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COLLEGE OF APPLIED AND BASIC SCIENCES

DIVERSITY AND ABUNDANCE OF INSECTS AT DIFFERENT HEIGHTS IN COCOA FARMS.

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DECLARATION

This is to certify that this thesis is the result of research undertaken by me, Nana Anima Adwoa Martinson towards the award of a Master of Philosophy Degree in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS), University of Ghana, Legon. I declare that all experimental procedures were carried out by me, and that all references made to the work of other researchers have duly been acknowledged. This thesis has not been submitted either in part or in full for any other degree.

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DEDICATION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABSTRACT

The usage of traps at a single stratum has mostly been investigated, which may underestimate or misrepresent the true abundance of insect species. Flowers along the stems, of cocoa trees, spreading out through the branches into the canopy, makes it unique and therefore may attract insects along its entire length. The goal of this study was to access the diversity and abundance of insects at different heights in cocoa farms. Pan traps consisting of yellow, blue and white colours were set at 3.0 m, 1.5 m, and 0.0 m on cocoa trees in three cocoa farms in the North-Eastern part of the Ashanti region. A total of 25,470 insects belonging to 87 species, 62 families, and 12 orders were catalogued and ranked. Thysanoptera was the most prevalent insect order, with 9,601 (37.7%), followed by Diptera with 7,079 (27.79%), and Hymenoptera with 6,101 (23.95 %). The three most dominant insect orders put together constituted between 62 – 95 % of the total coloured pan trap catches. The yellow pan traps proved to be the most effective, in terms of diversity of insects collected at the upper (3.0 m), middle \ (1.5 m) and lower (0.0 m) levels. The white pan traps performed better than the other traps at 1.5 m and 3.0 m. The white pan traps had the highest abundance of insects at 3.0 m and 1.5 m but for blue traps, height had little effect on its insect catches. Though there were no significant differences in insect abundance at different heights and trap performance, there were variations in total insect catches at the different levels and to pan trap colour. Knowledge on the distribution and collections of insects would help to control or conserve their numbers in a more systematic way and which can be a good reference in future, making sampling easier and increasing reliability. At different heights it could inform levels at which insect groups are likely to be concentrated, between times and seasons. This could be useful in pest management practices, as well as suggesting monitoring and sampling protocols future research activities.

Note: Height = Vertical level

keywords: Insect diversity & abundance, heights, cocoa, pan traps.

CHAPTER ONE

1.0. INTRODUCTION

1.1. **Background**

Cocoa (*Theobroma cacao* L., Family Malvaceae) ranks number three worldwide as a cash crop after coffee and sugar (World Wildlife Fund, 2006). Ghana, the second largest producer of cocoa after Cote d'Ivoire, is followed by Indonesia, Nigeria, and Cameroon (Wessel & Quist-Wessel, 2015). In Ghana, cocoa is cultivated in the Ashanti, Bono, Bono East, Ahafo, Central, Eastern, Western, Western North, Volta and Oti regions (Naminse *et al*., 2011), with the Western North region being the highest production zone. *Theobroma cacao* is a perennial crop but delicate and sensitive throughout its growth (Annon, 2006), mostly found in humid areas of which its origin is from the amazon, grown in rain forests areas, and prefers sandy loam soil, rich in humus. Its roots are able to penetrate and hold moisture in dry climatic conditions with good aeration (Motamayor *et al*., 2008). Even though cocoa can survive under direct sunlight, it is normally grown under shade, to protect it from direct wind though it can survive in full sunlight (Indriati *et al*., 2020). It does not necessarily need sunlight to mature fully. Under its growing conditions, cocoa farms have the potential to support over 1,500 species of insects (Entwistle, 1972), thus acting as an effective refugia for some tropical forest organisms (Adjaloo & Oduro, 2013). Insects play roles as pollinators, carnivores, herbivores, omnivores, scavengers, detritivores, and decomposers in ecosystems (Janzen, 1987, Kevan, 1999) such as in cocoa farms, and this reflects a trend in their species richness and community. Their presence in a cocoa ecosystem however, may be due to the availability of breeding sites, influence of surrounding vegetation, weather patterns or climatic conditions (Pedigo and Rice, 2006). Factors such as temperature, humidity, light intensity, and food resource availability may also affect their distribution, diversity, and abundance.

There are a lot of studies that indeed support the huge abundance and diversity of insects in cocoa agro-systems [Entwistle, 1972; Frimpong *et al.*, 2011; Adjaloo *et al.*, 2012; Adu-Acheampong *et al*. (2014, 2015); Akesse-Ransford, (2016, 2020); Bosu *et al*., 2018; Amon-Armah, (2020); Indriati *et al*. (2020)]. As a result of high insect numbers in cocoa farms, there have been several studies conducted to determine and access their diversity and abundance. Some studies on cocoa agro-ecosystems have also focused on insect groups such as cocoa pollinators (Frimpong *et al*., 2011; Bosu *et al*., 2018), cocoa pests (Adu Acheampong *et. al.*, 2014, 2015), and natural enemies (Mayer, 2009).

In attempts to control, monitor, or collect insects, there have been the uses of several trapping methods to estimate insect diversity and abundance in cocoa fields. Some common methods of collection used include the sweep nets, visual observations, coloured pan traps, pheromone traps, light traps, motorised aspirators, McPhail traps and chemical Knockdown. Sweeping of foliage using, flowers and the cocoa tree trunk with an insect net has occasionally been used in sampling cocoa insects (Brew, 1985). In visual observation counts, Adu-Acheampong *et al.* (2014) collected data on a temporal distribution of mirid population in Ghana by visually observing and counting them up to hand height. Others have also collected immature (eggs, larvae pupae), and adult forms of midges from wet decaying organic matrix, the breeding substrates of midges (Young, 1982) but this is mostly limited to wet season since most of the substrates dry up during the dry season (Brew, 1985). Others have also used pheromone traps such as in Sarfo (2013), where behavioural responses of cocoa mirids to sex pheromones were investigated. Athanassiou *et al*. (2004) added that important factors that needed to be considered in trapping are the design and placement of the trap because it affects insect catch. Motorised aspirators and McPhail traps have been regularly used to sample some cocoa insects as well (Frimpong *et al*., 2009; Kwapong & Frimpong Anin, 2013). In addition, (Gibbs and Leston, 1970) used Knockdown and (Adjaloo & Oduro, 2013) used light traps to investigate insect phenology in a forest cocoa farm. Out of these methods the most common ones used include visual counting, the motorized aspirators, McPhail traps and coloured pan traps.

Pan traps have however been introduced in a lot of related cocoa studies for sampling and more recently, pan traps have become part of standard biodiversity assessment instruments and have been documented as an effective method to assess the relative insect abundance in an environment. The Food and Agricultural Organisation (FAO) has also promoted the use of coloured pan traps as an efficient data collection methodological tool (Shrestha *et al.*, 2019). Assessing the vertical distribution of insect is an important thing to consider, although comparisons within the, single strata sampled can be made. Most researchers, that sample insect species using pan traps, may not have placed much emphasis on positions at which these traps are placed. In literature, sampling using coloured pan traps has mostly been at single height, either canopy (Frimpong *et al*., 2011), on the open ground (Potts *et al*., 2005; Adjaloo & Oduro, 2012; Mazon *et al*., 2018), and at trunk level (Adjaloo & Oduro, 2013; Bosu *et al*., 2018). For example, the use of coloured pan traps were used in sampling cocoa insect (Syarief *et al.*, 2017; Bosu *et al*., 2018) where these traps were set on a 1 m high PV stand to monitor insect populations in Cocoa Agro-Ecosystems. Following some procedures of Potts *et al*. (2005), coloured traps have been placed on the open ground with no tree canopy directly overhead at distances 5 m apart to capture and estimate cocoa insect numbers. Others also hanged sets of coloured traps in the canopy of cocoa trees to monitor cocoa pollinators (*Forcipomyia* spp.) populations as seen in Frimpong *et al*. (2011).

1.2. Justification

One of the unique features of cocoa trees is that they tend to bear flowers along the stems from bottom to top, and spread out through the branches. These flowers bloom seasonally from cushions on the trunk and bark of the stems (Thompson *et al*., 2001), compared to other tree crops, where flowers are restricted to the upper part such as in citrus and mango. It therefore stands to reason that insects that visit both flowers and pods will be found along the entire height of the plant and at each level insects would be attracted. This informs the assessment of insect groups along different vertical levels in cocoa plantations. The flowering and pod-bearing arrangement is coupled with the fact that cocoa trees are shade-loving and grow under many different shade-providing trees. The use of traps in most studies at a single stratum have mostly been explored and it is likely that in previous research, other levels may have been missed during insect sampling at a particular gradient at which these traps are set. This may influence their distribution over a period of time and may underestimate or give limited representations of their actual abundance.

Knowledge on these insect collections and their distribution would contribute to their conservation in a more systematic way and can be a good reference in future, increasing reliability. Insect abundance and distribution at different vertical levels could inform pest management practices, and also suggest monitoring and sampling protocols, serving as a basis for future research activities (Meneses *et al*., 2016). It can also provide information to assist in planning similar insect surveys in different crop plantations.

Research objective

The main objective of this study is to assess the diverse and abundant groups of insects at different heights.

The specific objectives include;

1. To catalogue and rank all insects recorded in the cocoa farms.
2. To determine the diversity and abundance of insects at different vertical levels.
3. To assess the performance of the coloured pan traps at different heights.

CHAPTER TWO

2.0.LITERATURE REVIEW

2.1.Botany of Cocoa

2.1.1. Origin of cocoa

Cacao is one of the most economically-important tree crops in West and Central Africa which is native to the tropical forests of South America. The botanical name of cacao is *Theobroma cacao* L. Theobroma is a Greek word that can be translated as 'Food of the Gods': 'theos' meaning 'god' and 'broma' meaning 'food' (Powis *et al.*, 2011). There are different species of cocoa but *Theobroma cacao* is the only species of economic importance which is widely cultivated Whitlock *et al*. (2001) stated that the region extending from the forests of the Amazon to the Orinoco and Tabaco in Southern Mexico to be the centre of origin of cacao. *Theobroma cacao*, is a small tree which occurs in the wild forest of Amazon and Orinoco Basins (Coe and Coe, 1996) and other tropical areas of South and Central America and begun to spread widely to various parts of the tropical forest belt since the 16th century. Cocoa belongs to the family Sterculiaceae and thrives best in the lower storey of an evergreen rain forest. There are over 20 tree species of cocoa of which aside *T. cacao*, an example of a species of *Theobroma* is the *T. bicolour* is also grown as a cash crop. For an optimum growth of cocoa, as a temperate, delicate and a sensitive crop, one of its requirement is to be grown under shade trees which helps to protect itself from strong winds (Anon, 2006). In Africa, cocoa is grown almost entirely in small holdings. Polly Hill (1962) had made it clear that in Ghana the size of farms held vary enormously, but the majority of farmers hold relatively small areas (0.4ha) and there are few farmers with more than 8 ha.

2.1.2. **Cocoa growth**

Flowers formation

The cocoa tree bears large number of waxy pink or white blossoms that are formed in groups on stems and branches that spread out into the canopy of the cocoa plant (Plate 1A) (Thompson *et al*., 2001). and produced seasonally (Anon, 2006) Thickened leaf axils known as cushions are called are responsible for bearing flowers of which about 50 flowers can be formed from a cushion. Only a few of them about (10 %) of flowers develop into fruits although they are produced in large numbers. A successfully pollinated flower produces pod whiles those that are not fertilized are aborted within 24 hours. Flowers are borne on long pedicels and have 5 free sepals, 5 free petals, 10 stamens and 5 united carpels. Petals are very narrow at the base but expand into a cup-shaped pouch and end in a broad tip. When a bud matures, sepal split during the afternoon and continue to open during the night. Early in the morning which is the best time for pollination, anthers release their pollen and style matures a little later. This is the only stage in the development of pod in which abscimon occurs (Zamora *et al*., 1960). Cocoa trees produce large numbers of flowers at certain times of the of the year, depending on environmental conditions but only about 1-5% of the flowers formed are pollinated effectively to develop into pods. Cocoa buds take 28 days to open fully and drops approximately after 2 days if not pollinated (Swanson *et al*., 2005). For every 1-5 years after planting in the field greenish white flowers are produced on cocoa trees (Are & Gwynne-Jones, 1974).

A. B.

Plate 1. Clustered flowers and pods on a cocoa tree. A = Flowers along the stem and branches of the cocoa tree, B = Ripe and unripe pods on the stem and branches.

Pod formation

The cocoa fruit is known as "pod", which contains seeds embedded in a sugary mucilaginous coating called "pulp". The mature height of the tree is about 3-8 m, with a canopy diameter of about 6-8 m (Are & Gwynne-Jones, 1974), and the pods can contain 20–40 seeds (Urquhart, 1961; Are & Gwynne-Jones, 1974). However, once the pod is opened, the mucilage decomposes rapidly and germination can begin because the seeds have no dormant period. On germination, the rootlet grows out first followed by the hypocotyl and the cocoa plant grows vertically until it reaches a height of about 1-2 m. When the cocoa plant enters its third growth, vertical growth ceases. The side branches which grow at an angle of 0-6 degrees have cotyledons, about 3 cm above the ground. Side branches with cotyledons? Subsequent growth occurs at intervals of approximately six-leaf arrangements called 'fan branches'. After pollination, the pod grows slowly for about 40 days, after which growth becomes more rapid and reaches a maximum at about 75 days. Developing pods are known as cherelles and takes about 5-6 months from the the time flowers get pollinated to pods to ripening (McKelvie 1956, Wood and Lass, 1985). Despite the fact that only a small percentage of the flowers are successfully pollinated, many fruits are normally set for the tree to carry through to maturity. As compared to fruits of all cultivated plants, cocoa pods show a great deal of genetic variation, and ripe cocoa pods vary considerably in length from 10-32 cm and in shape, surface texture, and colour. Certain physical characteristics of pods and beans are used as the foundation for classification into groups that may be named varieties, cultivars, types, or populations. The form varies from almost spherical to cylindrical, and the surface from warty and severely wrinkled to nearly smooth. Olivia and James (2003) estimate that an individual may harvest 650 pods each day from a cocao farm, but this must be done on a frequent basis because pods on a tree do not develop at the same time (Wood and Lass, 2001) Upon maturity, the pods turn dark green in colour, and yellow when ripe, and becomes very firm in texture (Urquhart, 1961) (Plate 1B). The economic life span of cocoa is 25-30 years, after which it is expected to deteriorate, necessitating the replacement of trees (Aranzazu, 1992). If pruning is utilized as one of the major agricultural practices, cocoa will begin to bear fruit between the third and fifth years after cultivation (Anon, 2003) and two years or earlier for hybrids.

