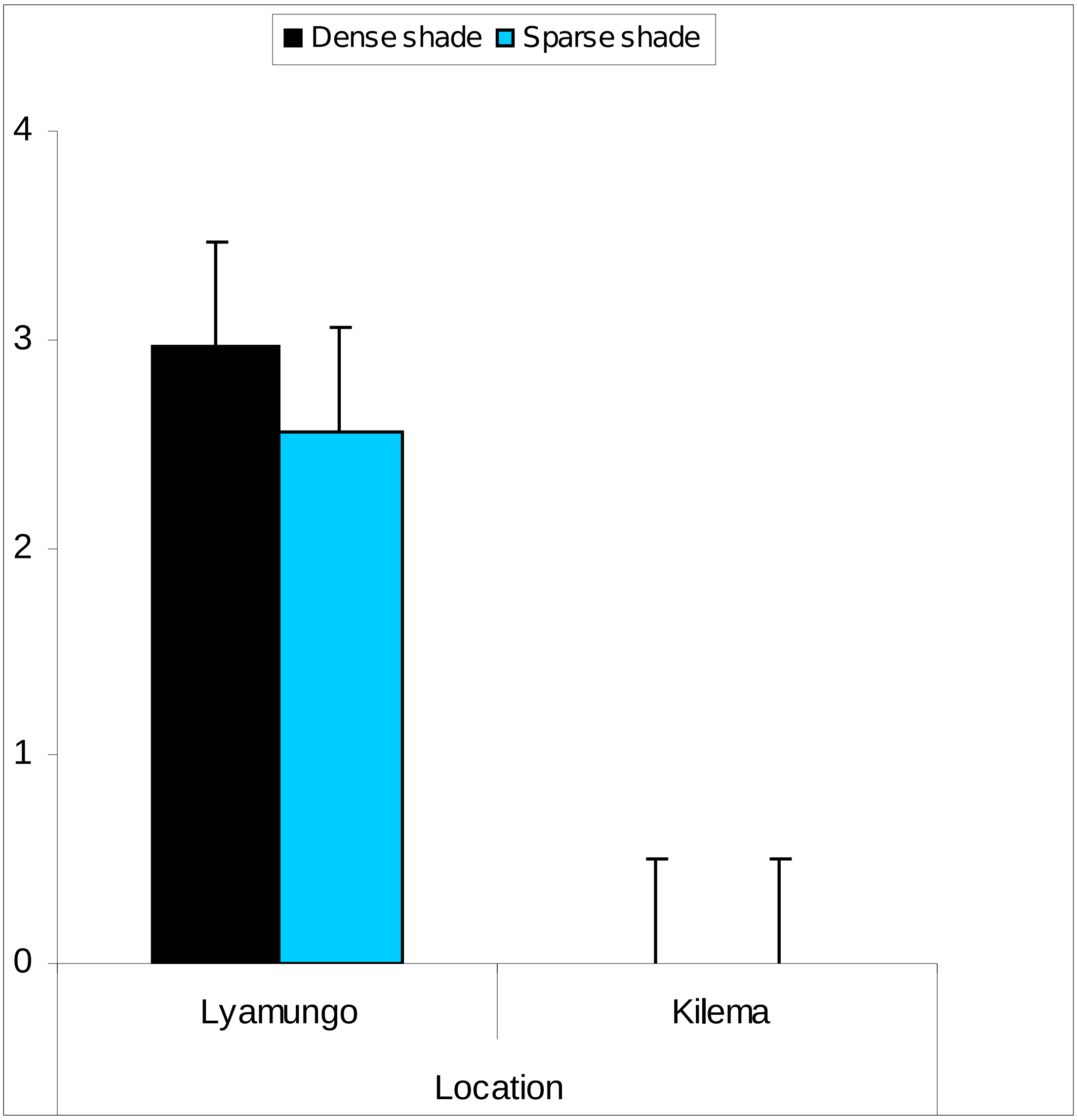


Figure 7: Population abundance of CBB between locations and microclimates

4.1.5 Species diversity and similality

The number of insect pests varied between altitudes and microclimate (dense and sparse shade) (Appendix 13). Shaded coffee, including many tree species is known to support generally high diversity of insects (Richer *et al.*, 2007). However in the study area many farmers have abandoned their farms, hence creating a new type of ecosystem, which has attracted increasing interest for biodiversity conservation. The Jaccard's similarity coefficients index of 0.95 shows a greater similarity between the habitats and species composition in the study area. Areas with closely related vegetations have no marked variation in species composition (Mulungu *et al.*, 2008). Jaccards index of distribution confirmed that the two locations are almost similar and may be closely related in terms of vegetation cover. However, the abundance of WCSB and antestia bugs in all locations and the absence of CBB in the higher altitude ecological zone have contributed to 5% less Jaccard index.

4.1.6 Species diversity

Species diversity was highest in September (1.036) and October (1.059) and lowest in January (0.682) at Lyamungo. In September and October the diversity was higher as compared to other months of the year because the number of both species was abundant due to availability of food for all species in the field (Appendix 13). On the other hand, the species diversity was low and the population abundance of both CBB and antestia bugs were also low in the rest of the year hence decreasing the diversity of pest individuals in the ecosystem. This may be attributed to the unavailability of food in the field especially for those species which depend on flowers and berries like antestia bug and CBB.

However, results obtained at high altitude (Kilema) indicated that the species diversity of the two coffee insect pests (antestia bugs and CBB) was low. WCSB is the only coffee pest which is more prevalent and occurs in larger numbers in this location. Hence, due to low population levels of antestia bug and lack of CBB in all year round makes the location to have low species diversity.

4.2 Temporal variation in abundance of insect pests in study areas

Temporal variations of abundance of WCSB, antestia bugs and CBB are presented in Fig. 8, 9, 10, 11, and 12. The results indicated that there were significant differences ($P \leq 0.05$) in population abundance of WCSB and antestia bugs. However, no significant differences were observed between population abundance of the pest with respect to relative humidity and rainfall. The fluctuations of the population of WCSB were negatively correlated with temperature. Population abundance of the pest decreased significantly ($P \leq 0.05$) with increasing temperature, while for antestia bugs, the population abundance increased with increasing temperature.

4.2.1 Temporal variation in abundance of WCSB in relation to abiotic factors

The results indicated that the infestation of WCSB persists throughout the cropping season of the year; however a gradual increase of WCSB occurred in November and February to March in both medium and high altitude agro-ecological zones (Fig. 8 and 9). This is probably due to the onset of rains. Le Pelley (1968) and Knight (1939) reported that activities of these pests particularly reproduction, and ultimately an increase in population occurs with the onset of the rains. In Kenya, Knight (1939) observed that many pupal chambers were excavated in November to December and March to April and the adults leave the chambers two to three- weeks after emergence, generally about a week after the heavy fall of rain.

The results are also in line with the report by Coste (1992) who indicated that the pest is particularly widespread in the high altitudes regions in East Africa although it was not mentioned up to what altitude level. A similar report reported by Knight (1939) in Kenya indicated that the pest has been recorded attacking coffee at altitudes of up to 1615.4 m .a s. l (5,300ft).

Contrary to the above report, the farmers' perspectives in Kilema are that in the past WCSB was not common, but it is currently a serious problem. It is not certain what caused this to happen. It might be a change in weather conditions, leading to an increase in temperature at Kilema which favour an increase of the population abundance of WCSB. Another factor, which may contribute to differences in abundance, is the management practices in coffee farms. During the study was observed that most of coffee farms in the study area were neglected. Wallner (1987) reported abandoned coffee farms act as breeding sites for WCSB which migrate to nearby farms.