If apical buds are damaged, buds found at the lower part of the stem will grow out upright and these are called “chupons”. “Chupons” are shoots of the cocoa seedling that grow to a height of 100–150 cm, and lateral branches known as fans begins to grow on the stem and this is collectively known as a jourquette. When light penetrates the farm, it facilitates chupon growth and this will cause them to grow higher taking over the cocoa tree canopy. If this process is repeated several times, it causes cocoa trees to grow higher and higher, reaching a height of 3-10 meters, depending on the spacing and degree of shade. Chupons may also arise from the base of the trunk and can be used to replace the main stem if a tree falls or dies off.

2.1.3. **Cultivation of cocoa**

Cocoa is cultivated in the humid tropical zone (Motamayor *et al*., 2008), and it requires a soil that allows its roots to easily penetrate and hold moisture, particularly during periods of drought. Cocoa farming in Ghana is typically done from November to March (Adams and Mckelvie, 1955) in regions with less than 250mm of rainfall. In Ghana, cocoa is cultivated in the Ashanti, Brong-Ahafo (Bono, Bono East, Ahafo), Central, Eastern, Western (Western, Western North), and Volta (Volta, Oti) regions (Naminse *et al*., 2011), with the Western region being the highest production zone. Cocoa producers in West Africa utilize suitable trees to offer shade for young cocoa during operations such as clearing and site preparation, while tree planting or replanting occurs during the wet season (Oke and Odebiyi, 2008). During the rainy season in Ghana, from April to July, cocoa seedlings are usually planted in polythene bags at a nursery (Entwistle, 1972). The two principal cocoa harvesting seasons in Ghana are the major crop season and the minor crop season, which occur between September and February and March and August, respectively (Adzaho, 2007).

2.2. **COCOA INSECTS**

2.2.1 **Pollinators of cocoa**

The most important group of pollinating insects are the midges belonging to several genera of the family Ceratopogonidae is known to be the most efficient pollinator (Kaufman, 1974). Kaufman (1973) and Maurray (1975) have indicated that cocoa flowers are odourless and nectarless. Despite the lack of fragrance and nectar in cocoa blossoms, insect studies have revealed that cocoa is entirely entomophilus (Ibrahim,1998). However, Young *et al*. (1988), have demonstrated that, cocoa flowers produce fragrance and nectar because he deduced that its floral oils could be used to attract midges. There are about 56 species and more of Ceratopogonids and some other groups of Ceccidomyidae family makes up about 45.6% of all cocoa flower visitors in West Africa (Toledo –Hernandez *et al.*, 2017) and a number of species of the genus *Forcipomyia* are the commonest pollinators of cocoa. that are 3mm in size (Tscharntke *et al*, 2011). These midges are so small that they are difficult to see and are called 'no see 'ems' in the West Indies. Ceratopogonids are generally in high numbers during the wet season and they reduce in numbers over the dry season. They are gregarious insects of which during only their first three lives from egg to larvae to pupae, they become more vulnerable to predators such as ants, millipedes and pseudoscorpions (Kaufman, 1975). Their life-cycle is about twenty-eight days and the population builds up during the rainy season. Both sexes (male and female) are involved in pollinating cocoa flowers, but the greater part is affected by the female midges and pollinating activity is greatest soon after dawn and in the evening. Adults can however live up to an average of 12 days depending on food and water resources available. A lot of other insects that visit the cocoa tree are also seen as important in the cocoa ecosystem. Some earlier authors (Etwistle 1972; Kaufman, 1973) had presented that other insects other than midges have the potential to pollinate cocoa flowers such as bees, ants, aphids and thrips (Entwistle, 1972). Some insects may visit with the aim of just collecting pollen or other floral rewards (Adjaloo & Oduro, 2013). In, Chumacero de Schawe *et al*, (2016) sampled 1160 flowers and observed only 6 ceratopogonid species representing 2 % of the total cocoa flower visitors and concluded that, Hymenopterans (mainly prasitoids), were the most abundant visitors with 118 individuals. In Ghana, Adjaloo & Oduro (2013) sampled 578 ceratopogonids during flowering period of cocoa and also observed that they only constituted 25 % of the total insect abundance sampled in cocoa plantations. In Brazil, Winder (1977) observed that out of 12000 flowers surveyed in cocoa plantations only 81 ceratopogonids were collected and non- pollinating species represented almost half of the flower visitors which included high numbers of ants and bees. Ant communities have been suggested to indirectly enhance pollination by disturbing pollinators and increasing pollinator success and this mechanism of pollination enhancment have also been investigated in other studies (Greenleaf & Kremen 2006, Philpott *et al*., 2006). Early cocoa flowering occurs in Ghana between February and April, depending on the severity of the rainfall pattern, and a second peak of bloom occurs in June-July, but decreases dramatically from September to December, when pollinators are plentiful (Frimpong et al 2009). In some cases, the hybrids almost flower throughout the year.

2.2.2. **Pest of cocoa**

Capsids, shield bugs, stem borers, and mealy bugs are some of the most damaging cocoa pests (Hill, 1993). Defoliators like *Adoretus lineola* sp., *Zonocerus variegatus*, and stem borers like *Tragocephala* sp. are common cocoa pests (Hill, 1993). In Ghana the defoliators are mainly *Anomis Leona* Schaus and *Earis biplaga* Wlk. Termites, foliage feeders such psyllids (*Tyora tessmanni*), aphids (*Toxoptera aurantii*), thrips *Selenothrips rubrocinctus* (Etwinstle, 1972), *Pseudococcus citri*, mealy bugs (Hill, 1993), *Bathycoelia thalassina* (Owusu-Manu, 1971), *Tragocephala* spp (Entwistle, 1972; Padi and Owusu, 2020).

Cocoa mirids

Two mirid bug species, *Sahlbergella singularis* (Hagl.) and *Distantiella theobroma* (Dist). (Hemiptera: Miridae) as well as cocoa mosquito *Helopeltis* sp are important insect pests of cocoa which causes annual crop losses of about 25 % in Ghana (Padi & Owusu 2015, (Baah and Anchirinah 2011; Adu-Acheampong *et al*. 2014; Awudzi *et al*. 2016; Ninsin and Adu-Acheampong 2017) These are widespread in countries such as Nigeria, Cote d'lvore, Congo and Sierra Leone. In a more recent study by Awudzi *et al*. (2016), most cocoa farmers attributed 30–40% of their annual crop loss to mirid bug damage, which represents a huge economic loss to the country. In a study that assessed the seasonal abundance of mirid bugs on cocoa trees in 2012, Adu-Acheampong *et al*. (2014) noted that the highest population of mirid bugs occurred in areas within the Eastern and Central regions of Ghana. However, for several decades, a nationwide recommendation on the control of mirid bugs on cocoa farms in Ghana had been to spray insecticides from August to December, skipping November (Adu-Acheampong *et al*., 2006). Understanding the population dynamics of cocoa mirids is crucial for monitoring, and controlling their population. Research in Ghana shows that mirid populations increase rapidly in April and first peaks in May, followed by a quick accumulation in June (Awudzi *et al*., 2017). The nymph and adult of *S. singularis* and *D. theobroma* cause economic damage to the succulent parts cocoa pods and cherells. Their feeding activities on young twigs and flush of leaves, often results in the deterioration of the canopy which eventually leads to the death of the cocoa trees. The greatest damage occurs ccoa plantations that are lightly shaded and have no shade and this is where the highest insect populations and more or less populations are present respectively (Wessel & Quist-Wessel, 2015). Their long pointed mouthparts have a needle like structure is to use to pierce and suck out the sap from the shoots and pods. As a result of feeding by mirids, pods may crack and cocoa beans will begin to decay and also feeding could result in mirid pocket and mirid blast. Mirid pocket cause deteriotation of canopies and mirid blast causes leaves and branches to die off (Awudzi *et al*., 2009) as dead leaves may remain hanging on trees and appear burnt in colour (Asante 1997). Factors which accounts for mirids population in cocoa farms includes, prevalent weather conditions and dense shade cocoa trees. It was observed by Etwinstle (1972) mirids population may be seen more on an average weather conditions. Shield bugs (*Bathycoelia thalassina*) are also one of the major pest of pest of cocoa and its local name is “Atee”. However, constant application of synthetic insecticides or chemical insecticides can be used to control these capsids (Awudzi *et al*., 2009). The eggs of *B. thalassina* are laid on leaves, trunks, and branches. Shield bugs feed by piercing with their probocises or mouthparts into the pods, and sucking sap from the cocoa beans. Both immature and older pods are sucked by them. When it comes to grazing on immature pods, early ripening occurs and matured pods also turn to have their beans stuck to the inner lining of the pods as a result of the mucilage around the beans being sucked. Feeding on matured pods leads to discolouration from yellow to black and growth ceases. In the cocoa farms, when disturbed due to its sentivity, *B. thalassina* flies from one place to the other, in short or long distances (Akesse-Ransford *et al.*, 2016).

Termites

Termites have become economically important in several parts of Ghana in recent years (Ackonor, 1995). *Ancistrotermes* sp., *Amitermes* sp., *Macrotermes* sp., *Microtermes* sp., *and Nasuitrotermes* sp. are some of the most well-known and damaging termite species connected with cocoa (Awudzi *et al*., 2009). Termites can live in both the canopy and the ground. They target seedlings or young trees at the base, causing trees to wilt and die if not controlled. This form of damage can also occur in mature trees. The plant's woody portion is destroyed. The leaves of cocoa wilt as a result of termite infestation, yet they remain attached to the branch (Afreh-Nuamah, 1999). Termites dwell underground or in tree canopies and they can damage and expose tree surfaces, allowing other infestations to take hold. They also attack the roots and drill holes into the branch, sometimes filling them with earth, and are capable of constructing mud tents at the plant's base and occasionally on its branches. They also attack the roots and dig holes in the branches, sometimes filling them with earth, and can build mud tents at the plant's base and on its branches. Termites can be culturally managed by destroying the mud tent and removing the queen. Termites find it unpleasant to feed on botanicals such as neem, Azachiracta indica (Ackonor and Nkansah, 2001).

Psyllids and Aphids

Psyllids (Order; Hemoptera: Family; Psyllidae) are also known as Plant lice. Adults are winged and feed on the cocoa tree's buds and blooms, limiting its growth. During lean or drought seasons, psyllids (*Tyora tessmanni* Aulmann) deposit massive amounts of eggs in terminal buds, causing desiccation and bud death, as well as growth retardation in seedling shoots. Aphids are a minor pest in Ghana and West Africa. *Toxoptera aurantii* is a parasite that produces sporadic outbreaks (Entwistle, 1972). Aphids are insects that extrude sap from new, succulent stems, reducing plant vigour during huge blooms and slowing development on afflicted cocoa plants. They also eat the lower surface of the leaves, which can become rolled over time. Aphids inflict minor harm and may not result in significant financial loss (Awudzi *et al*., 2009). According to Firempong (1984), the temperature ranges most favorable for its life function are 20-25 degrees Celsius, with 22 being the ideal temperature, and adult maturity occurs in six days. Aphids have solely females in their population, with parthenogenetic reproduction and viviparous reproduction. According to Broughton and Harris (1971), *T. aurantii* is the only aphid with audible stridulation, and aphids are suitable for researching many current concerns in ecology and plant breeding due to their tiny size, parthenogenetic reproduction, rapid multiplication capacity, and international distribution (Ransford *et al.*, 2016). Insects are usually uncontrolled, but severe outbreaks on young cocoa can be devastating (Awudzi *et al.*, 2009).

2.2.3. **Beneficial insects in cocoa ecosystems**

Ants are the most common social insects and are found all over the world (Wilson, 1971). Ants are predators, scavengers, herbivores, detritivores, and granivores, and they have relationships with plants and other insects (Holldobler & Wilson, 1990). Ants are also vital for aeration and nutrient redistribution in the soil (Ho11dobler and Wilson, 1990) and are significant in ecological research. They have become a prominent indicator group in studies of diversity and ecosystem function for these reasons, as well as the ease with which they may be sampled and identified (Agosti & Alonso, 2000).).

Weaver ants

Oecophylla longinoda (Fig 8) species are the most diverse in contrast to other social insects like bees and termites (Holldobler and Wilson, 1990). *Oecophylla smaragdina* (Fabricius) is found in tropical Asia, Australia, and numerous Pacific islands, whereas *O. longinoda* (Latreille) is widespread in tropical Africa (Van Mele and Cuc, 2000), including Ghana. Both *O. longinoda* and *O. smaradgina* are canopy ants that enjoy sunny settings and employ a wide range of host trees. They construct their home on a cocoa tree by gluing together leaves with silk produced by their larvae (Offenberg *et al.*, 2006). The nest is plainly visible and is dispersed over the ant's canopy region (Holldobler, 1990). He argues that *Oecophylla longinoda* is aggressive and territorial, with a single colony capable of actively defending its tree against invaders, based on his knowledge of biology (Holldobler, 1990). *O. longinoda* has been discovered as an effective biological control agent for numerous insect pests in most tree crops, including cocoa, due to its predatory nature (Van Mele, 2008). Another distinguishing characteristic of the weaver ant is its rectal and sternal glands, which are located near to the anus and produce chemicals to attract a colony of ants when conditions demand it (Woodruff, 2001). A drop of fluid is produced from the rectal vesicle as these ants find a new home range. These places have a distinct scent that differentiates them from the alien invaders (Woodruff, 2001).

African weaver ants are largely insectivorous, attacking and consuming any ants or other insects that come into contact with their nest. They'll fight and eat weaver ants from neighboring colonies as well. Honeydew excrement from herds of scale insect nests is another important food source for weaver ants Holldobler and Wilson (1994). *O. longinoda* ants have been found to defend more than 12 distinct tropical crops from more than 40 different pest species. When compared to standard pesticide regimens, protection by *Oecophylla* sp can result in a 70% increase in net income (Peng and Christian, 2005a). In the presence of *Oecophylla longinoda*, cocoa bugs such as *Distantiella theobroma* (Dist.) and *Sahlbergella singularis* (Hagl.) Leston (1973), can be intimidated and attacked.