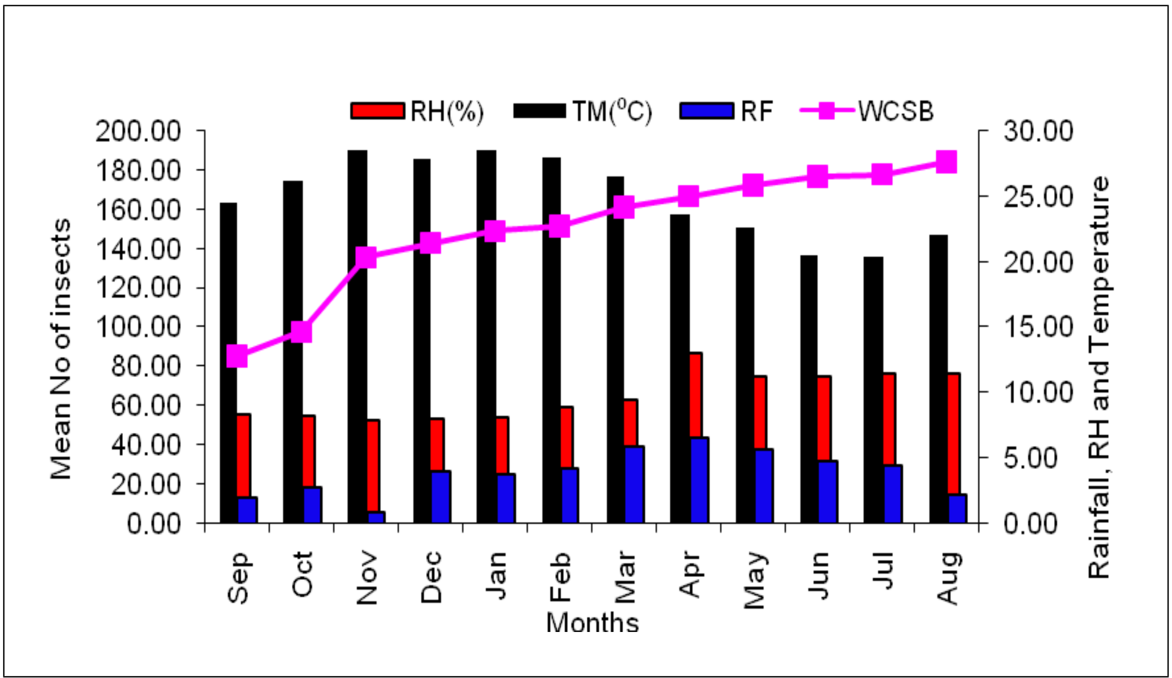


Figure 8: Population dynamics of WCSB at Lyamungo

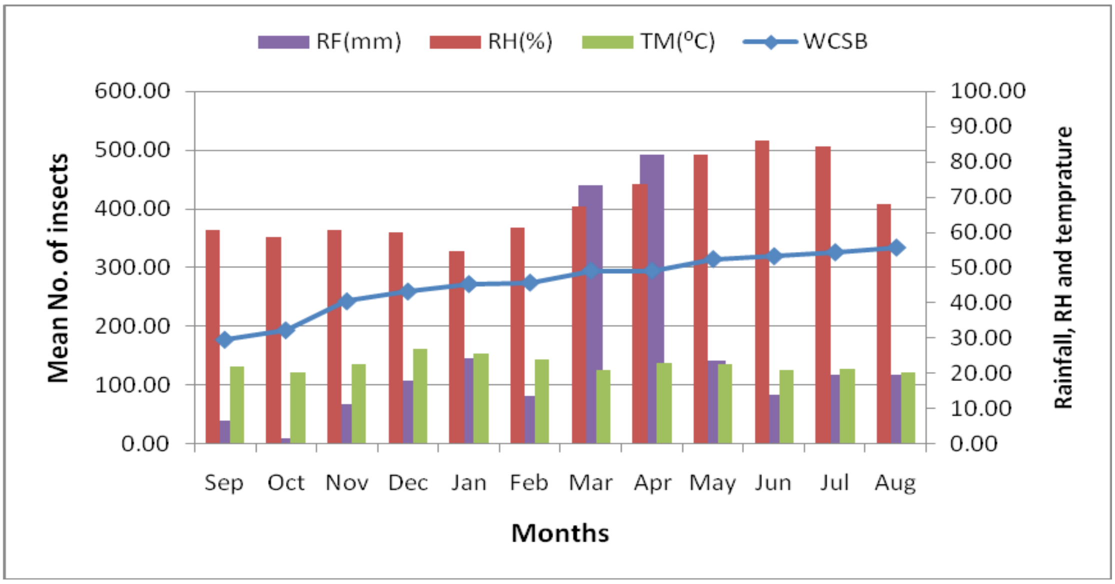


Figure 9: Population dynamics of WCSB at Kilema

4.2.2 Temporal variation in abundance of antestia in relation to abiotic factors

The population abundance of Antestia bugs showed a marked increase in numbers between November and February at both high and medium altitude areas than the rest of the months (Fig. 10 and 11). These observations could suggest that climatic changes were responsible for changes in the insect population abundance. Population of antestia bugs is known to increase with an increase in temperature which shortens the life cycles and results to many generations of the pest within a short period of time and hence an increase of the population abundance (Makundi, 2007; Canon, 1998; Robinson, 1964; Le Pelley, 1968). For example, the pest requires about eight weeks completing its life cycle in warm weather and about four months in cold weather (Robinson, 1964). This may explain why the population of antestia bugs was low at the higher altitude where the temperature is relatively low (Fig. 10 and 11) and higher at the medium altitude (Lyamungo), where temperatures are much higher. Kilema is cooler and is at high altitude ranging between 1600 to 2100 m a.s.l. as compared to Lyamungo which is a medium altitude (1200 to1600 m. a.s.l) and warmer.

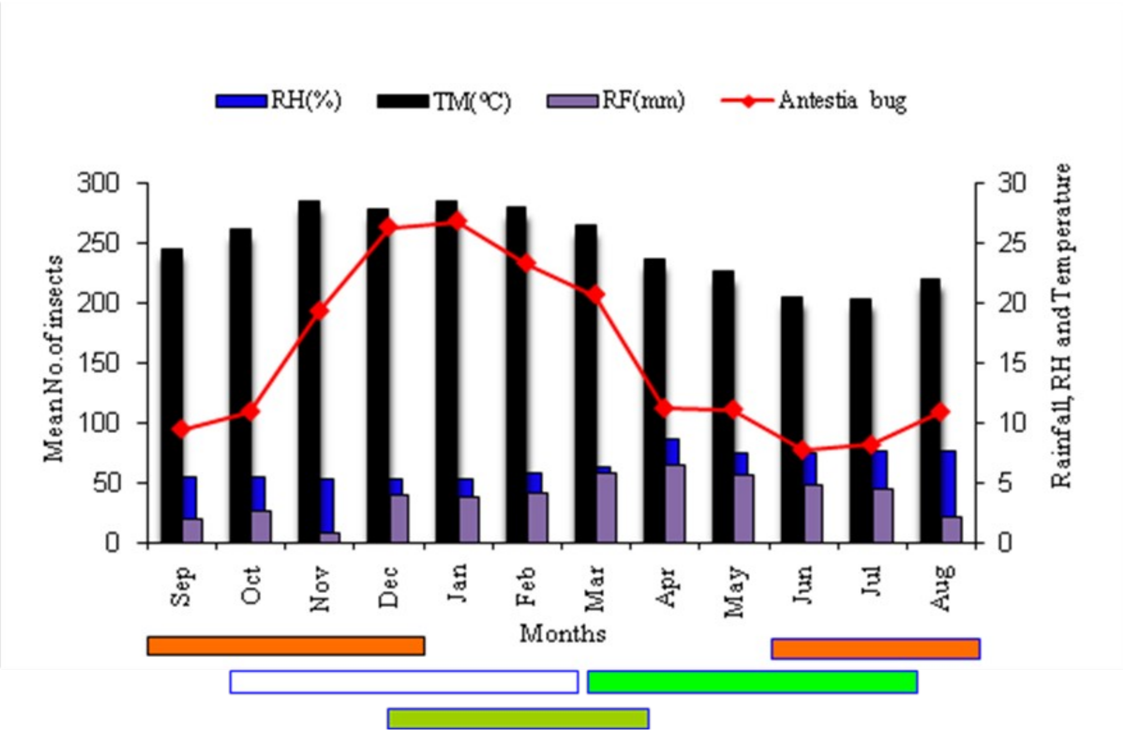


Figure 10: Population dynamics of antestia bugs at Lyamungo

Key:

Flowering (flower buds and inflorescent buds)