2.3. **Insect surveys in cocoa plantations.**

For any type of ecological study, the development of effective surveying and monitoring methods is critical (Frimpong *et al*., 2009). This enables long- and short-term monitoring of insect groups across seasons and habitats, as well as evaluation of the influence of agrochemicals on them. The efficacy and ease of application of each method in cocoa fields varies with respect to the vertical plane of the cocoa trees, according to Frimpong *et al*. (2011). Long-term periodical sampling reveals temporal variations in insect population, distribution, and community. Several methods have been used in cocoa insect research, and observing pollinators like thrips, aphids, and psyllids is particularly difficult. Traditional methods such as brushing foliage, blossoms, and around the trunk with insect nets had been utilized on occasion for insects such as cocoa pollinators. Cutting the flower pedicel and placing the flower in alchohol were some of the earliest methods of sampling cocoa pollination midges. This method proved useful for detecting cocoa-pollinating midges, but it was insufficient because the insects had a high tendency to flee before the bloom fell into the alchohol (Posnette, 1944).

Frimpong *et al*., 2009, published the first study of using pan traps to sample insects such as cocoa pollinators in recent years. Pan traps had been successfully employed in the forest and agricultural settings to sample bees in tree canopies (Potts *et al*., 2006). Pan traps were introduced to aid sample insects in the cocoa canopy where other traps, like as the sunction pump, have restricted access (Frimpong *et al*., 2009).

Hand plucking flowers and collecting flowers in sealed glasses (Kaufman 1975, Adjaloo & Oduro, 2013), and using a motorized sunction pump (Frimpong *et al*., 2011; Kwapong & Frimpong-Anin, 2013) are some of the ways used. Malaise traps, sticky cards, pit fall traps, light traps, sweep nets (Frimpong *et al*., 2011; Tarmadja, 2015). Insects in cocoa fields have been sampled using McPhail - distilled flower traps (Frimpong *et al*., 2011) and flower - sticky glue (Chumacero de Schawe *et al*., 2018). Adu-Acheampong *et al.* (2014) proved that apart from trapping, additional methods of sampling cocoa pests such as *Distantiella theobroma* (Dist.) and *Sahlbergella singularis* (Hagl.) by visual observation at hand height can be used. However, each methodology has its own set of drawbacks, such as the difficulty in obtaining large numbers of spatial and seasonal duplicates, the time commitment, and the cost of sampling methods.

2.3.1. **Sampling at vertical levels.**

Although it is possible to compare insects at a particular level or height in an ecosystem, it is critical to examine the overall vertical distribution of insect fauna. The use of coloured pan traps in sampling fields to account for differences in insect spatial distribution assures unbiased samples, and the colour of the traps is an essential factor that influences insect catches in vertical planes (Campbell and Hanula, 2006). Comparative studies of insect fauna in terrestrial ecosystems such as cocoa plantations on the other hand, have generally concentrated on sampling within many types of single level, with the results primarily focusing on where the traps were put.

2.3.2. **The use of coloured traps**

Insects are attracted to various colours of traps, which may mirror images of plant parts such as leaves, flowers, fruits, and so on, and this becomes a significant source of bias in coloured trap surveys (Vrdoljak *et al*., 2012). Because it catches insects by a mix of interception and attraction (Vrdoljak, 2012), trap size and location (Pucci, 2008), adjacent plants (Wilson *et al*., 2008), and habitat & weather conditions, the success of using coloured traps may vary.

Hue combinations, rather than just a single colour, may result in discovering more diverse insects, since insect diversity change with different colours and altitudes, according to Russo *et al*. (2011). The appeal of neutral colours like brown, black, and grey is low. Pan trapping is the most common approach used in bee surveys in Europe and the United States, and it has been proven to be the most successful technique in farmland and semi-natural grasslands, with yellow, blue, and white being the most effective colours (Westphal *et al*., 2008).

Coloured pan trapping has long been used to collect agricultural pests and phytophagous insects (Boiteau, 1983), but it is now being employed to collect pollinating insects (Gollan *et al*., 2011). Its absence of collector bias makes it ideal for comparing invertebrate communities, such as insect communities, through time and space (Westphal *et al.*, 2008). More recently, similar traps have been presented as an efficient technique to gather and analyze relative insect abundance in ecosystems, and have been supported by the Food and Agricultural Organization (FAO) as a data collecting tool (Shrestha *et al.*, 2019). According to Nutmann *et al.* (2011), the approach of deploying coloured traps aerially enables for different types of insect populations to be determined. It was also reported that using coloured aerial pan traps, researchers were able to sample insect populations at heights of up to 30 meters in a variety of habitats in Ghana, ranging from an agricultural matrix to a main tropical rain forest. Their study found that pan traps may be used successfully at low vegetation levels, and at heights above the ground.

According to their research, the versatility of pan trap usage over vertical strata, as seen by their effective use from ground level to 30 m, implies that aerial pan trapping for insects might be a valuable supplement to other commonly used sampling methods. Although they did not directly compare canopy to ground, they did guarantee that all components of the insect fauna are captured throughout all vertical levels of a habitat, including tree canopies. Pan trapping has been tried and proven as a viable ground-level survey method, and Nutmann *et al*. (2011) indicates that it is adaptable enough to sample vastly different habitats ranging from open agricultural regions to closed-canopy habitats. Pan traps have long been recognized as one of the most efficient ways to sample insect species such as Hymenopterans, Lepidopterans, and Dipterans (especially essential pollinators in most ecosystems). Yellow attracts Hymenopterans and Dipterans in general, whereas white attracts a wide range of Dipterans, but repels specific Hymenoptera groups (Dafni *et al.*, 1990).

2.3.3. **Sampling in other Orchards at vertical levels using coloured pan traps.**

Chavelle *et al*. (2019) looked at the monitoring of orange wheat blossom midge using yellow water pan traps at three different heights (0.2 meters, 0.6 meters, and 1 meter above ground level) and found that yellow pan traps were the best at sampling at 0.6 meters. Differences in flying behavior among species were obviously connected to relative trap efficiency and height locations. Atakan (2004) investigated the use of sticky cards at various heights (60, 80, 100, and 120 cm) in sampling cotton insect pests and found that trap height had no effect on total thrips captures. Meneses *et al*. (2016) used yellow pan traps and yellow sticky cards to investigate the vertical distribution of leaf hoppers in maize fields at two heights (0.5 and 1.5 meters). Their research took place throughout both rainy and dry seasons, and they discovered that corn quantity was higher after it emerged. It was also noted that, despite the great quantity collected at 1.5m, it was more frequent in the dry season, suggesting that traps should be placed at 0.5m and 1.5m for monitoring leaf hoppers at earlier and later phases, respectively. Leksono *et al*. (2005) used a water pan trap set at 0.5 m, 10 m and 20 m, to obtain data on the vertical and seasonal distribution of flying beetles in temperate deciduous forests. Their findings indicated variations in the abundance at different vertical levels with the Attelabidae and Cantharidae families being the most abundant in the upper layer, and the Eucneumidae and other scanvangers were found to be the most abundant in the lower layer. These patterns revealed that the abundance of distinct feeding guilds changed vertically between seasons.

Yellow pan traps, have been used effectively in sampling bees in tree canopies in the forest and agricultural systems (Potts *et al.*, 2006) and observations show that, coloured pan traps can be used to survey and monitor pollinator abundance and diversity as well as other insect groups (Westphal *et al*., 2008). Tuell and Issac (2009) used coloured pan traps across a relatively small vertical height (0 to 1.8 m) above ground level to sample bees and found out that capture rates varied with height and the most abundant bee species were best sampled at pan traps elevated in the canopy. (Vega *et al* ,1990) used adjustable water pan traps to simultaneously monitor aphids and Cicadelids at three different heights in a maize-bean-pumpkin tree culture and traps were adjusted to any desired height up to 2.2 m. His results suggested that insect activities (as reflected in trap catches) varied with height. He concluded that sampling using different coloured pan traps at vertical heights can be used to monitor arrival times of insect groups across different seasons and the height best sampled when insect population is very low and high at different periods.

According to Su and Woods (2001)., coloured traps are more likely to catch insects closer to the ground than traps above ground Insects that lay their eggs in the soil are more likely to be caught in traps close to the ground than in traps higher above. Another study (Lawton *et al.*, 1987) discovered that species richness diminishes as altitude increases. Species richness, on the other hand, peaks at intermediate elevations rather than low elevations, according to another study (Janzen *et al.,* 1976), and so environmental constraints can affect population distributions. Upper limits of distributions are often influenced by climatic severity and resource constraints, whereas lower limits are influenced by climatic severity and predation (Young, 1982). Some schools of thought also believe that plant photosynthetic and respiratory rates are high at low altitudes and low at high elevations, and that the net accumulation of photosynthate is highest at mid-elevations. The "additional" photosynthate offers a bigger resource base for herbivorous insects, allowing more herbivorous insect species and their dependant predators to peak at higher elevations (Janzen, 1973).

The bulk of ground-dwelling insect studies have shown similar or greater insect richness (Humphrey *et al.*, 1999), whereas canopy insect studies have generally found lower insect richness (Williams & Roger, 1976). On the other hand, Abdelmutalab, (2019) investigated the connection between *Antestiopsis thunbergii* (Hemiptera: Order) populations and elevation in 24 coffee estates placed along a transect defined over an elevation gradient in the range 1000–1700 m on Mt. Kilimanjaro, Tanzania. Their density was assessed for three different climatic seasons, the cool dry season in June 2014 and 2015, the short rainy season in October 2014 and the warm dry season in January 2015. It was concluded that the bug prefered coffee at the highest elevations at all seasons.

2.3.4. **Sampling using cloured pantraps in cocoa plantations**

When employed in ecosytems such as cocoa fields, these traps endure a long time, and the water pan traps are the most commonly used (Adjaloo & Oduro, 2013). According to Frimpong *et al*. (2009), coloured pan trapping is an indirect approach employed in cocoa fields that is most efficient in terms of sampling effort when set in cocoa tree canopies, particularly the yellow. It was also stated that, in comparison to other traps such as the motorized aspirator and sunction pump, which effectively sample cocoa insects. Coloured pan traps are more efficient at the canopy level in sampling insects such as cocoa insect pollinators (*Forcipomyia* sp.) but not bees and it can be used singularly during insect surveys.

Bosu *et al*. (2018) employed coloured pan traps to keep track of possible cocoa insect pollinators such midges, bees, and parasitoids. These coloured pan traps were placed at a height of 1 meter above the ground to collect data on these insects during the major and minor cocoa flowering seasons, and it was discovered that trap colours yellow and white were the most appealing to pollinators.

Syarief *et al*. (2017) used yellow pan traps positioned at 1m above ground level in cocoa plantations to sample parasitoids in the Family Braconidae, Platygastridae, and Eulophidae families to examine the variety and number of *Helopeltis antonii* (Order; Hemiptera) natural enemies. Adjaloo and Oduro (2012) observed insect assemblages in cocoa plantations in response to distance from natural forest and the usage of coloured pan traps positioned at ground level, which followed certain Potts *et al* techniques (2005). According to Frimpong *et al*. (2009), coloured pan traps sampled a small number of cocoa capsids in the cocoa tree canopy, but that with the right colours, they may be collected in reasonably significant quantities for effective monitoring and pest control.

CHAPTER 3

3.0. MATERIALS AND METHODS

3.1. Experimental sites

The work was carried out in three cocoa farms at Nsutem, Akrofoso, and Juaben in the North-Eastern part of the Ashanti Region of Ghana. All sites have tropical climate temperatures between 20 ^{0}C to 32 ^{0}C, and have global positioning coordinates of 1° 24' 25.6026" **W**; 6° 52' 38.1072" **N**, Elevation = 313 m; 1° 23' 50.5926" **W**; 6° 54' 26.3118" **N**; Elevation = 357.0 m;, 1° 25' 14.1816" **W**; 6° 47' 14.8308" **N**; Elevation = 368.0 m, respectively (Figure 1).

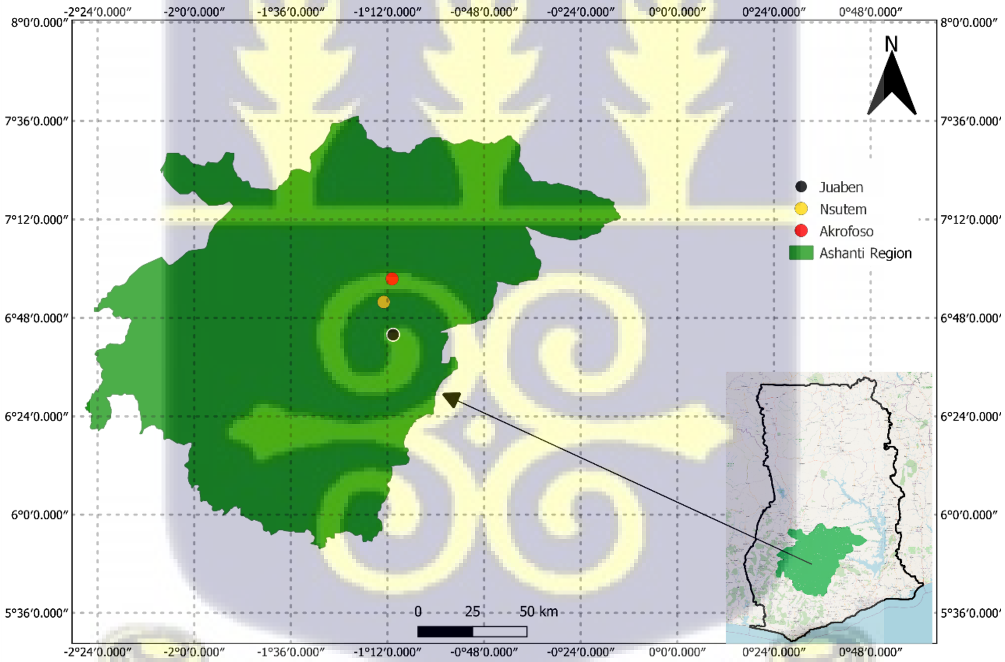

Figure 1. Map of Ghana showing study areas in the North-Eastern part of the Ashanti region.