Small green berries

Large green berries

Ripe and overripe berries

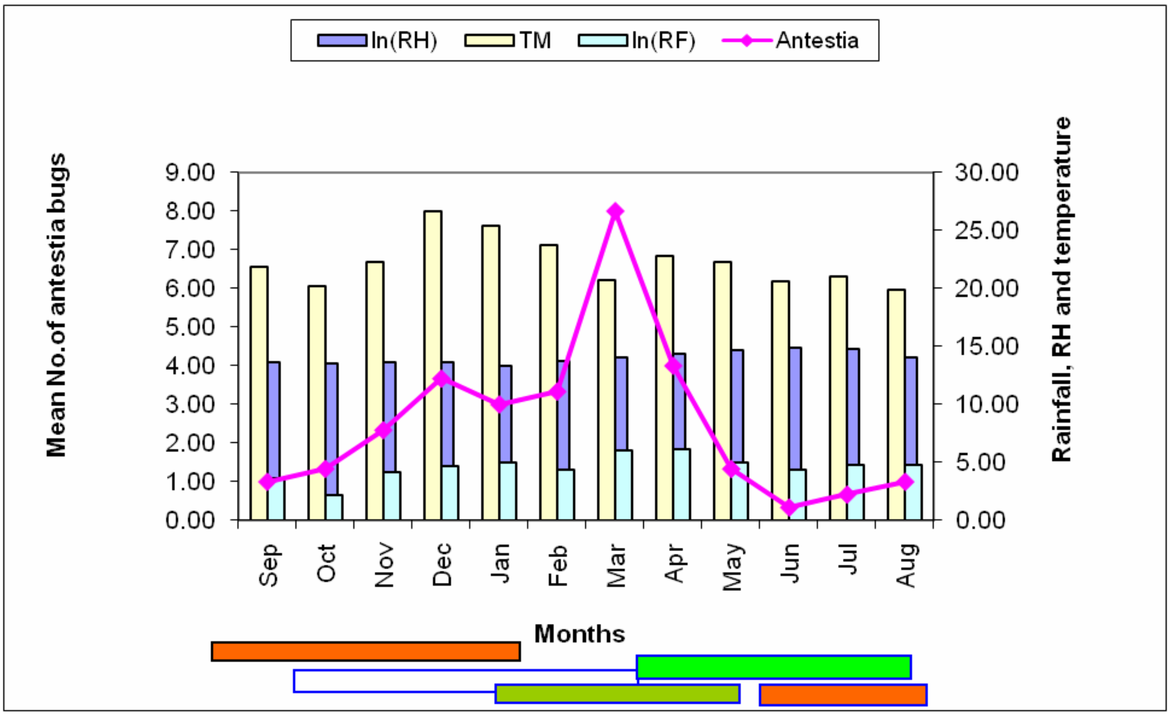


Figure 11: Population dynamics of antestia bugs at Kilema

Key:

Flowering (flower buds and inflorescent buds)

Small green berries

Large green berries

Ripe and overripe berries

4.2.3 Temporal variation in abundance of CBB in relation to abiotic factor

The population abundance of the coffee berry borer (CBB) was high in November to April and decreased from September to March (Fig. 12). This may be due to the fact that at this time there were few coffee berries in the field which the pest depends on for food. Report by Le Pelley (1968) indicated that insects like CBB that use coffee berries as breeding sites maintain high population in the presence of fruits especially over a long period. The insect thrives and breeds in the hardened maturing fruits. When there are few fruits in the field during the stripping off of fruits at the last season (observed in November to January in the study period), the population abundance' decreases to low levels (Fig. 10). In November to April there was an increase in population levels due to the formation of fruits in the field, where by the pest started to establish itself by infesting the new young fruits, large green berries, ripe, over ripe and dried fruits.

CBB were not recorded at Kilema during the study period. Reports by Wrigley (1988) and Le Pelley (1968) in Uganda and Kenya indicated that the pest is favoured by low-altitude Arabica coffee, and is seldom serious over 1370m (4500ft) rare at 1525m, and has not been found at 1680m. Similarly, another report has indicated that low temperatures and relative humidity under 50% are limiting factors for its development (Jansen, 2005). For this reason, it is less problematic in areas above 1500 m in the tropics (Jansen, 2005). These findings suggest that the pest is not yet able to establish at the higher altitudes like in Kilema where the temperature is low compared to the medium altitude of Lyamungo.

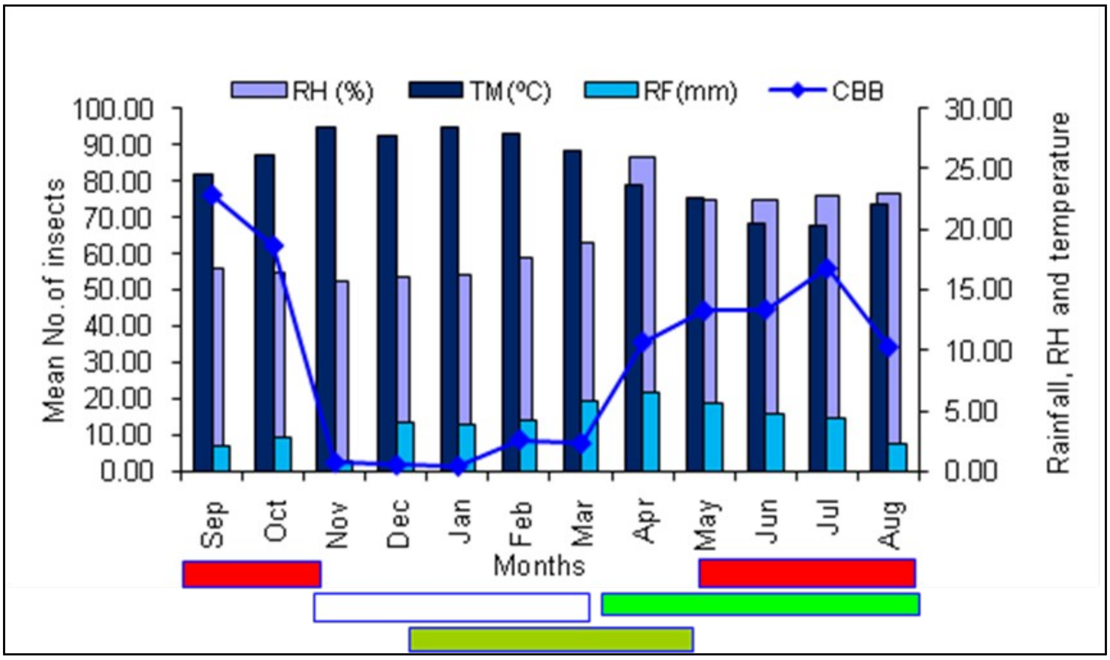


Figure 12: Population dynamics of CBB at Lyamungo

Key:

Flowering (flower buds and inflorescent buds)

Small green berries

Large green berries

Ripe and overripe berries

4.2.4 Weather pattern (wet and dry seasons)

Results of rainfall recorded in the study area are presented on Appendix 9 and 10. During the short and long rains high populations of pests occurred, hence rainfall conditions had strong influence on abundance of this insect pest. Population changes of the important pests under study are discussed in relation to weather conditions (wet and dry). The discussion is based on weather because the availability of food (flowers and fruits) which is an important factor for the increase in population for antestia bug and CBB is determined by rainfall. Also WCSB normally emerges from coffee stem during the beginning of short and long rains (Le Pelley, 1968).

Kilimanjaro region has a bimodal rainfall pattern (with a long and short rain seasons). The long and short rainy seasons normally occur in November to December and February to May, respectively. The short and long seasonal rains have a major effect on coffee flowering, fruit setting and fruit formation (Coste, 1992).

Temperature has a direct effect on the insect's abundance. Seasonal variations of weather parameters have direct effect on the coffee plant as well as the abundance of the pests in the field. Weather parameters also have direct effect on the biology of coffee pests. For example the life cycle of Antestia bugs – *Antestiopsis* spp (*A. orbitalis* and *A. intricata*) on coffee have shorter life cycles with increasing temperature (Makundi, 2007; Le Pelley, 968; Robinson, 1964). The lifecycle requires about eight weeks to be completed in hot weather and up to four months in cold weather (Robinson, 1964). Appendix 9 and 10 show weather parameters recorded during the current study, while appendix 7 shows the six years (2002 to 2007) monthly averages of weather parameters. This year was generally wet all over the months hence it was very difficult to partition the wet and dry seasons.

4.2.5 Temporal variation in abundance of WCSB, antestia bugs and CBB in relation to fruit phenology

The population abundance and infestation levels of the three insect pests are also discussed in association with the stage of fruit phenology throughout the study period. The results show an increase in population abundance of antestia bugs and CBB when flowers and fruits are present in the field (Fig. 10, 11 and 12). However, WCSB does not depend on fruit phenology but depends on coffee stems for survival in the field (Fig. 9 and 10). The antestia bug was observed to be abundant from November to March, which is the period for flower formation and fruit setting. On the other hand, CBB decreased in November to March due to the absence of fruits and increased in other months of the year because of fruit presence in the field. These results are consistent with the report by Le Pelley (1968) that insects that breed in the coffee and attack flowers and those that attack the berries (like CBB and antestia bug) can be expected to maintain themselves in high population if flowers or berries in the right stage are available especially over long periods. This is because the pests depend on fruits (young cherries and ripe) for food. Further, the study by Robinson (1964) indicated that antestia bug populations increase considerably at the time of cherry development, i.e. from flowering to the long rains.

4.3 Relative importance of WCSB, antestia bugs and CBB in coffee ecosystems

Assessment of crop damage is vitally important for implementing proper management strategies. For insect pests' management, fields should be scouted several times of the year depending on the type of the pest to adequately monitor changing pest populations. Longer periods between field monitoring can mean detecting pest damage only after significant losses have occurred. Insect pests that permanently live on the perennial crop like coffee always take advantage of particularly favourable conditions that cause serious damage to the crop leading to a population explosion (Le Pelley, 1968).