The farms are about 8-12 km apart, and each farm is one acre (0.4 ha) in size. The farms were selected based on ease of accessibility, in active fruit production phase and willingness of farmers to allow fields to be used for the study. All three farms were well-managed, with planting distances of 3 m x 3 m between trees (Plate 2). The farms were between the ages of 10 and 16 years, and most cultural practices are done manually using simple farms tools. Selected farms were intercropped with other crops such as banana, plantain, pawpaw, bamboo, cassava, palm trees, cocoyam, and oranges. There was considerable reliance on agro-chemicals such as fertilizers, herbicides and pesticides in the farms.

Plate 2. One of the cocoa farms studied, showing the regular planting distances between trees.

3.2. Insect sampling procedures

The sampling protocol was based on the use of water coloured pan traps (yellow, blue and white) (Plate 3). Coloured pan traps, are easy to set, cheap, requires less labour effort and can be used efficiently. Water pan trapping uses coloured shallow bowls or pans partially filled with water mixed with non-fragrant detergent to break water surface tension. This will cause insects that get trapped to sink at the bottom of the pans. Preservatives such as glycerine or salts can also be added when traps are left for longer period such as a week or more to prevent insects from decaying (Laubertie *et al*., 2006). The coloured water pan traps used in this study were open vessels made of plastic material with a diameter of 20 cm, base of 9 cm in diameter, and a depth of 5 cm.

Plate 3. The three Colours used in the trapping study (Yellow, Blue, and White).

Copper wires, 5 mm thick and 36 cm long, were attached to the pan traps to serve as support and keep them securely attached when hanged on selected trees for 12 weeks (Plate 4). Traps placed on the ground did not have wires attached. Traps were filled with 300 ml of water and mixed with 20 ml of non-fragrant detergent/liguid soap to the break surface tension of the water to allow captured insects to sink in the water. Twenty (20 g) of Sodium Tetraborate (Borax) was added to the solution as a preservative to prevent captured insects in water from decaying or deteriorating. Each farm was divided into nine (9) sub-plots of approximately 20 m x 20 m. A tree was chosen at the centre of each sub-plot, from where traps were deployed. Traps were placed at 3 levels; 0.0 m (on the ground), 1.5 m, and 3.0 m above ground (Plate 5). Nine traps each of yellow, blue and white were deployed at each height (i.e. 3 traps x 3 heights x 3 farms = 27 per farm in a completely randomized fashion (Figure 2). For the three farms, a total of 81 traps (3 farms x 27 traps per farm) were set.

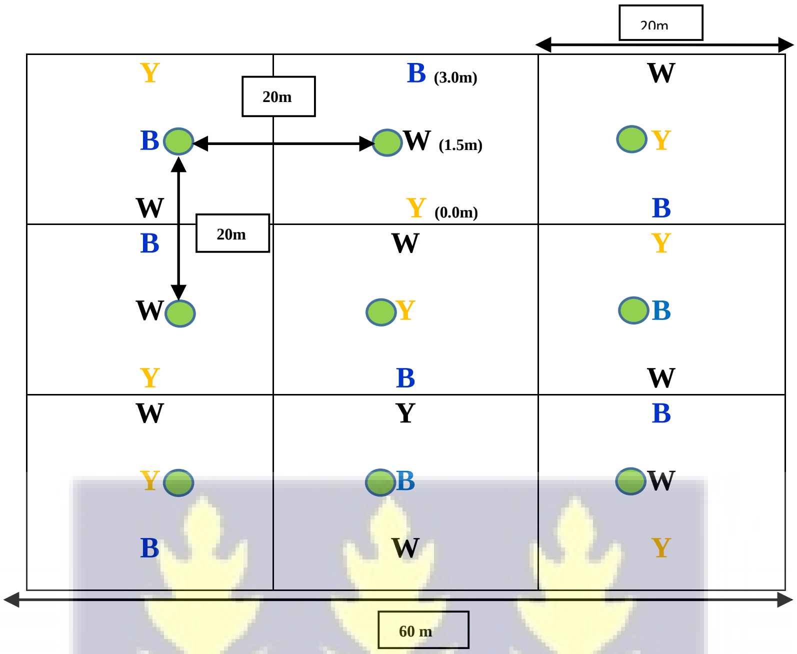

Figure 2. Schematic representation of the completely randomized arrangement of coloured traps (Y = Yellow, B = Blue **W** =White**)** on cocoa trees at the three heights in the farm.

Traps were checked for collection on biweekly basis, during which time, trap contents were strained using a finely-meshed tea strainer and the content placed in labelled vials with 70% ethanol for preservation (Plate 6). Traps were also serviced by discarding the original solution, cleaning them and refilling with a fresh mixture (water + detergent + Borax). Sampling was carried out for a period of six months (July to December). During the period, observations were also made on 100 selected cocoa trees along the diagonals of each farm to have an idea of the group of insects that could probably be present in the farms. Some behavioural activities of insects such as nesting by some insect groups and mutualistic relationship that exist between some insects were also observed.

Plate 4. Coloured pan traps with copper wires hooked through punctured holes and tied firmly to cocoa trees.

Plate 5. Installation of coloured traps at different heights on cocoa trees.

Plate 6. Inspecting insect collection from a Blue trap in the field.

Identification of insects

Insect samples were transported to the Laboratory of the Department of Animal Biology and Conservation Science (DABCS) for sorting and identification, using a Leica EZ4 D Digital Stereo Microscope (Leica MicroSystems Inc., NY, USA) (Plates 7 & 8). Insect groups were sorted, counted and identified to the lowest taxonomic rank as possible, and confirmed by Dr. Maxwell K. Billah of the Department of Animal Biology and Conservation Science (Plate 9). Voucher specimens were deposited at the museum at Animal biology and conservation sciences. All insects collected from each farm were recorded and organized in Microsoft Excel.

Plate 7. Insect samples in 100 ml vials grouped on a bench at the laboratory in an arrangement according to each trap (Top). Insects sorted out in petri dishes to be identified (Bottom).

Plate .8 Indentification of insects in the laboratory using a Leica EZ4 D Digital Stereo microscope.

3.3. **Data Analysis**

Diversity indices were computed from the data using (Shannon-Wiener Diversity index, Simpson diversity index, Evenness index, and Richness index). Shannon-Wiener index takes into account species richness and evenness, while Simpson's index is to know the dominance of species collected among the insect groups (Though both indices were calculated Shannon – Wiener diversity was the most suitable for the purpose of this study). Species richness captures the number of all species making allowance for the number of individual species, and abundance takes into account the number of individual species captured. For species richness, it is more sensitive to sample size and measures how evenly the individuals are distributed among different species. Eveness informs the equal distribution of insect abundance within an area.

Shannon-Wiener (H') Diversity Index

Formula to calculate Shannon-Wiener Diversity Index

$$H' = - \sum pi \times \ln(pi)$$

where,

H'= Shannon –Wiener Diversity Index

pi = Individual proportion of insect species (ni/N)

ni = total number of individual of the i'th species

N = Total number of individuals for all species combined.

Simpson Diversity index (Ds)

Formular to calculate Simpson Diversity index:

$$Ds = \sum (pi)^2$$

where,

Pi = Individual proportion of insect species = ni/N

ni = total number of individuals of the i'th species

N = total number of individuals for all species

Eveness index (Pielou's index (J')):

Formular to calculate Pielou's index:

J' = H'/Hmax

where,

J' = Pielou's eveness index

Hmax = In(S) = the maximum value that H' can have for a particular sample,

H' = Shannon –Wiener Diversity Index

S = Total number of species in the sample

Richness index (Margelef index (DMg)

Formular to calculate Margelef index:

Dmg = (S-1)/ln(N)

where,

DMg = Margalef species richness index

S = Total number of species in sample

N = Total number of individuals in sample

Comparisons at the different vertical levels and among traps over the period was done using the general linear model (GLM) measure, with vertical level (3.0 m, 1.5 m and 0.0 m (ground level), and trap colours (yellow, blue and white). The abundances were log-transformed and means separated using the Student–Newman–Keuls (SNK) test at P = 0.05 with Statistical Analysis Software (SAS) version 8.2 (SAS Institute, Inc, 2003). SAS is known to deal with different error structures associated with occurrence data and it is more flexible and suitable for analyzing ecological relationships such as relative abundances between insect distribution and elevation (Guisan *et al*., 2002).

Chapter 4

4.0. RESULTS

4.1. Catalogued and ranked insect numbers

A total of 25,470 individual insects belonging to 87 species, 62 families and 12 orders were recorded (Table 1). Nine insect Orders - Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Thysanoptera, Isoptera, Lepidoptera, and Orthoptera were common to all three farms. Diptera was the most diversed Order with 32 species, followed by Hymenoptera with 26 species, and Coleoptera with 12 species. The least abundant insect species belonged to the orders Hemiptera (6), Lepidoptera (3), Orthoptera (2), Thysanoptera (1), Blattodea (1), Mantodea (1), Neuroptera (1), Isoptera (1), and Phasmatodea (1) (Table 1).

The most abundant insect order was Thysanoptera with 9,601 (37.7%), followed by Diptera with 7,079 (27.79%), and Hymenoptera with 6,101 (23.95%). The Orders with the least number of individuals were, Coleoptera with 1,173 (4.61%), Hemiptera with 977 (3.84%), Lepidoptera with 199 (0.78%), Orthoptera with 144 (0.57%), Isoptera with 91 (0.36%), Blattodea with 81 (0.32%), Neuroptera with 19 (0.07%), Mantodea with 3 (0.01%), and Phasmatodea with 2 (0.01%) (Table 1). The Hymenopteran consisted mainly of ants (*Brothroponera* sp., *Crematogster* sp., *Oecophylla longinoda, Pheidole* sp., *Tetramorium* sp.), bees (*Megachile* sp., *Helictid* sp., *Apis* sp.), wasps (Pompilids and Vespids), and parasitoids (Braconids, Ichneumonids). Diptera consisted mainly of Ceratopogonidae (*Forcipomyia* sp.), Ceccidomyidae (*Ceccidomyid* sp.), Culicidae (*Aedes* sp.), and Lauxanidae (*Lauxanid* sp.), Neriidae (*Nerius* sp.), while the Thysanoptera consisted of only *Frankliniella* sp. (Appendix 1). The highest insect abundance was recorded in Farm 2 which was statistically different from Farms 1 and 3 ($F = 6.38$, $df = 2, 26$, $P = 0.0060$) (Table 2). Below is Plate 9 which shows a gallery of some of the insects catalogued.

Table 1. Insect Orders and percentage (%) abundance.

Order	Number of species	Number of individuals	Proportion of individuals (#/total)/100)
Blattodea	1	81	0.32
Coleoptera	12	1,173	4.61
Diptera	32	7,079	27.79
Hemiptera	6	977	3.84
Hymenoptera	26	6,101	23.95
Isoptera	1	91	0.36
Lepidoptera	3	199	0.78
Mantodea	1	3	0.01
Neuroptera	1	19	0.07
Orthoptera	2	144	0.57
Phasmatodea	1	2	0.01
Thysanoptera	1	9,601	37.7
Total	**87**	**25,470**	**100**

Table 2. Total of mean ± SE of insect abundance from the three farms.

Variable	Stats Parameters	Average ± SE
Farm 1		682.89 ± 74.76 b
Farm 2		1504.56 ± 319.92a
Farm 3		642.44 ± 58.40b
	F	6.38
	Df	2,26
	P-values	0.0060

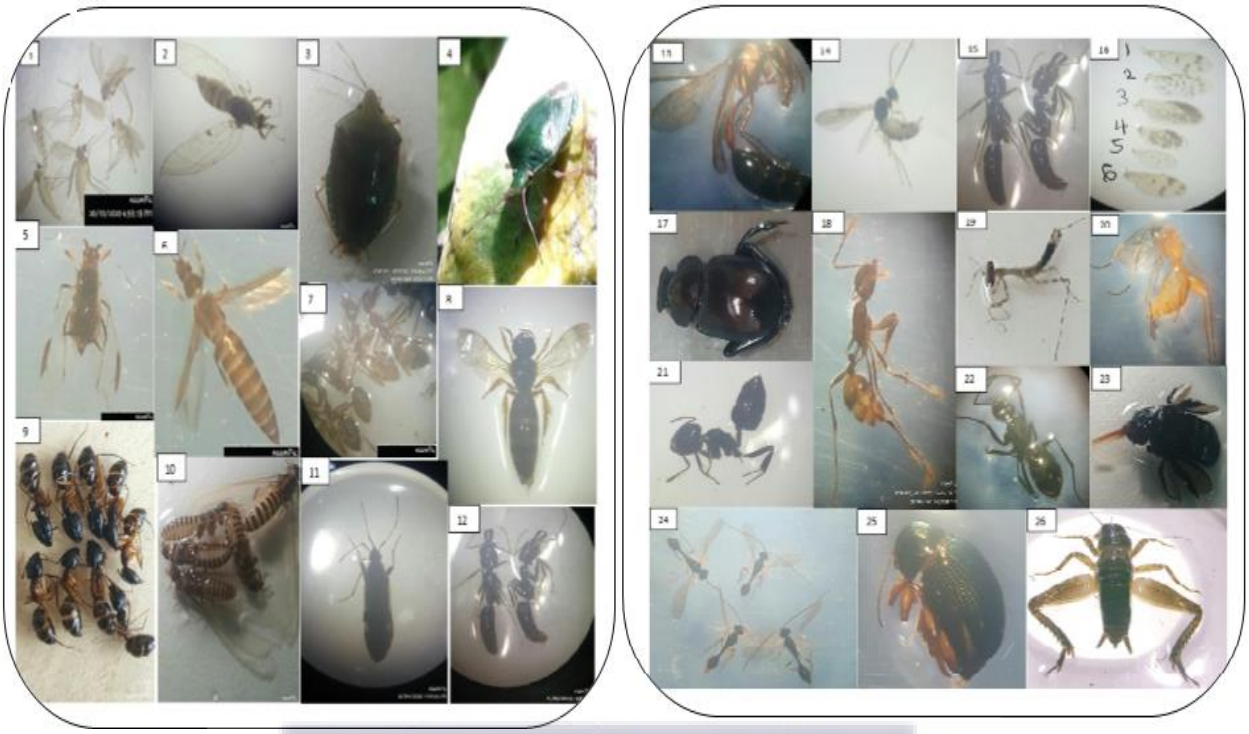

Plate 9. Gallery of the wide range of insect groups collected from the field using pan traps. [1 = *Forcipoyia* sp., 2 = *Tyora tessmanni*, 3 & 4 = *Bathyceolia thalassina*, 5 = *Toxoptera aurantii*, 6 = *Frankliniella* sp., 7 = *Oecophylla longinoda*, 8 = *Megachile* sp., 9 = *Pheidole megacephalus*. 10 = *Macrotermes* sp. 11 = *Pseudotheraptus devastus*, 12 = *Odontomachus* sp. 13 = *Polistes* sp, 14 = *Cotesia* sp, 15 = *Odontomachus* sp, 16 = wings of *Lauxanid* spp, 17 = *Scarabid* sp, 18 = *Tetramorium* sp, 19 = *Phamatid* sp, 20 = *Ophion* sp, 21 = *Crematogaster* sp, 22 = *Polyrachis* sp, 23 = *Apis* sp, 24 = *Sceliphron* sp, 25 = *Chrysochus* sp, 26 = *Gryllus* sp]

4.2. **Population trends of insect collections.**

Overall fluctuation trends of the insect abundances over the study period were observed. Insect numbers were generally high between the months of July and September, and dropped sharply in the latter part of September to early October. Population of insects increased slightly in the latter part of October and maintained a steady pattern until the latter part of December, where insect populations begun to rise again. A peak in insect population reached 6,100 individuals in the month of August and a sharp fall to below 50 individuals at the beginning of October, and begun to rise again towards the end of December (Figure 3).

4.2.1. **Population fluctuation trends at the three vertical levels.**

Trends in total monthly collections at the three different heights (these are pooled collections in each trap at a specific height from all three sites) were also observed and recorded. At the elevation of 3.0 m, insect populations begun to rise from a population of less than 1,000, to in July, and peaked above 2,500 individuals in August where insect numbers fell and maintained a study population below 100 till December. At the elevation of 1.5 m and ground level (0.0 m), insect populations rise from 1,000 and 1,500 in July respectively. Populations at 1.5 m rise to 1500 in August and drops sharply below 50 individuals in September where it maintains a population below 200 individuals to December. Insect populations at the ground level fell slightly in early August and rose to about 2,300 individuals in earliest part of September where there was a decrease in population below 500 individuals from early October throughout to December. These trends were reflected at all three sampling sites (Figure 4).

4.2.2. **Population fluctuation trends in coloured traps at the three heights.**

Figure 5A shows the total insect distribution in different coloured traps at the upper level (3.0 m). White traps captured high number of insects between the month of July to early part of September where insect numbers begun to increase from less than 500 and reaches its peak at 2,000 individuals in August. Populations decreased drastically to less than 50 individuals in the latter part of September and maintained the numbers up to December. For collections in yellow and blue traps, populations of insects were maintained below 500 individuals from July to early September where insect populations peaked at 500 individuals. There was a reduction in insect numbers below 50 individuals from September to December. Figure 5B shows total insect distribution in different coloured traps at the middle level (1.5 m). White traps captured high number of insects between the month of July to the latter part of September where insect numbers begun to increase from less than 400 individualsa and reached its peak at 720 individuals in early part of September. Populations decreased drastically to less than 50 individuals in the latter part of September until December. For collections in yellow traps populations decreased from 400 to 200 individuals in early August and increased again to 410 and droped in later part of September until December. Insect numbers collected in blue traps, maintained its population from 300 in July but increased slightly to 310 individuals and droped sharply to less than 50 individuals in the latter part of September. Population trends from October in the three traps, were below 100 individuals until December when it begun to rise slightly. Figure 5C shows remember figures cant talk, so they CANNOT explain. They only show. total insect distribution in different coloured traps at the ground level (0.0 m). Yellow traps captured high number of insects between the month of July to latter part of September where insect numbers at 800 reduces to 400 individuals in early August and increased to 1,100 in early part of September. Reduction in insect numbers continues to decrease until it falls below 50 individuals in early October and population trends rises slightly and falls below 200 individuals up to December. For collections in white traps populations increased from 500 to 10,000 individuals in early September and decreased in early October where population of insects and dropped below 50. Insect numbers collected in blue traps in July were 300 individuals and peaked at 400 individuals in the latter part of August, where it fell in early October till December, where insect numbers were below 50. Insect numbers were below 50 until December. These trends were repeated in the coloured pan traps at all three sites.

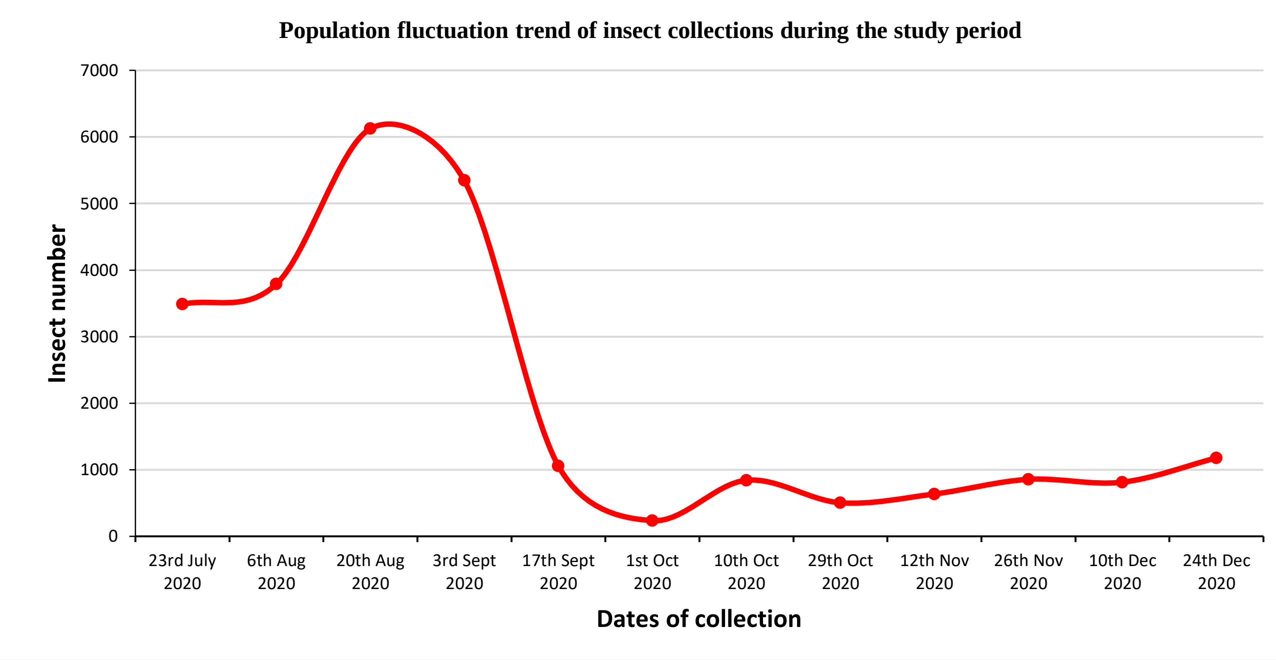

Figure 3. Population fluctuation trend of insect collections during the study period (July-Dec, 2020).

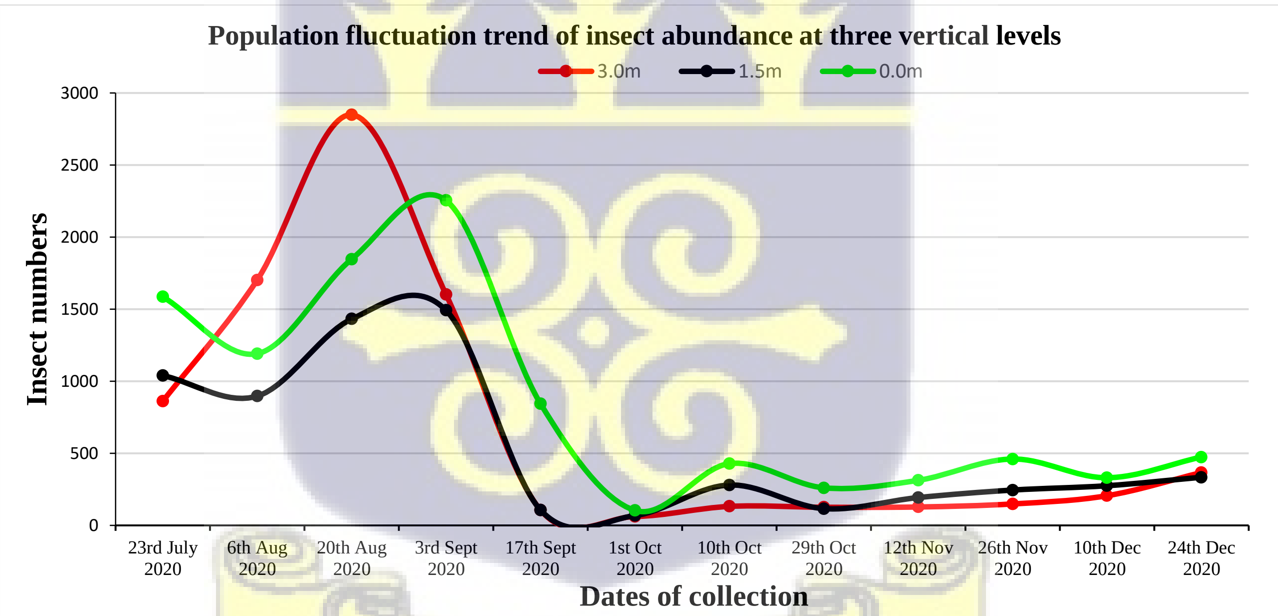

Figure 4. Population fluctuation trend of insect collections at different vertical levels during the study period (July-Dec, 2020).

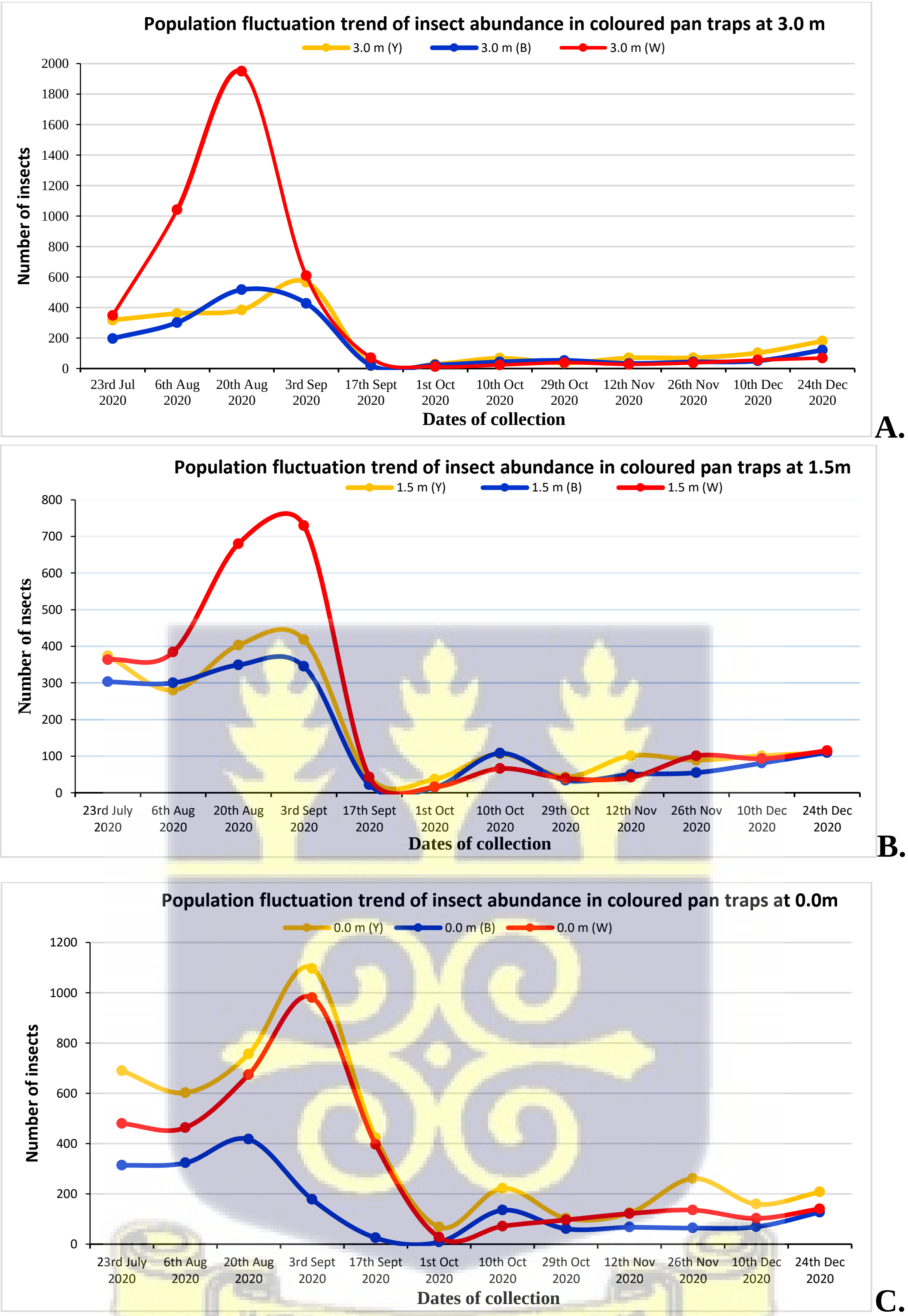

Figure 5. Total Population fluctuation trend of insect collections in coloured pan traps at 3.0 m (A), 1.5 m (B), and 0.0 m (ground level) (C), during the study period (July-Dec, 2020). Y = Yellow; B = Blue, W = White during the study period (July-Dec, 2020).

4.3. Assessment of diversity

For diversity, two different approaches were used,

i). assessment at each vertical level (where insects from the three coloured traps were pooled together as a single collection from one level, and the three levels compared with each other)

ii). assessment of collections by each of the three coloured traps (trap performance) at each vertical level as three collections from one level, and compared with each other at that level. This was repeated for the two other levels, and the 3 levels compared (Table 4)

At each vertical level, trap performance, species diversity, richness, and evenness were assessed, using the Shannon-Wiener index (H'), Margelef richness (Dmg), and Pielou's evenness (J') indices.