Results on the damage associated with the three important pests are presented in Table 4. Damage assessments were undertaken for the same coffee insect pest at the same locations so that better management strategies could be devised. In general, all insects in the two locations caused on average, damage ranging from 22.4 to 36.01%. However damage by WCSB was estimated to range from 44.8 to 67.7 % followed by CBB (0 to 4.32% in both locations. In separate locations damage of WCSB ranged from 35.1% to 66.9% at Lyamungo and 54.6% to 68.6% at Kilema (Table 4). The damage associated with CBB ranged between 0 to 8.63%) % and it was only found at the medium altitude and no damage was observed at high altitude (Table 4). These result indicated that WCSB was a problem at both high and medium altitudes, while antestia bug was more problematic in the medium altitude as compared to high altitude. On the other hand CBB was only problematic in the medium altitude and was not observed in the high altitude ecological zones.

Table 4: Damage caused by WCSB and CBB

Location	**Percent damage**	
	WCSB	CBB
Lyamungo	35.1 - 66.9	0 - 8.63
Kilema	54.6 - 68.6	0 - 0
Total mean	**44.8 - 67.7**	**0 - 4.32**
Grand mean	**22.4 – 36.01**	

4.3.1 Damage of coffee caused by WCSB

There was significant variation in the number of WCSB infesting coffee trees in both locations (Fig. 13). The infestation level of borers per tree ranged from one to ten borers. However most of the trees had about 1-2 borers and very few had 10 borers/tree. A comparison of coffee damage for the three insect pests indicated that WCSB is the most serious pest followed by antestia bug and CBB in the study area. These results confirmed the farmer's assertion during a survey by Magina *et al.* (2007) in Hai district that WCSB ranked high followed by antestia bug and CBB in economic importance. However, the overall pest of economical importance across the study area (Hai and Moshi rural districts) was antestia bug followed by WCSB and CBB. WCSB was noted by farmers to contribute a greater loss by killing the coffee trees in coffee plantations. The damaging stage of the pest is larva (Plate 7). Every year farmers are stumping infected coffee trees for rejuvenating. Other highly damaged trees are uprooted completely and replaced with new coffee trees (Plate 8). The trend of infestation (Fig. 14) shows that the pest has a greatest potential to steadily increase in severity. A study by Wrigley (1988) indicated that coffee trees growing on eroded or shallow soils or near shade trees are particularly liable to attack. Adult white coffee stem borer is shown in Plate 6.

Plate 6: Adult white coffee stem borer (*Monochumus leuconatus* Pascoe)

Plate 7: Larva of white coffee stem borer (*Monochumus leuconatus* Pascoe) in the coffee stem

Bore holes in the stem

Plate 8: Stumped coffee tree after heavy infestation by WCSB in coffee plantations

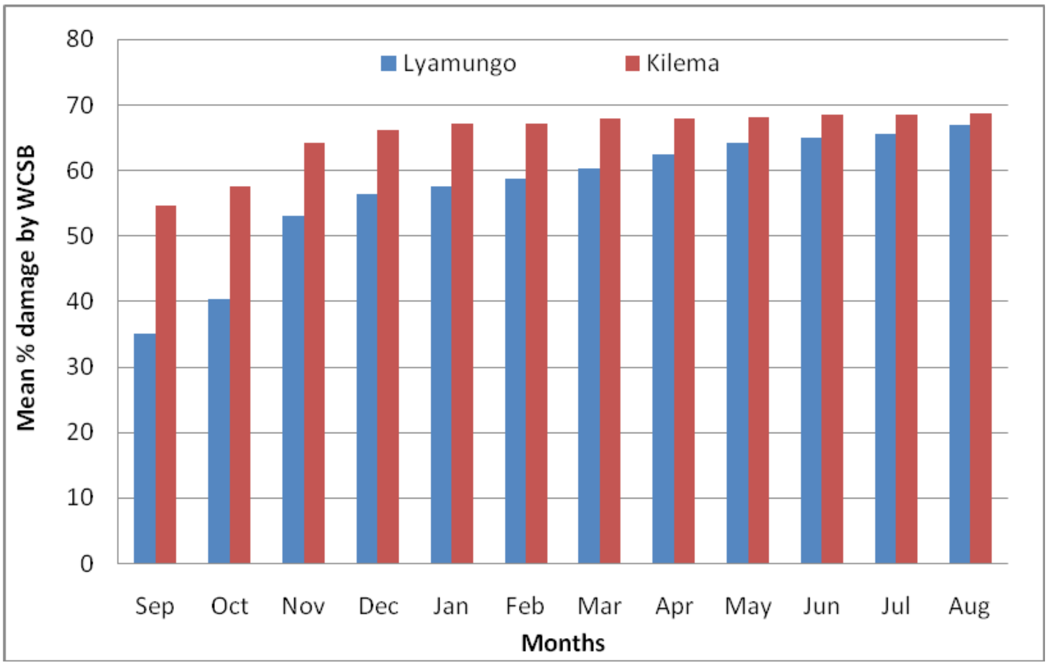


Figure 13: Estimated percentage damage of coffee by WCSB at Lyamungo and Kilema

4.3.2 Damage of coffee caused by antestia bug

In the case of antestia bug the infestation period was between November to April in all locations (Fig. 10 and 11). Estimate of damage was not made for this pest.

4.3.3 Damage of coffee caused by CBB

Results of damage caused by CBB are presented in Fig. 14. The results indicated that the pests caused a progressive damage from March to October and diminished in November. The damage ranged from 0 to 25 %.(Table 4 and Fig. 14). The damage trend coincides with the development of fruiting in coffee in the medium altitude ecological zone. CBB in Ethiopia has been observed to exist under a wide range of altitudes ranging from 1200 at Tepi to 1900 m.a.s.l. A study by Mendesil *et al.* (2004) showed the mean percentage damaged berries ranged from 8-60%. A study by Wrigley (1988) indicated that more attacks occur where the coffee is grown under heavy shade or is closely planted and un-pruned. A single very large, dense shade tree can attract the pest and cause a serious local infestation. The fruits of wild coffee growing in the dense forest are frequently heavily infested. In Brazil the infestation is greater in damp, shaded plantations than in dry, open areas (Wrigley, 1988). Sometime, during periods of severe infestation more than one female may bore into a single berry, each female with its own entrance hole (Wrigley, 1988).

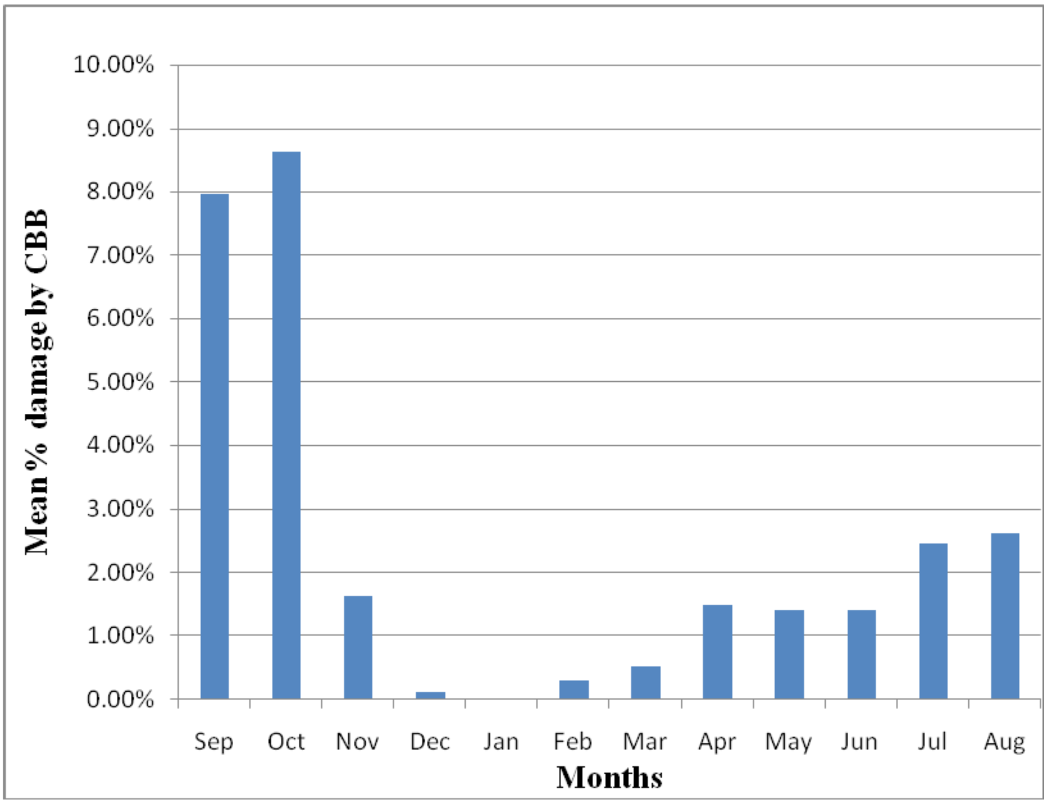


Figure 14: Estimated percentage damage of coffee by CBB at Lyamungo

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

Based on the results, the following conclusions and recommendations can be drawn from this study:

5.1 Conclusions

a) The important insect pests, which are widely distributed in Kilimanjaro are WCSB and antestia bugs. However, WCSB is possibly a potentially important pest in the area because it is found abundantly in all locations unlike antestia bugs and CBB which are found in low numbers or were not found in other areas of the study. Antestia bug was found to be an important pest in the medium altitude and very little in the upper altitude. CBB was found to be an important pest only in medium and possibly in lower altitude ecological zone.

b) The WCSB was significantly abundant in all locations in the study area compared to antestia bugs and CBB and the most damaging insect pest in the small holder farmers' plantations in Kilimanjaro region.

c) The species diversity and distribution pattern of major coffee insect pest appears to be largely attributed to different ecological zones, which are complex and heterogeneous.