4.3.1. Pooled assessment at the Vertical levels

A. Abundance and diversity in Farm 1

Collections in Yellow (480), Blue (508) and White 738) traps at height 3.0 m totaled 1,726, and calculation of diversity from the pooled 1,726 insects produced the following indices; H' = 1.853, Dmg = 6.977, and J' = 0.467. At height 1.5 m, the pooled number of 2,439 from the three traps (Y = 741, B = 564, and W = 1134) produced the following indices; H'= 2.104, Dmg = 7.565, and J' = 0.514. At height 0.0 m (ground level), collections in traps yellow, blue, and white were 741, 564, and 592, respectively which totaled 1,981. The indices produced were; H' = 2.823, Dmg = 8.958 and J' = 0.722 (Table 3). At the three levels (0.0 m, 1.5 m, and 3.0 m), no statistical differences in abundance were observed ($F = 0.83$, $df = 2, 8$, $P = 0.4815$) (Table 5).

B. **Abundance and diversity in Farm 2**

Collections in yellow, blue, and white traps of 1120, 815 and 2,899, totalled 4,834 individuals at height 3. 0 m. The pooled figure produced indices as follows; H’ = 1.179, Dmg = 6.363, and J’ = 0.294). At height 1.5 m, yellow, blue and white traps recorded 736, 800 and 989, totaling 2,525 individuals and indices of H’ = 2.128, Dmg = 7.537, J’ = 0.510. At height 0.0 m, the yellow, blue and white traps recorded 2941, 814 and 2,428, totaling 6,183 individuals and produces indices of H’ = 2.632, Dmg = 8.019, and J’ = 0.618 (Table 3), with no significant differences in abundances at the three levels (F = 1.36, df = 2, 8, *P* = 0.3247) (Table 5).

C. **Abundance and diversity in Farm 3**

Collections in yellow, blue and white traps were 595, 496 and 654, respectively at height 3.0 m, and the pooled value of 1,745 individuals producing indices of H’ = 2.069, Dmg = 7.636, and J’ = 0.510). Total collections in yellow blue and white traps at height 1.5 m were 600, 478, and 562, respectively and a total of 1,640 individuals. This produced the indices H’ = 2.764, Dmg = 8.738, and J’ = 0.653). With a total of 2,397 insects collected from the yellow (1,062), blue (600), and white (735) traps at height 0.0 m, the following indices were calculated H’ = 3.057, Dmg = 9.051, and J’ = 0.669 (Table 3), and there were no significant differences in abundance at the three levels (F = 2.52, df = 2, 8, P = 0.1604) (Table 5).

Table 3. Species Diversity at the different vertical levels.

				Diversity Indices			
Farms	Vertical levels (m)	Insect abundance	Number of individuals	Shannon-Wiener	Simpson's Diversity	Margelef Richness	Pielou's Evenness
F1	3.0	1,726	52	1.853	0.360	6.977	0.467
F2	3.0	4,834	54	1.179	0.600	6.363	0.294
F3	3.0	1,745	57	2.069	0.344	7.636	0.510
F1	1.5	2,439	59	2.104	0.281	7.565	0.514
F2	1.5	2,525	59	2.128	0.237	7.537	0.510
F3	1.5	1,640	67	2.764	0.172	8.738	0.653
F1	0.0	1,981	68	2.823	0.087	8.958	0.722
F2	0.0	6,183	68	2.632	0.133	8.019	0.618
F3	0.0	2,397	69	3.057	0.132	9.051	0.669

4.3.2. **Trap assessment/performance at the different heights**

Abundances of insect taxa in each trap was counted and recorded at the upper level (3.0 m), the middle (1.5 m), and at at the ground level (0.0 m). At each level, the 3 traps were compared. This was then repeated at the two other levels to establish trap performances at the 3 vertical levels. Catches from each one of the traps were then pooled from the three Farms and compared to give an indication of how each trap type performed in the study area. The insect Orders Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Orthoptera, and Thysanoptera were common to all three colours of traps.

A. Trap performance in Farm 1

Height 3.0 m

Insect numbers in white traps recorded 738 individuals, blue traps recorded 508 individuals whiles yellow traps collected 480 individuals. However, for comparisons, between the different traps at 3.0m, diversity and richness was highest in yellow pan traps (H' = 2.104, Dmg = 6.803) and lowest in white pan traps (H' = 1.393, Dmg = 4.543), evenness was highest in blue pan traps (J' = 0.537) and lowest in yellow pan traps (0.049). White pan traps recorded the highest number of individuals and lowest record in yellow traps (Table 4).

Height 1.5 m

Insect numbers in white traps recorded 1134 individuals, Yellow traps collected 741 individuals. blue traps recorded 564 individuals. For comparisons between the different traps, diversity, richness and evenness was highest in yellow pan traps (H' = 2.879, Dmg = 7.646, J' = 0732) and lowest in white pan traps (H' = 1.486, Dmg = 4.976, J' = 0.732). However, evenness was highest in blue pan traps (J' = 0.537) and lowest in yellow pan traps (0.049). White pan traps recorded the highest number of individuals and lowest was recorded in blue traps (Table 4).

Height 0.0 m (Ground level)

Yellow traps collected 916 individuals, white traps collected 592 individuals and blue traps collected 473 individuals. For comparisons between the different traps, diversity among was highest in yellow pan traps (H' = 3.056) and lowest in blue pan traps (H' = 2.750), richness was highest in yellow pan traps (Dmg = 9.091) and lowest in blue pan traps (Dmg = 6.657) and evenness was highest in white pan traps (J' = 0.771) and lowest in yellow pan traps (0.738) (Table 4).

B. Trap performance in Farm 2

Height 3.0 m

White pan traps collected 2,899 insects, Yellow pan traps collected 1,120 insects and Blue pan traps collected 815 insects at 3.0 m. For comparisons between traps at 3.0 m, diversity, richness and evenness was highest in Yellow pan traps (H’ = 2.03, Dmg = 6.124, J’ = 0.537) and lowest in white pan traps (H’ = 0.532, Dmg = 3.761, J’ = 0.155). White pan traps recorded the highest number of individuals and lowest record was in blue traps (Table 4).

Height 1.5 m

White pan traps collected 989 insects, Blue pan traps collected 800 and Yellow pan traps collected 736 insects at 1.5 m. For comparisons between traps at Diversity, richness and evenness was highest in Yellow pan traps (H’ = 2.351, Dmg = 7.110, J’ = 0.607), and lowest in white pan traps (H’ = 1.843, Dmg = 5.085, J’ = 0.514). White pan traps recorded the highest number of individuals and the lowest record of what? was in blue traps (Table 4)

Height 0.0 m (Ground level)

Yellow pan traps collected 2,941 insects, Blue pan traps collected 814 insects, white pan traps collected 2,428 insects at 0.0 m. For comparisons between traps, diversity was highest in yellow pan traps (H’= 2.704) and lowest in white pan traps (H’ = 2.098), richness was higher in yellow pan traps (Dmg = 7.388) and lowest in blue pan traps (Dmg = 5.085) and evenness was highest in yellow pan traps (J = 0.661), but lowest in white pan traps (J’ = 0.519) (Table 4).

C. Trap performance in Farm 3

Height 3.0 m

White pan traps collected 654 insects, Yellow collected 595 insects and Blue traps collected 496 individuals. For comparisons between traps, diversity, richness and evenness was highest in Yellow pan traps (H’ = 2.518, Dmg = 7.670, J’ = 0.644) and lowest in white pan traps (H’ = 1.47, Dmg = 4.627, J' = 0.428), (Table 4). White pan traps recorded the highest number of individuals and the lowest record was in blue traps.

Height 1.5 m

White pan traps collected 562 insects, Yellow collected 600 insects and Blue traps collected 478 individuals. For comparisons between traps, diversity, was highest in Yellow pan traps (H' = 2.797) and lowest in white pan traps (H' = 2.080) (Table 7). Richness was highest in white pan traps (Dmg = 7.739) and lowest in yellow pan traps (Dmg = 7.504) and evenness was highest in blue pan traps (J' = 0.736) and lowest in yellow pan traps (J' = 0.437) (Table 4). Yellow pan traps recorded the highest number of individuals and lowest record was in blue traps.

Height 0.0 m (Ground level)

In farm 3 Yellow pan traps collected 1,062 insects, Blue pan traps collected 600 and white pan traps collected 735 insects. For comparisons between traps, diversity, richness and evenness was highest in Yellow pan traps (H' = 3.036, Dmg = 8.324, J' = 0.745) and lowest in blue pan traps (H' = 2.112, Dmg = 6.878, J' = 0.612) (Table 4).

Table 4. Species Abundance, Diversity, Richness and Evenness in coloured pan traps at three vertical levels.

Trap Colour	Farm	Height (m)	No. of insects	No of Species	Diversity Indices		
					Shannon-Wiener (H')	Margelef Richness (Dmg)	Pielou's Evenness (J')
Yellow	F1	3.0	480	42	2.104	6.803	0.049
Blue	F1	3.0	508	35	1.922	5.618	0.537
White	F1	3.0	738	30	1.393	4.543	0.406
Yellow	F1	1.5	741	50	2.879	7.646	0.732
Blue	F1	1.5	564	35	1.958	5.525	0.546
White	F1	1.5	1134	35	1.486	4.976	0.412
Yellow	F1	0.0	916	62	3.056	9.091	0.738
Blue	F1	0.0	473	41	2.750	6.657	0.736
White	F1	0.0	592	47	2.935	6.893	0.771
Yellow	F2	3.0	1120	43	2.031	6.124	0.537
Blue	F2	3.0	815	26	1.394	3.879	0.423
White	F2	3.0	2899	30	0.532	3.761	0.155
Yellow	F2	1.5	736	47	2.351	7.110	0.607
Blue	F2	1.5	800	36	2.010	5.386	0.557
White	F2	1.5	989	35	1.843	5.085	0.514
Yellow	F2	0.0	2941	59	2.704	7.388	0.661
Blue	F2	0.0	814	47	2.404	7.013	0.621
White	F2	0.0	2428	56	2.098	7.184	0.519
Yellow	F3	3.0	595	49	2.518	7.670	0.644
Blue	F3	3.0	496	33	1.783	5.317	0.506
White	F3	3.0	654	30	1.471	4.627	0.428
Yellow	F3	1.5	600	48	2.797	7.504	0.437
Blue	F3	1.5	478	43	2.803	6.970	0.736
White	F3	1.5	562	49	2.080	7.739	0.532
Yellow	F3	0.0	1062	58	3.036	8.324	0.745
Blue	F3	0.0	600	44	2.112	6.878	0.548
White	F3	0.0	735	48	2.383	7.273	0.612

Table 5. Mean insect abundance (± SE) in coloured pan traps and the mean insect abundance at three vertical levels at study sites.

Variables		Statistical Parameters	Mean ± SE		
Vertical level (m)	Traps		F1	F2	F3
	Blue		515.00 ± 26.50a	809.67 ± 4.84a	524.7 ± 38.0a
	White		821.33 ± 161.92a	2105.33 ± 582.25a	650.3 ± 49.97a
	Yellow		712.33 ± 126.68a	1598.67 ± 680.31a	752.33 ± 154.84a
		F	1.68	1.60	1.40
		Df	2, 8	2,8	2,8
		P-values	0.2628	0.2783	0.3175
0.0			660.33 ± 132.36a	2061.00 ± 640.84a	799.00 ± 137.15a
1.5			813.00 ± 168.44a	836.67± 71.66a	546.67 ± 36.04a
3.0			575.33 ± 81.73 a	1616.00± 654.45a	581.67 ± 46.10a
		F	0.83	1.36	2.52
		Df	2, 8	2,8	2,8
		P-values	0.4815	0.3247	0.1604

Means in the same column followed by the same letters are not significantly different from each other and those in the same column followed by different letters are significantly different (P = 0.05), using Student –Newman-Keuls (SNK) test.

4.4. Overall assessment of the three Farms.

Here collections from all three farms were pooled according to levels and trap colour. At the levels, all collections from each of the levels in Farms 1, 2, and 3 were pooled together. At the trap level, collections from each trap type and at each height were also pooled. This provided the overall totals of each of the trap types (Y, B, W) at each height, and from all three farms. This accounted for the overall collection at the vertical levels, and in the different trap colours from the North-eastern part of the Ashanti region where the study was undertaken.

A. Overall diversity at vertical levels (from the 3 Farms).

Height 3.0 m

At total of 8,305 individuals were recorded and the overall diversity, richness and evenness pooled from all three farms at vertical level 3.0m were (H' = 1.700, Dmg = 6.992, J' = 0.424) (Table 3). Insect taxa sampled at 3.0 m n > 100 were dominated by *Frankliniella* sp. (5,760), *Aedes* sp. (323), *Oecophylla longinoda* (296), *Forcipomyia* sp. (195), *Pheidole* sp. (181), *Chrysomelid* sp. (178) *Tetramorium* sp. (142), *Chrysochus* sp. (137) and *Crematogaster* sp. (135) (Appendix 2)

Height 1.5 m

Overall total number of insects collected at 1.5 m, was 6,604 individuals as well as overall diversity, richness and evenness at vertical level 1.5m recorded, H' = 2.352, Dmg = 7.947, J' = 0.559 respectively (Table 3). Insect taxa sampled at 1.5m can be found in were dominated by *Frankliniella* sp. (2,832), *Aedes* sp. (985), *Pheidole* sp. (335), *Oecophylla longinoda* (290), *Chrysomelid* sp. (219) *Forcipomyia* sp. (215), *Crematogaster* sp. (202) *Tyora tessmanni* (153) *Toxoptera aurantii* (139) and *Chrysochus* sp. (129) (Appendix 3).

Height 0.0 m

Total abundance of insects collected was 10,561 individuals as well as diversity, richness and evenness at vertical level 0.0 m were (H' = 2.837, Dmg = 8.676, J' = 0.670) respectively (Table 3). Insect taxa sampled at 0.0 m where n > 100 were dominated by *Aedes* sp. (2,190), *Pheidole* sp. (2,014), *Frankliniella* sp. (1,009), *Lauxanid* sp. 2 (754), *Oecophylla longinoda* (515), *Pheidole megacephalus* (401), *Forcipomyia* sp. (341), *Cotesia* sp (306), *Crematogaster* sp. (257), *Tyora tessmanni* (229), *Toxoptera aurantii* (213), *Tetramorium* sp. (158), *Bothroponera* sp. (143), *Chrysomelid* sp. (126), *Gryllus* sp. (126) *Chrysochus* sp (104) and *Odontomachus* sp. (103) (Appendix 4). Statistically, there was no significant difference in the total insect abundance recorded at 0.0 m, 1.5 m, 3.0 m (F = 0.93, df = 2,26, P = 0.4090) (Table 7).