5.2 Recommendations

The study has come out with information that is pre-requisite for formulating an effective IPM program for the major coffee insect pest in Kilimanjaro region. The important information generated out of this study includes the relative importance of the insect pests, spatial and temporal distribution and abundance. From the findings of this study, suitable and sustainable ecologically based IPM program can be formulated and used in the farmer's fields.

From these, results it can be recommended that:

a) Management strategies for WCSB should be geared towards encouragement of proper shading recommended for the pest. This could be done by planting more shade trees in all sparsely shaded farms with the light intensity between 20 to 40 lux.

b) For management of antestia bug, the proper management of shades by pruning the coffee and trees so as to improve the aeration within the plant canopy. Proper pruning will help to deny the antestia bugs the hiding grounds, and will expose it to adverse weather conditions such as less light to penetrate and air to circulate thus reducing the humidity and temperature in the canopy. More studies are needed to determine the actual damage of this pest because it was not established in this study due to time limitation.

c) At present CBB is not a problem in the high altitude and minimal in the medium altitude, but may possibly migrate to high altitude where it was not found during the study period. Therefore, it is important that the pest be monitored during the crop phenology. Suitable and sustainable means of prevention of the spread to higher altitudes should be devised. Such methods includes: shade management (prune regularly to reduce heavy shade for both coffee tree and shade trees), trapping adult CBB by use of alcohols, chemical spray and proper field hygiene (by removal of left over berries and off-season crop immediately prior to flowering to avoid carry-over of the pest from one season crop to the next), picking by using mates in the ground to minimize fruit that fall on the ground (gleanings), banning the movement of coffee cherries from infested to un-infested areas or borer free areas.

d) From damage assessment data, WCSB is more responsible for crop damage in both medium and high altitudes; hence more pest management strategies are advised towards the control of WCSB.

e) The infected plants with WCSB should be removed every year before the flight periods to prevent escape of the adult beetles back into the farmers' fields. If this is not done regularly, the cumulative effects of spread from neglected farms to well maintained farms would be very severe.

f) Further studies are recommended for the management of WCSB, in order to reverse the reduction of production of coffee caused by increased killing of coffee trees as a result of WCSB infestation.

REFERENCES

Abebe, M. (1987). Insect pests of coffee with special emphasis on antestia bug, *Antestiopsis intricate*, in Ethiopia: Advances in research on tropical entomology. *Insect science and its Application* 8(6): 977 - 980.

Anderson, T. J. (1919). *The Coffee Bug, Antestia lineaticollis*, Britain East Africa. Department of Agriculture Division, Nairobi, Kenya. 53pp.

Bardner, R. (2006). Pest Control in Coffee: Pest Control for Major Tropical Crops. *Pesticide Science* 9(5): 458 – 464. [www3.interscience.wiley.com/cgi-bin/home] site visited on 13/11/2009.

Bohlen, E. (1978). *Crop Pests in Tanzania and Their Control.* Agency for Technical Cooperation, Ltd (Gtz), Berlin, Germany. 142pp.

CAB International (2005). Crop Protection Compendium. CAB International, Wallingford Oxford, UK. [www.cabicompedium.org/CABI] site visited 25/7/2008.

CAB International (2007). Crop Protection Compendium. CAB International, Wallingford Oxford, UK. [www.cabicompedium.org/CABI] site visited 11/10/2008.

CABI/EPPO (2005). *Monochamus leuconotus:* Distribution Maps of Plant Pests. CAB International, Wallingford, UK. [www.cabicompedium.org/CABI] site visited 25/7/2008.

Cannon, R. J. C. (1998). The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global Change Biology* 4(7): 785 - 796.

Caresche, L. (1938). Preliminary report on the coffee berry borer in Phu-qui (Annam): A study of its ecology and economic impact on coffee estates. *Economic Bulletin* 41: 836 – 50.

Coste, R. (1968). *Coffee*. Maisonneuve and Larose, Paris. 310pp.

Coste, R. (1992). *Coffee, the Plant and the Product*. The Macmillan Press Ltd, London. 328 pp.

Davies, R. M. (1937). The control of white stem borer of coffee. *East African Agricultural Journal* 2(4): 293 - 297.

Duffy, E. (1957). A monograph of the immature stages of African timber beetles (Cerambycidae). *Journal of Insect Science* 38(41): 113 - 117.

FAO (2006). FAO Statistics. Rome, Italy. [http://www.faostat.fao.org/site/htm] site visited on 30/12/2006.

Fergnani, P., Sackmann, P. and Cuezzo, F. (2008). Environmental determinants of the distribution and abundance of the ants, *Lasiophanes picinus* and *L. valdiviensis*, in Argentina. *Journal of Insect Science* 8(36): 1 - 21.

Grant, I. F. and Tingle, C. C. D. (2002). *Hand Book: Ecological Monitoring Methods for the Assessment of Pesticide Impact in the Tropics.* Natural Resources Institute, University of Greenwich, London, UK. 266pp.

Hillocks, R. (2001). Coffee: Is it still a viable cash crop for smallholders in Africa? *Journal of Insect Science* 30(3): 205-212.

Indigo Guide (2008). Your Online Travel Companion. [Http:/indigoguide.com/Kilimanjaro/weather.htm] site visited on 04 /08/2008.

Jacard, P. (1901). A study to compare the variation in flora between areas in the Alpes and in the Jura. *Social Bulletin of Natural Science* 37: 547-579.

Jansen, A. E. (2005). *Recommendations for the Common Code for the Coffee Community-Initiatives.* Published by Deutsche Gesellschaft für Technische Zusammenarbeit, Germany. 65pp.

Kimani, M., Little., T and Vos, J. G. M. (2002). Introduction to Coffee Management through Discovery Learning. In: *Farmer Participatory Training and Research Programme. IPM Source Book.* [http://wwww.CABI-Bioscience.org] site visited on 18/2/2007.

Knight, C. D. (1939). Observations on the life-history and control of the white borer of coffee in Kenya. *East African Agricultural Journal* 5(1): 61 - 67.

Kothari, C. R. (2004). *Research Methodology Methods and Techniques,* 2nd Edition. New age international (P) Limited Publishers, New Delhi- India. 401pp.

Koul, O and Cuperus, G.W. (2007). Ecologically Based Integrated Pest Management: Present Concept and New Solutions. In: *Ecologically Based Integrated Pest Management* (Edited by Koul, O and Cuperus, G.W). Biddles Ltd, King's Lynn, UK. pp. 1 – 17.

Krebs, C. J. (2001). *Ecology: The Experimental Analysis of Distribution and Abundance*. Wesley Longman, Inc., New York. 695pp.

Kyamanywa, S., Ogwang, J. A. and Kucel, P. (2006). *Biological Monitoring of Arabica Coffee Insect Pests in the Mount Elgon Area.* Makerere University, Kampala, Uganda. 10pp.

Le Pelley, R. H. (1942). The food and feeding habits of antestia in Kenya. *Bulletin Entomological Research* 33: 71 - 89.

Le Pelley, R. H. (1968). *Insect Pests of Coffee.* Longmans, London,UK. 590pp.

Lyamungu Research and Training Institute (1997). *Recommended Technologies in Coffee Production*. Ministry of Agriculture and Food Security, Tanzania. 12pp.

Lyons, D. J., Dunworth, P. M and Tilbury, D. W. (2000). Ecological sampling method. [http://www.countrysideinfo.co.uk/biol_sampl_cont.htm] site visited on 26/04/2007.

Magina, F. L., Mbowe, D. F and Teri, J. M. (2005). *Trapping Adult Coffee Berry Borer (Hypothenemus hampei Ferrari) Using Different Alcohol Traps.* Proceedings of the Tanzania Entomological Association (TEA), 6th Annual Scientific Conference. (Edited by Kilonzo, B. S. *et al*.), *28th* -30th, November, 2005, Arusha-Tanzania. 21pp

Magina, F. L., Maro, G. P., Monyo; H. E., Nkya, E. O., Mbowe, D. F., Malinga, S. E., Kisanga, V. E., Lyatuu, U. A., Manento, W. S; Teri, J. M and Maerere, A. P. (2007). *The important insect pests of Arabica coffee Coffee arabica and management practices by farmers in Hai and Moshi rural districts, Kilimanjaro region, Tanzania.* Proceedings of the Tanzania Entomological Association (TEA), 7th Annual Scientific Conference. (Edited by Makundi, R.H. *et al*.), 28 – 30th November 2007, Arusha, Tanzania. 30pp

Makundi, R. H. (2007). I*mpact of climate change on infestation of crops by pests and disease outbreaks.* Preceedings of the Tanzania Entomological Association (TEA), 7th Annual Scientific Conference. (Edited Makundi, R. H. *et al*,.), 28 – 30th November 2007, Arusha, Tanzania. 20-21pp

Mayne, W. W., Narashimhan, M. J and Sreenivansan, K. H. (1933). 'Spraying of coffee in South India', *Journal of Entomological Research*. 9: 66pp.

Mbungua, J. N. (1995). *Control of Insect Pest*. Kenya Coffee, Nairobi, Kenya. 70pp.

Mcharo, E. Y. (1980). *Entomology Progress Report*. Moshi, Tanzania. 13pp.

Mcnutt, D. N. (1979). Control of *Antestiopsis* spp on coffee in Uganda. *Journal of Entomological Research* 25: 5 - 15.

Mcnutt, D. T. (1960). The white coffee borer, *Anthores leuconotus* Pascoe and its control. *Bulletin of Entomological Research* 51: 279 - 301.

Mendesil, E., Jembere, B., Seyoum, E and Abebe, M. (Eds.) (2004). *The Biology and Feeding Behaviour of the Coffee Berry Borer, Hyppothenemus hampei (Ferrari) (Coleoptera: Scolytidae) and its Economic Importance in Southwestern Ethiopia*. Proceedings of the 20th International Scientific Conference on Coffee. ASIC, Bangalore, India, 11 – 15 October 2004. 45-51pp.

Mulungu, L. S., Makundi, R. H., Masawe, A. W., Machang'u, R. S and Mbije, N. E. (2008). Diversity and distribution of rodent and shrew species associated with variations in altitude on Mount Kilimanjaro, Tanzania. *Mammalia Journal* 72: 178-185.

Murphy, S. T. and Moore, D. (1990). Biological control of the coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae): Previous programmes and possibilities for the future. *Bio control News and Information* 11: 107 - 117.

Oduor, G. I. and Simons, S. A. (2003). *Biological control in IPM for coffee.* CAB International-Africa Regional Centre, Nairobi, Kenya. 347 - 362pp.

Richter, A., Klein, A. M., Tscharntke, T and Tylianakis, J. M. (2007). Abandonment of coffee agro forests increases insect abundance and diversity. *Agrofrestry Systems* 69(3): 175 - 182.

Robinson, J. B. D. (1964). *A Hand Book on Arabica Coffee in Tanganyika*. Tanganyika Coffee Board, Lyamungu, Tanzania. 182pp.

Schoeman, S. (1998). Pest Management Programme: White stem borer. [http://science.dec.wa.gov.au/] site visited on 25/07/2007.

Smith, A. H. (1996). *The Integrated Pest Management (IPM) Concept: Integrated Pest Management Fact Sheet.* Utah State University, Logan, USA. 67pp.

Sreedharan, K., Vinod Kumar., P. K and Basavaraj (2005). Coffee white stem borer and its effective management. *Indian Coffee Board Monthly Bulletin* 38(19) 17 - 24.

Stambuli, M. (1988). The problem of coffee insect pest in Tanzania. In: *TARO Newsletter* Lyamungu-Moshi, Tanzania. 10 – 14pp.

Strategic Action Plan (2002). *Tanzania Coffee Research Institute (TaCRI).* Lyamungu-Moshi, Tanzania 49pp.

Subramaniam, T. V. (1934). ‘The coffee stem borer’. *Journal of Entomological Research* 11: 18 - 21.

Tanzania Coffee Board. (2001). *Coffee Sector Strategy 2001/2006*. Ministry of Agriculture, Dar es Salaam, Tanzania. 45pp.

Tanzania Coffee Research Institute. (2007). *Baseline Survey Report for Arabica Coffee (Coffee arabica) in Hai and Moshi rural District.* Tanzania Coffee Research Institute (TaCRI), Moshi, Tanzania. 21pp.

URT (1996). *Coffee Production, Processing and Marketing*. Ministry of Agriculture, Dar es Salaam, Tanzania. 25pp.

Wallner, W. E. (1987). Factors affecting insect population dynamics: Differences between outbreak and non-outbreak species. *Annual Review of Entomology* 32: 317 - 340.

Waterhouse, D. F. and Norris, K. R. (1989). *Biological control: Pacific Prospects.* Australian Centre for International Agricultural Research, Canberra, Australia. 75pp.

Wrigley, G. (1988). *Coffee*: *Tropical Agricultural Series.* Longman Singapore Publishers Ltd, Singapore. 639pp.

Zar, J. H. (1999). *Bio statistical Analysis.* Prentice Hall, Inc. Upper Saddle River, New Jersey. 663pp.

APPENDICES

Appendix 1: ANOVA tables: Population dynamics of insect pests in locations and microclimates

Comparison of population dynamics of WCSB at two locations (Lyamungo and Kilema) and within microclimate

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	332.5657752	332.5657752	2.70	0.1039
Microclimate	1	820.0764596	820.0764596	6.66	0.0115
Location*microclimate	1	64.1214985	64.1214985	0.52	0.4724

Comparison of population dynamics of antestia bug at two locations (Lyamungo and Kilema) and within microclimates.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	481.3138234	481.3138234	48.51	<.0001
Microclimate	1	98.2206234	98.2206234	9.90	0.0023
Location*microclimate	1	40.7655125	40.7655125	4.11	0.0458

Comparison of population dynamics of CBB at two locations (Lyamungo and Kilema) and within microclimates

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	1	100.5919294	100.5919294	23.27	<.0001
Microclimate	1	0.5812805	0.5812805	0.13	0.7147
Location*microclimate	1	0.5812805	0.5812805	0.13	0.7147

Appendix 2: Population mean insect pest per month per three villages per location

	Lyamungo			Kilema	
Months	WCSB	Antestia bug	CBB	WCSB	Antestia bug
September	85.00	94.67	76.33	177.67	1.00
October	97.33	109.33	62.33	193.67	1.33
November	135.33	192.67	2.33	243.00	2.33
December	142.67	262.33	1.67	259.67	3.67
January	148.67	267.33	1.33	272.33	3.00
February	151.33	232.33	8.67	274.67	3.33
March	161.00	206.33	7.67	295.00	8.00
April	166.33	112.00	35.67	295.00	4.00
May	172.00	111.00	44.33	314.67	1.33
June	176.33	77.33	44.67	319.67	0.33
July	177.67	81.67	56.00	326.33	0.67
August	184.00	109.00	34.33	334.33	1.00
Mean	149.81	154.67	31.28	275.50	2.50

Appendix 3: Estimated percentage damage of CBB at Lyamungo

Months	Mulama (R1)	Lysinde (R2)	Lykati (R3)	Total%	Mean%	%damage/tree (n=135)
Sep	2390.12	696.17	135.83	3222.12	1,074.004	7.96
Oct	2203.38	1160.12	130.18	3493.68	1,164.56	8.63
Nov	142.85	413.37	100	656.22	218.74	1.62
Dec	42.85	0.00	0.00	42.85	14.28	0.11
Jan	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	85.28	28.22	113.5	37.83	0.28
Mar	81.83	97.21	24.38	203.42	67.81	0.50
Apr	297.23	186.04	117.3	600.57	200.19	1.48
May	174.41	225.39	164.89	564.69	188.23	1.39
Jun	127.05	271.08	169.74	567.87	189.29	1.40
Jul	348.02	445.75	196.76	990.53	330.18	2.45
Aug	383.44	507.07	166.89	1057.4	352.47	2.61