B. Overall insect abundance in coloured pan traps (from the 3 Farms)

The overall total number of insects sampled in each colour (pooled insect numbers from all three farms at all three levels for each trap colour) from the three sites in Yellow, Blue and White pan traps were 9,191, 5,548, and 10,731 individuals, respectively. Diversity, richness and evenness in yellow (H' = 2.609 Dmg = 7.518 J' = 0.572), blue (H' = 2.126, Dmg = 5.916 J' = 0.579) and white (H' = 1.802 Dmg = 5.787 J' = 0.483) (Table 3). However, there was no significant differences in insect abundance recorded in coloured traps (F = 1.76, Df = 2, 26, P = 0.1927) (Table 7) but, numerically, white coloured pan traps recorded the highest number of individuals followed by yellow and then blue pan traps. The highest insect taxa recorded in coloured pan traps were Order Thysanoptera, Diptera and Hymenoptera. However, statistically, there was no significant differences in total insect abundance in three coloured traps within farm 1 (F = 1.68, Df = 2, 8, P = 0.2628), farm 2 (F = 1.60, Df = 2, 8, P = 0.2783) and farm 3 (F = 1.40, Df = 2, 8, P = 0.3175) (Table 5).

Total insect abundance in coloured traps at the different heights.

a. Traps at height 3.0 m

The total insect abundance in each trap at 3.0 m (pooled insect numbers in each traps from all three farms at 3.0 m), for yellow traps were 2195, blue traps were 1819 and white traps were 4,291. Also the overall insect diversity (H'), richness (Dmg) and evenness (J') yellow pan traps recorded (H' = 2.218, Dmg = 6.866 J' = 0.410), blue recorded (H' = 1.700, Dmg = 4.938, J' = 0.489) and white recorded (H' = 1.132, Dmg = 4.310, J' = 0.330) at 3.0 m (Table 4).

b. Traps at height 1.5 m

The total insect abundance in each trap at 1.5 m (pooled insect numbers from all three traps in all three farms at 1.5m), recorded 2,077 in yellow traps, 1,801in blue traps were and 2,685 in white traps. The total insect diversity (H'), richness (Dmg) and evenness (J') yellow pan traps recorded (H' = 2.676, Dmg = 7.420, J' = 0.592), blue recorded (H' = 2.257, Dmg = 5.960, J' = 0.635) and white recorded (H' = 1.803, Dmg = 5.933, J' = 0.486) (Table 4).

c. Traps at height 0.0m

The total insect abundance in each trap at 0.0m (pooled insect numbers from all three pan traps in all three farms at 0.0m), recorded 4,919 in yellow traps, 1,887 in blue traps were and white traps were 3,755. The total insect diversity (H'), richness (Dmg) and eveness (J') at 0.0m, yellow pan traps recorded (H' = 2.932, Dmg = 8.268, J'= 0.592), blue recorded (H' = 2.422, Dmg=6.849, J'=0.635) and white recorded (H' = 2.472, Dmg = 7.117, J' = 0.634) (Table 7) in yellow pan traps (J' = 0.745) and lowest in blue pan traps (J' = 0.612) (Table 4).

Among the three coloured pan traps there were no significant differences in insect abundance between yellow, blue and white pan traps at each vertical level; 3.0 m (F = 1.00, df = 2,8, P = 0.421), 1.5 m (F = 1.51; df = 2,8; P = 0.295) and 0.0 m (F = 1.00; df = 2,8; P = 0.423). Again, between three vertical level, yellow pan traps recorded no significant differences in insect abundance (F = 1.85; df = 2.8, P = 0.237), blue pan traps recorded no significant differences in insect abundance between vertical levels (F = 0.01; df = 2,8; P = 0.90), and white also recorded no significant differences in insect abundance between vertical levels. (F = 0.25; df = 2,8; P = 0.632) (Table 6). Overall insect diversity in the North - Eastern part of Ashanti region recorded, Shannon-diversity were, (H') = 2.578 while Species richness (Dmg) = 8.674 and Species evenness (J') = 0.574 but diversity was highest in farm 3 compared to the other two farms (Table 8).

Table 6. Mean insect abundance (± SE) in coloured pan traps at three vertical levels.

Variables		**Statistical Parameters**	**Mean ± SE**
Vertical levels (m)	**Traps**		**F1 +F2 +F3**
3.0	Blue		606.33 ± 104.39a
	White		1435.00 ± 739.40a
	Yellow		731.67 ± 196.99a

Variables		Statistical Parameters	Mean ± SE
Vertical levels (m)	**Traps**		**F1 +F2 +F3**
			712.33 ± 126.68a
		F	1.00
		Df	2, 8
		P-values	0.421
1.5	Blue		614.00 ± 96.26a
	White		890.33 ± 170.46a
	Yellow		692.00 ± 46.03a
		F	1.51
		Df	2, 8
		P-values	0.295
0.0	Blue		629.00 ± 99.50a
	White		1251.67 ± 589.61a
	Yellow		1639.67 ± 652.03a
		F	1.00
		Df	2,8
		P-values	0.423
3.0	Blue		606.33 ± 104.39a
1.5			614.00 ± 96.25a
0.0			629.00 ± 99.50a
		F	0.01
		Df	2,8
		P-values	0.900
3.0	White		1435.00 ± 739.40
1.5			890.33 ± 170.46a
0.0			1251.67 ± 589.61a
		F	0.25
		Df	2,8
		P-values	0.632
3.0	Yellow		731.67 ± 196.98
1.5			692.00 ± 46.03
0.0			1639.67 ± 652.03
		F	1.85
		Df	2,8
		P-values	0.237

Means in the same column followed by the same letters are not significantly different from each other and those in the same column followed by different letters are significantly different (P = 0.05), using Student –Newman-Keuls (SNK) test.

Table 7. Total mean ± SE insect abundance in coloured traps and at vertical heights.

Variable	Stats Parameters	Trap/Height(m)	Average ± SE F1 + F2 + F3
Total Collection From Traps		Blue	616.44 ± 50.16a
		White	1192.33 ± 288.71a
		Yellow	1021.11 ± 250.57a
	F		1.76
	Df		2,26
	P-values		0.1927
Total Collection From Vertical levels		0.0	1173.44 ± 294.77a
		1.5	732.11 ± 71.15a
		3.0	924.33 ± 257.54
	F		0.93
	Df		2, 26
	P-values		0.4090

Means in the same column followed by the same letters are not significantly different from each other and those in the same column followed by different letters are significantly different (P = 0.05), using Student –Newman-Keuls (SNK) test.

Table 8. Species Diversity indices recorded at sampling sites.

Farm	Total Insect Abundance	Number of Species	Shannon-Wiener Diversity	Simpson's Diversity	Margelef Richness	Pielou's Eveness
1	6,146	75	2.260	0.249	7.833	0.568
2	13,541	75	1.980	0.323	7.306	0.474
3	5,782	78	2.653	0.216	8.475	0.651
F1 + F2 + F3	**25,470**	**78**	**2.578**	**0.184**	**8.674**	**0.574**

CHAPTER 5

5.0. DISCUSSION

5.1. **Catalogued and ranked numbers of insects in cocoa farms.**

The results showed that cocoa farms have the potential to support wide variety of insect species and numbers. The diversity of insects was generally high in this study with very high insect abundance of individuals. The high diversity and abundance of insects recorded in this research probably might be due to certain factors favorable to the insect species. Viz: Phenological stages of the cocoa plant, management practices, food availability and microhabitat conditions such as temperature and humidity **(**Bale *et al*., 2002; Menéndez *et al*., 2007). According to Hunter (2002), insects dwell within complex ecosystems and interact with other taxonomic groups and the abiotic environment as whole.

The Order Diptera, having the most diverse insect species of 32 different kinds, the main cocoa insect pollinators, *Forcipomyia* sp. (Adjaloo and Oduro, 2013) was among the dominant species of Dipterans recorded in addition to *Aedes* sp. and *Lauxanid* spp. (Appendix 1). The presence of decaying matter-wood, plantain stems, cocoa leaf litter, and cocoa pod husks (the pod-breaking points) which were common in the cocoa farms where this study was conducted might have provided a variety of microhabitats for midges (*Forcipomyia* sp.) to breed. According to Adjaloo *et al.* (2012), such microhabitats conditions are conducive for midges. *Aedes* spp was the most dominant dipteran species recorded. *Aedes* spp usually breeds in natural or artificial water-holding containers such as leaves, plastic tanks and rubber tyres (Chareonviriyaphap *et al*., 2003). The high numbers of *Aedes* spp. recorded may have been due to collection of rain water on cocoa leaf litters, leaves on branches and plastic gallons (which were common on the farms).

Among the Hymenopterans ants dominated with very high numbers and studies by Bosu *et al.*, 2018 indicated that high number of ants in cocoa ecosystem is due to their natural abundance and the essential role they play in the tropical environment. Ants are common, diverse, and abundant representing about 80% of the animal biomass in tropical ecosystems (Hölldobler and Wilson, 1990). Their high numbers recorded and ranked in the cocoa ecosystem may show that they are beneficial, as some species have been identified as natural enemies to some important pests of cocoa. For example, in Ghana, Williams (1954) observed that *Oecophylla longinoda* on cocoa trees were less damaged by mirids. This may have also accounted for the low number of mirids recorded in this study. In contrast, some ant species may contribute to the propagation of the black-pod disease of cocoa which leads to pod losses (Bosu *et al*., 2018). Another important role of ant species was proposed that, ants help to facilitate the success of pollination by attacking pollinators which had been stated and confirmed by Bisseleua *et al*. (2017). This increases their movement, transfering pollen between flowers. Again, some parasitoid species such as the braconids and ichneumonids recorded in this study and according to Rahman *et al*. (2005) these are the commonest parasitoids that can be found within the tropical ecosystems. Bee populations among the Hymenopterans were very low in numbers, numerically representing (0.27 %) of the total population of insects recorded. It may be speculated that, the important function of bees in the ecosystem due to their mutualistic interactions with some flowering plants and the fact that they are regarded worldwide as essential pollinators, may not necessarily make them pollinators of cocoa, as stated by Adjaloo *et al*. (2012). Even though, the red banded thrips *Selenothrips rubrocinctus*.is very common throughout the tropical regions especially on cocoa according to Muraleedharan (2017) none was recorded in this study. Instead, thrips belonging to order Thysanoptera recorded only one genus group (*Frankliniella* sp.) and it was the most abundant insect order (9,601) recorded in this study. High numbers of Thysanoptera were recorded at a period when cocoa inflorescence was dominant and according to Young (1987), 70 % of thrips were found on cacao flowers where Pickett *et al*. (1988) and Yudin *et al*. (1988) had also observed that *Frankliniella* sp. prefers plants with flowers. When blooming reduces, populations of the western flower thrips diminishes (Arzone *et al*., 1989).

Insect abundance in all three farms was high but Farm 2 recorded the highest insect numbers. This could be as a result of factors such as high environmental heterogeneity (different plants intercropped with cocoa in the same farm). Some of the crops that were observed to be intercropped included maize, cocoyam, cassava, palm trees, mango, avocado, plantain, banana, *Ceiba pentendra* (locally known as Onyina) and some ornamental palm trees. Studies by Dauber *et al*. (2003) also observed that the heterogeneity of the environment affects insect communities sampled. Farm 2 had drier and warmer temperatures as a result of exposure to direct sunlight due to its open canopy and this could be a contributing factor to its high population density of insects sampled. This Hoffman *et al*. (2003) indicated that high temperature affects the distribution and abundance of insects and Kang *et al*. (2009) also added that, the population growth and size of insects such as pests are determined by high temperatures. The nature of Farm 3 on the other hand was such that its canopy was completely closed creating a denser environment. Some authors (Nair, 1984; Beer, 1987) have stated that the cocoa tree crowns virtually merge to create self-shade which could prevent the direct and extreme impact of the solar radiation on the soil surface, resulting in a conducive micro-environment for diverse groups of insects to dwell in. This factor may have led to the high insect diversity in Farm 3 compared to the lowest diversity in Farm 2 which had its canopy open. This finding is also in accordance to Adjaloo *et al*. (2012), who recorded high insect species diversity in heavily shaded cocoa farms as compared to widely spaced cocoa farms with less canopy cover.

Fluctuations in the population trend of insects over the months, from July to December were directly proportion to the phenological stages of cocoa i.e., during the times (July –September) in this study, when the cocoa was dominated by flowers the peak of insect numbers was high during the sampling periods. Kwapong and Frimpong-Annin (2014) had postulated that, a second peak of flower bloom on cocoa occurs from June throughout to July and diminishes gradually towards the other subsequent months, at the time that pollinators abound. However, at stages where flowers were out of season, some of insects other than those who were not avaible at that time and maintained a fairly constant trend in low numbers. Shimadzu *et al.* (2013) populations had proved that, some of the most marked temporal fluctuations in species abundances are linked to seasons. He also added that diverse assemblages of insect species can persist if species use shared resources at different times thereby minimizing interspecific competition and this will have an influence on the fluctuations in numbers over a period.

5.2. **Insect abundance and diversity at different Vertical levels.**

Comparatively, the ground level was the most diverse and the most abundant in insect numbers among the three levels studied. High numbers of insect species sampled at the ground level might have been due to the fact that, the presence of decaying matter-wood, cocoa pod husks, cocoa leaf litter might have provided microhabitats and breeding sites for some high number of the species. According to de Schawe *et al.* (2018), the main pollinators of cocoa *Forcipomyia* sp. which breed close to the ground in cocoa pod husks, leaf-litter, were recorded in higher numbers at the 0.0 m (ground level), compared to the other heights sampled as seen in this study. Even though diversity decreased from the 0.0m to 3.0 m, insect abundances did not follow the same trend. Abundances were higher at the upper level and ground level. By observations, upper level was influenced by fluctuations in insect abundances due to the dominance of certain groups of insect species of which *Frankliniella* sp. in the Order Thysanoptera (69.36 % of the total insect catches at 3.0 m) happens add up to the numbers. Food availability and breeding sites in flowers concentrated more at the cocoa canopy for these insects could in their high abundance occurence and this was in contrast to the main pollinators of cocoa. Loomans et. al., (1995) confirmed that flowers were food source and habitat for the western flower thrips. Again, *Forcipomyia* sp. numbers increased from 3.0m to 0.0 m (ground level) in the ascending order 195 < 215 < 341, respectively. This corresponds to earlier stud+ies by Young (1982) which stated that over a period of time, leaf-litter may break down and become attractive to midges as suitable breeding sites for them. Comparatively, *Frankliniella* sp. increased from the ground level to the upper level (3.0 m) in the ascending order 1009 < 2832 < 5760, respectively. However, among the three farms, thrips present was extremely high in Farm 2 and which had an open canopy. Ant species such as the *Oecophylla longinoda* were more abundant at the upper and this could be as a result of their nest being built within the canopy (Dejean, 1990). In constrast, most of their numbers were most dominant at the ground levels where most of the other insect species were concentrated in relation to this study. It was however observed that, the predative nature of *Oecophylla longinoda* makes them available at levels where insect numbers a generally high. This confirms studies by Dejean 1990 that *Oecophylla longinoda are* very effective predators in the tropicsal ecosystems. For important decomposers such as *Phediole* species, numbers increased as the height decreased and thus these ant species increased from 253 individuals from the upper level to 335 at the middle level and the 2,014 at the ground level. This factors in because of the specific roles they play as decomposers which is in agreement to the findings of Shukla *et al*. (2013), which confirmed that, an important role of *Pheidole* sp. in the ecosystem is the regulation the soil nutrients which results in decomposition.