Appendix 4: Estimated percentage damage by WCSB at Lyamungo

Month	Lyamungosinde	Mulama	Lyamungokati	Total	Mean
Sep	45	38	59	305	35.05
Oct	55	42	66	378	40.25
Nov	70	65	80	444	53.09
Dec	74	73	82	462	56.43
Jan	74	77	82	471	57.53
Feb	78	78	82	482	58.77
Mar	78	84	82	497	60.25
Apr	85	86	82	513	62.46
May	89	89	82	523	64.2
Jun	92	89	82	528	64.93
Jul	94	89	82	536	65.43
Aug	97	90	84	3047	66.91
Total	931	900	945	2776	
Mean	77.58	75	78.75		

Appendix 5: Estimated percentage damage by WCSB at Kilema

Months	Ruwa	Makamijuu	Kyou	Total	Mean
September	68	57	96	454	54.57
October	79	57	97	493	57.53
November	90	70	100	528	64.2
December	92	70	106	540	66.17
January	92	74	106	544	67.16
February	92	74	106	547	67.16
March	92	74	109	550	67.9
April	92	74	109	551	67.9
May	93	74	109	553	68.15
June	94	74	109	554	68.39
July	94	74	109	555	68.39
August	95	74	109	3462	68.64
Total	1073	846	1265	6368	
Mean	89.42	70.50	105.42	777.58	

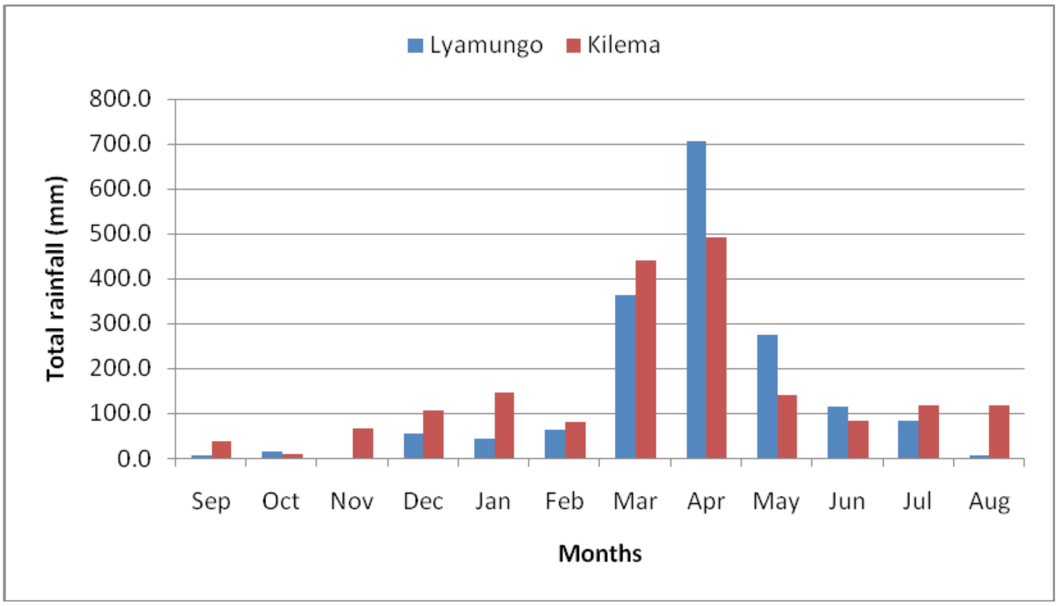
Appendix 6: Weather data between September 2007 – August 2008 at Lyamungo and Kilema

	Lyamungo			**Kilema**		
Months	RF(mm)	RH (%)	TM(ºC)	RF(mm)	RH (%)	TM(ºC)
September	7.80	55.80	24.50	37.20	60.40	21.86
October	15.50	54.68	26.08	8.55	58.67	20.20
November	2.35	52.57	28.46	65.60	60.45	22.32
December	55.30	53.60	27.79	105.90	59.72	26.62
January	46.00	53.98	28.49	144.90	54.55	25.46
February	65.80	59.03	27.87	79.60	61.28	23.71
March	364.30	63.00	26.40	438.70	67.06	20.75
April	704.90	86.43	23.60	491.70	73.53	22.77
May	277.10	74.71	22.51	141.10	81.90	22.27
June	115.60	74.93	20.50	83.10	86.00	20.58
July	85.80	76.16	20.32	115.90	84.42	20.99
August	9.40	76.29	21.99	117.00	67.74	19.90

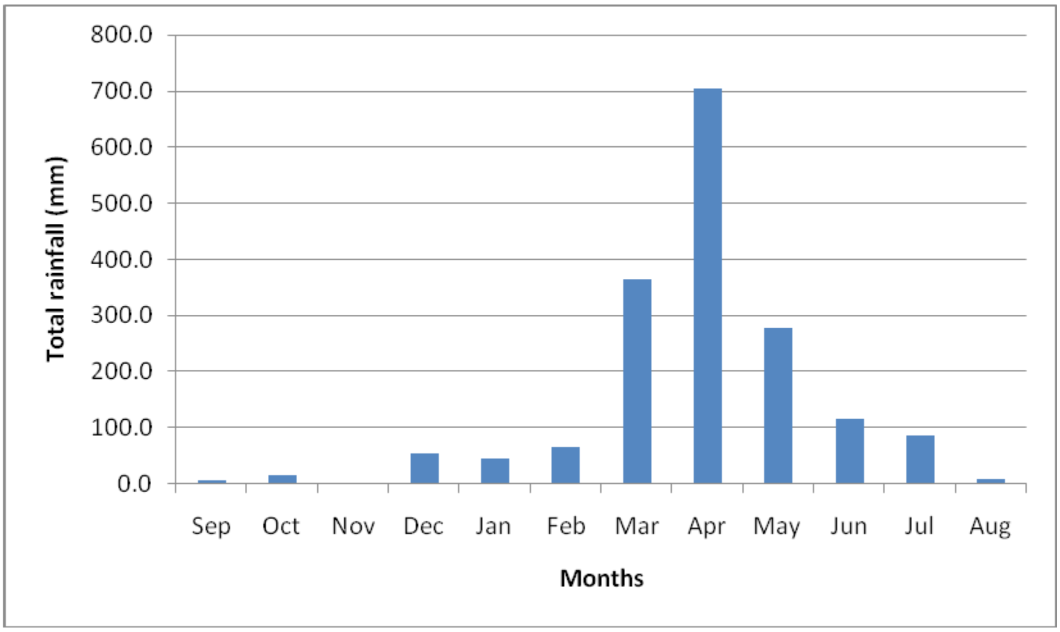
Appendix 7: Mean rainfall at Lyamungo for a period of six years 2002 - 2007

Months	Mean rainfall (mm)
January	2.10
February	1.24
March	2.55
April	12.95
May	11.48
June	2.86
July	1.29
August	1.42
September	0.79
October	1.88
November	3.58
December	3.05

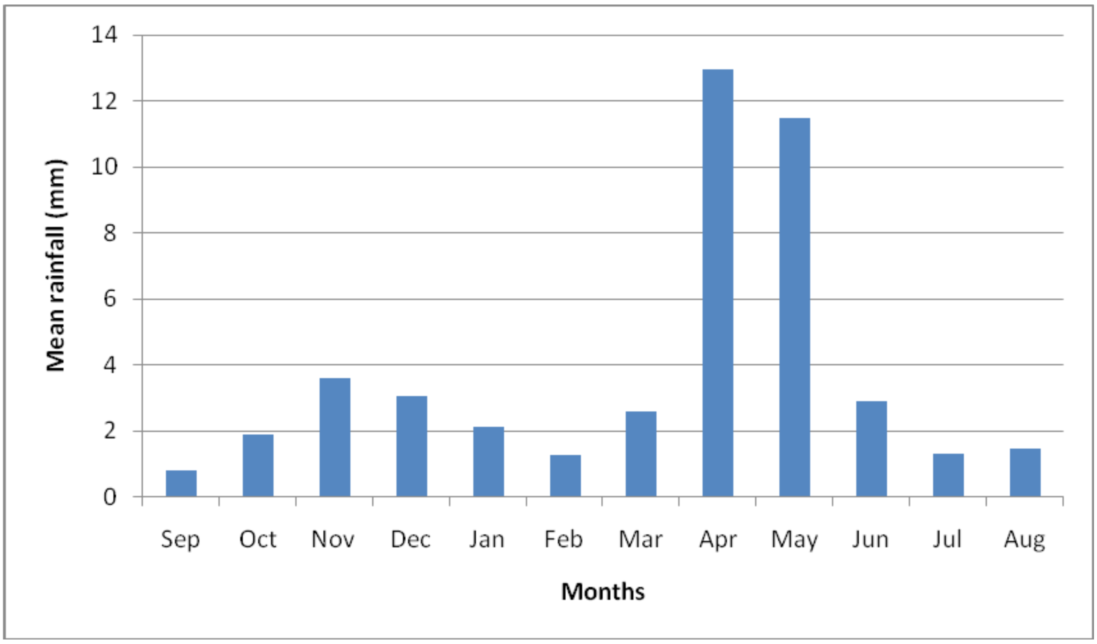
Appendix 8: Rainfall comparison between Kilema and Lyamungo for September, 2007-August,2008 at Lyamungo



Appendix 9: Total rainfall for September, 2007-August,2008 at Lyamungo



Appendix 10: Mean rainfall data at Lyamungo for a period of six years 2002-2007



Appendix 11: Sample of the data sheet

Seasonal Biological Monitoring of coffee Pests Data Sheet											
Farmer's name						Village			Altitude		
Date											
						WCSB		Antestia bug		CBB	
Altitude	Replic. (Village)	Microc.	Month	Farmer No.	Tree No.	No. of Insects	% damage	No. of Insects	% damage	No. of Insects	% damage
1	1	1	1	1	1						
1	1	1	1	1	2						
1	1	1	1	1	3						
1	1	1	1	1	4						
1	1	1	1	1	5						
1	1	1	1	1	6						
1	1	1	1	1	7						
1	1	1	1	1	8						
1	1	1	1	1	9						
1	1	1	1	2	1						
1	1	1	1	2	2						
1	1	1	1	2	3						
1	1	1	1	2	4						
1	1	1	1	2	5						
1	1	1	1	2	6						
1	1	1	1	2	7						
1	1	1	1	2	8						
1	1	1	1	2	9						
1	1	1	1	3	1						
1	1	1	1	3	2						
1	1	1	1	3	3						
1	1	1	1	3	4						
1	1	1	1	3	5						
1	1	1	1	3	6						
1	1	1	1	3	7						
1	1	1	1	3	8						
1	1	1	1	3	9						
1	1	1	1	4	1						
1	1	1	1	4	2						
1	1	1	1	4	3						

Important notice	
Fruiting stage (flowering, small, large & ripe berries)	Microclimate: 1 – sparse shade 2 – dense shade
Cropping systems	Altitudes: 1 – medium altitude 2 – High altitude
Last time sprayed with chemical	Seasons: 1 = dry 2 = wet
Age of the coffee trees	Light Intensity (Lux)

Appendix 12: Average Light Intensity in different farms with dense and sparse shades at high altitude (Kilema) and low altitudes (Lyamungo).

Farm Number	Location	Microclimate	Average Light Intensity (Lux)
1	Lyamungo	DS	32.07
2	Lyamungo	DS	30.21
3	Lyamungo	DS	35.45
4	Lyamungo	DS	37.13
5	Lyamungo	SS	51.89
6	Lyamungo	DS	43.53
7	Lyamungo	DS	24.67
8	Lyamungo	DS	25.49
9	Lyamungo	DS	36.32
10	Lyamungo	DS	36.11
11	Lyamungo	SS	58.04
12	Lyamungo	DS	31.23
13	Lyamungo	DS	30.65
14	Lyamungo	DS	29.54
15	Lyamungo	DS	26.28
16	Lyamungo	DS	31.27
17	Lyamungo	DS	27.44
18	Lyamungo	DS	29.25
19	Lyamungo	DS	26.43
20	Lyamungo	DS	34.33
21	Lyamungo	SS	91.78
22	Lyamungo	DS	34.76
23	Lyamungo	DS	38.23
24	Lyamungo	SS	46.01
25	Lyamungo	DS	26.37
26	Lyamungo	DS	22.38
27	Lyamungo	DS	22.09
28	Lyamungo	DS	23.03
29	Lyamungo	DS	26.98
30	Lyamungo	DS	30.19
31	Lyamungo	DS	24.42
32	Lyamungo	DS	24.97
33	Lyamungo	DS	28.46
34	Lyamungo	DS	24.02
35	Lyamungo	SS	47.44
36	Lyamungo	DS	25.30
37	Lyamungo	SS	60.84
38	Lyamungo	SS	62.43
39	Lyamungo	DS	29.38
40	Lyamungo	DS	26.80
41	Lyamungo	DS	37.11
42	Lyamungo	DS	31.56
43	Lyamungo	DS	23.20
44	Lyamungo	DS	33.43
45	Lyamungo	SS	35.13
46	Kilema	SS	87.34
47	Kilema	SS	84.35
48	Kilema	SS	80.98
49	Kilema	DS	37.09
50	Kilema	DS	36.98
51	Kilema	SS	43.54
52	Kilema	SS	52.80
53	Kilema	SS	76.91
54	Kilema	SS	47.82
55	Kilema	DS	34.63
56	Kilema	SS	49.36
57	Kilema	SS	43.84

Appendix 13: Shannon-Wenner species diversity index values for coffee insect pests at medium and high altitudes (Lyamungo and Kilema)

Location	Months	Species	No. of insects	P*i*	ln	P*i*Xln
Lyamungo (1200-1600m.a.s.l)	September	WCSB	276	0.45	-0.799	0.36
		Antestia bug	112	0.18	-1.715	0.309
		CBB	229	0.37	-0.994	0.368
					∑=	**1.036**
	October	WCSB	325	0.47	-0.755	0.355
		Antestia bug	176	0.26	-1.347	0.35
		CBB	187	0.27	-1.309	0.353
					∑=	**1.059**
	November	WCSB	441	0.54	-0.616	0.333
		Antestia bug	377	0.46	-0.777	0.357
		CBB	7	0.01	-4.605	0.046
					∑=	**0.736**
	December	WCSB	463	0.5	-0.693	0.347
		Antestia bug	411	0.47	-0.755	0.355
		CBB	5	0.01	-4.605	0.046
					∑=	**0.747**
	January	WCSB	481	0.52	-0.654	0.34
		Antestia bug	481	0.52	-0.654	0.34
		CBB	4	0.004	-0.487	0.002
					∑=	**0.682**
	February	WCSB	491	0.53	-0.635	0.337
		Antestia bug	413	0.44	-0.821	0.361
		CBB	26	0.03	-3.507	0.105

					∑=	**0.803**
	March	WCSB	515	0.58	-0.544	0.316
		Antestia bug	343	0.39	-0.942	0.367
		CBB	23	0.03	-3.507	0.105
					∑=	**0.788**
	April	WCSB	535	0.62	-0.478	0.296
		Antestia bug	219	0.25	-1.386	0.347
		CBB	107	0.12	-2.12	0.254
					∑=	**0.897**
	May	WCSB	551	0.6	-0.51	0.306
		Antestia bug	229	0.25	-1.386	0.347
		CBB	133	0.15	-1.897	0.285
					∑=	**0.937**
	June	WCSB	565	0.65	-0.431	0.28
		Antestia bug	172	0.2	-1.609	0.322
		CBB	134	0.15	-1.897	0.285
					∑=	**0.887**
	July	WCSB	568	0.61	-0.494	0.301
		Antestia bug	192	0.21	-1.561	0.328
		CBB	168	0.18	-1.715	0.309
					∑=	**0.938**
Kilema (1600-2100m.a.s.l)	September	WCSB	603	0.99	-0.01	0.01
		Antestia bug	3	0.01	-4.605	0.046
					∑=	**0.056**
	October	WCSB	650	0.991	-0.009	0.009
		Antestia bug	6	0.01	-4.605	0.046
					∑=	**0.055**
	November	WCSB	806	0.991	-0.009	0.009
		Antestia bug	7	0.01	-4.605	0.046
					∑=	**0.055**
	December	WCSB	859	0.986	-0.014	0.014
		Antestia bug	12	0.01	-4.605	0.046
					∑=	**0.06**
	January	WCSB	897	0.987	-0.013	0.013
		Antestia bug	11	0.01	-4.605	0.046
					∑=	**0.059**
	February	WCSB	907	0.987	-0.013	0.013
		Antestia bug	12	0.01	-4.605	0.046
					∑=	**0.059**
	March	WCSB	965	0.973	-0.027	0.026
		Antestia bug	27	0.03	-3.507	0.105
					∑=	**0.131**
	April	WCSB	969	0.98	-0.015	0.015

			5		
	Antestia bug	15	0.02	-3.912	0.078
				∑=	**0.093**
May	WCSB	1024	0.996	-0.004	0.004
	Antestia bug	4	0.01	-4.605	0.046
				∑=	**0.05**
June	WCSB	1039	0.999	-0.001	0.001
	Antestia bug	1	0.001	2.263	0.002
				∑=	**0.003**
July	WCSB	1065	0.998	-0.002	0.002
	Antestia bug	2	0.002	0.628	0.001
				∑=	**0.003**

Where, H = Index of species diversity

P*i* = No. of individual of one species /Total no. of individuals in the sample

ln = Natural logarithm