For the numbers of bees caught which were extremely low throughout the sampling period, although a few of them were occasionally observed foraging in the cocoa canopy (upper level). The numbers of bees sampled were extremely low throughout the sampling period at 3.0 m and 1.5 m, although a few of them were occasionally observed foraging in the cocoa canopy (3.0 m). Kaufman (1975) explained that different families of Hymenopterans; Aphidae, Megachilidae and Halictidae, gather pollen at the canopy level of cocoa trees and in the process pollinate about 42% of cocoa flowers. Cocoa capsids were not captured at the canopy or ground level, and similar findings had been confirmed that they are mostly found hovering around the trunk level in Darko

(2014). In terms of species evenness, Pielou's index showed that generally, insect species were not evenly distributed across heights (i.e. different evenness values at each height). The evenness at the vertical levels recorded highest at the ground.

5.3. **Trap Colour Performance**

In absence of collector bias by using different colours of pan traps, it have been made ideal for different insect communities, through time and space as observed by Westphal *et al* (2008). The relative proportions of insect species suggest that the various insect groups potentially respond differently to the colour and placement of pan traps. The height at which each coloured trap was set was a major determinant in the variation of species richness, diversity and abundance. This is because it was observed that, there were some fluctuations in insect abundances with respect to the trap colour trap as vertical levels either decreased or increased. Vrdoljak, (2012), had stated that, catches of insects by different colours is by attraction trap and Pucci (2008), confirmed that pan trap catches are also influenced by the set location. Thus, certain groups of insects were attracted to specific colours in very low or high numbers at specific heights. Pan traps that were set at the ground level collected the highest diversity of insects. Su and Woods (2001) suggested that coloured traps are most likely to catch different kinds of insects more close to the ground where they are predicted to be most active than in traps above the ground. It was further stated that, insects that oviposit in soil are more likely to be captured in traps close to the ground than in traps above ground.

Throughout the work, yellow pan traps collected the highest number of diverse insect species (62), followed by white (56) and blue pan traps (47). Yellow being the best at sampling most diverse insect numbers confirms similar findings of Disney *et al*. (1982) that, yellow pans collects most diverse groups of insects at the ground level and when it is elevated above the ground. Also work done by Frimpong *et al.* (2009), where yellow, blue and white pan traps were set together in the canopy, yellow was the most efficeient. Even though yellow pan traps were best at sampling for insect diversity, white pan traps collected higher number of insect species, compared to the blue pan traps, Shannon-Wiener diversity index calculated low diversity index value in white pan trap collections. This is because insects were` poorly distributed (uneven distribution) in white pan traps. This observation was concluded to the reason that, Shannon-Wiener index does not account for species richness only, but evenness as well.

On the other hand at 3.0 m, white pan traps performed better in terms of insect abundance compared to the other trap colours by recording 52 % of the total trap catches. Again, at 1.5 m the white pan traps still performed better than the other colours by recording 41 % of the total trap catches. High insect numbers collected in white pan traps at 3.0 m and 1.5 m was influenced by a the highly dominating insect species, *Frankliniella* sp. which was attracted to the white pan traps during the period when cocoa plantations were dominated by flowers. In a study conducted by Mao *et al*. (2018), white sticky cards were confirmed to have the strongest attraction ability for *Frankliniella intonsa* among 13 different coloured sticky traps evaluated in cowpea greenhouse trials. Among the three vertical levels, the yellow pan traps performed better than the other colours by recording, 47 % of the total trap catches at the ground level. For instance, the highest number of cocoa midges, the important cocoa pollinator (*Forcipomyia* sp.) was recorded in the yellow pan traps compared to white and blue pan traps. The abundance of midges in yellow pans confirms Potts' (2005) postulation that flies are biased towards yellow colour.

The trapping of a small number (16 individuals) of capsids (*Pseudothraptus devastus* and *Bathycoelia thalassina*) by the coloured pan traps were also observed throughout this study, and it is in agreement with some findings by Frimpong *et al.* (2009), where it was stated that, yellow, blue and white pan traps were not effective in attracting cocoa capsids. Though coloured pan traps have been used efficiently to collect bees in agricultural systems, Potts *et al*. (2006), had stated that they appear ineffective in sampling bees in the cocoa agroecosystem. This also confirms similar results in this study where only two *Apis* sp. were recorded where yellow pan traps recorded one individual of *Apis* sp at 3.0 m but blue pan traps recorded one at 1.5 m. Similarly, blue and white pan traps recorded 1 and 4 individuals of *Megachile* sp. and *Halictid* sp respectively at 3.0 m. Low catches of bees by pan traps was observed by Frimpong *et al*. (2009).and stated that, although this method is efficient in sampling bees, it is not effective in cocoa orchards and this reason might have accounted for their low captures in this study.

Hymenoptera, Diptera and Thysanoptera were the most abundant insect orders recorded in the coloured pan traps. These three orders put together constituted between 62 to 95 % of the insects recorded across vertical levels. For dipterans and At 3.0 m, the white pan trap performed better than the other colours by recording 95 % of the three Orders, with Thysanoptera dominating. The blue pan trap performed better than the other colours at 1.5 m by recording 91 % of the three Orders, and again with Thysanoptera dominating. At the ground level, the yellow pan trap performed better than the other two colours, recording 93 % of the three Orders, with Diptera dominating. However, high numbers of insects in coloured traps with respect to height was greatly influenced by the phenological stages of cocoa. According to (Vega *et al* ,1990) it was suggested that insect activities (as reflected in trap catches) varied with height and he concluded that sampling using different coloured pan traps at vertical heights can be used to monitor arrival times of insect groups across different seasons and the height best sampled when insect population is very low or high in abundance.

CHAPTER 6

6.0. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The high numbers of insect species and abundance catalogued and ranked in this study shows that cocoa agro-systems are species-rich; and with different coloured pan traps, the assessment of diverse insect groups can be ascertained. The most abundant orders recorded were, Hymenoptera, Diptera and Thysanoptera with the highest percentage abundance belonging to order Thysanoptera. Vertical levels at which insect groups were sampled had an influence on the diversity and abundance of species of which there were no significant difference in insect abundance sampled at the three different vertical levels but numerically highest abundance and diversity was recorded at the ground level. Relative to the others, thrips (*Frankliniella* sp.), were extremely high at the upper level. For trap colour performance, the insect orders Hymenoptera, Diptera and Thysanoptera dominated. These three insect orders put together constituted between 62-95 % of the total trap catches. Even though, there was no statistical significance between the three coloured pan traps in terms of total trap performance across vertical levels, the white pan trap performed better than the other coloured pan traps in terms of insect abundance at 1.5 m and 3.0 m. However, at the ground level, the yellow pan trap was the best in terms of diversity but the blue pan traps were virtually the same at all three heights. The attraction of *thrips* enormously to white coloured traps at 3.0 m and 1.5 m, midges in yellow pan traps at 0.0 m (ground level) as well as trapping of *Oecophylla longinoda* by pan traps at all three levels may inform monitoring and sampling protocols. However due to their high numbers they could be economically important in cocoa agroecosystem. Similar to some findings of Russo *et al.* (2011), colour combinations rather than the use of a single colours, results in finding more diverse insects because insect taxa would respond differently to colours when set at different vertical levels.

6.2. RECOMMENDATIONS

Insects were catalogued and ranked only in the North – Eastern part of Ashanti region to assess their abundance, using pan traps. It is therefore recommended that this work should be repeated in other cocoa growing areas in Ghana. because of the differences in ecological and environmental conditions. The main pollinator of cocoa which is already known and documented to be the *Forcipomyia* sp. and another flower loving insect (*Frankliniella* sp.) has also been recorded in high numbers on flowers of cocoa, the relationship between these and cocoa flowers should be investigated. High numbers of insects such as the *Forcipomyia* sp. recorded at the ground level indicates that in terms of breeding or foraging the ground level is most sutable for them and therefore the use of agrochemicals such as weedicides and pesticides on cocoa litter should be minimal. The trapping of high number of thrips (*Frankliniella* sp.) especially at the upper level during the flowering periods informs us about their arrival times and the level at which they are mostly concentrated. This is very informative when it comes to farm management practices; if these insects are harmful or beneficial to cocoa then their economic importance on cocoa should be further investigated. More colours of pan traps apart from yellow, white and blue should be incorporated and evaluated to ascertain their performance to other insect groups at different vertical levels until their efficiency is attained in cocoa agro-systems. Furthmore from the study, it is recommended that, white pan traps should be used as a monitoring tool to capture high numbers of thrips (*Franklineilla* sp), especially at the upper and middle levels during periods when cocoa has a lot of flowers.

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APPENDIX

Appendix 1. Insect Orders, families, species, and percentage (%) abundances at the study sites.

Order	Family	Species	Number of Insects				Proportions from each Farm		
			Farm 1	Farm 2	Farm 3	Total (F1+F2+F3)	F1	F2	F3
							(#/total)/100	(#/total)/100	(#/total)/100)
Blattodea	Blattidae	*Blattid* sp.	26	31	24	81	0.42	0.23	0.42
Coleoptera	Cantharidae	*Cantharid* sp.	16	6	37	59	0.26	0.04	0.64
	Carabidae	*Carabid* sp.	7	3	10	20	0.11	0.02	0.17
	Cerambycidae	*Cerambycid* sp.	2	0	5	7	0.03	0	0.09
	Chrysomelidae	*Aulacophora* sp.	5	8	12	25	0.08	0.06	0.21
		Chrysochus sp.	198	88	174	460	3.22	0.65	3.01
		Chrysomelid sp.	234	88	112	434	3.81	0.65	1.94
	Coccinelidae	*Coccinelid* sp.	0	0	1	1	0	0	0.02
	Cuculionidae	*Hadramphus spinipennis*	0	0	1	1	0	0	0.02
		Curculionid sp.	6	9	19	34	0.1	0.07	0.33
	Nitidulidae	*Carpophilus* sp.	8	10	9	27	0.13	0.07	0.16
	Scarabidae	*Scarabid* sp	22	37	21	80	0.36	0.27	0.36
	Styphalinidae	*Styphalinid* sp	17	12	8	37	0.28	0.09	0.14
Diptera	Asilidae	*Asilid* sp	3	0	1	4	0.05	0	0.02
	Calliphoridae	*Calliphora* sp	28	32	10	70	0.46	0.24	0.17
	Ceccidomyidae	*Ceccidomyid* sp	38	37	72	147	0.62	0.27	1.25
	Ceratopogonidae	*Forcipomyia* sp	250	283	218	751	4.07	2.09	3.77
	Chironomidae	*Chironomus* sp	1	2	0	3	0.02	0.02	0
	Culicidae	*Aedes* (larvae) sp	777	1414	1305	3496	12.64	10.44	22.57
	Diopsidae	*Diasemopsis* sp	2	18	6	26	0.03	0.13	0.1
Diptera	Drosophillidae	*Drosophila* sp	80	35	58	173	1.3	0.04	1
	Ephydridae	*Ephydra* sp	53	50	46	149	0.86	0.37	0.8

Order	Family	Species	Number of Insects				Proportions from each Farm		
			Farm 1	Farm 2	Farm 3	Total (F1+F2+F3)	F1	F2	F3
							(#/total)/100	(#/total)/100	(#/total)/100)
	Phoridae	*Megaselia* sp	13	14	15	42	0.03	0.1	0.26
	Lauxanidae	*Lauxanid* sp. 1	6	9	4	19	0.1	0.07	0.07
		Lauxanid sp. 2	72	718	61	851	0.08	5.3	1.06
		Lauxanid sp. 3	99	97	25	221	0.16	0.72	0.43
		Lauxanid sp. 4	47	77	14	138	1.17	0.57	0.24
		Lauxanid sp.5	1	7	7	15	1.61	0.05	0.12
		Lauxanid sp.6	5	0	1	6	0.76	0	0.02
		Lauxanid sp.7	10	4	5	19	0.02	0.03	0.09
	Micropezidae	*Micropeza* sp	6	24	6	36	0.1	0.18	0.1
	Muscidae	*Musca domestica*	29	13	16	58	0.47	0.1	0.28
	Mycetophillidae	*Mycetophilid* sp	23	10	7	40	0.37	0.07	0.12
	Nerridae	*Nerrius* sp	15	43	48	106	0.24	0.32	0.83
	Orusidae	*Orusid* sp	1	1	1	3	0.02	0.01	0.02
	Ptycopteridae	*Ptycoptera* sp	8	5	6	19	0.13	0.04	0.1
	Sarcophagidae	*Sarcophaga* sp	11	12	15	38	0.18	0.09	0.26
	Sciaridae	*Sciarid* sp	4	6	73	83	0.07	0.04	1.26
	Stratiomyiidae	*Ditylometopa* sp	0	5	0	5	0	0.26	0
		Plecticus posticus	13	13	19	45	0.21	0.1	0.33
		Stratiomyid sp	0	0	2	2	0	0	0.03
		Hermetia illucens	7	1	12	20	0.11	0.11	0.21
	Tachinidae	*Tachinid* sp	1	0	0	1	0.02	0	0
	Tephritidae	*Ceratitis* sp	7	10	3	20	0.11	0.07	0.05
	Tephritidae	*Perilampsis* sp	1	0	0	1	0.02	0	0
	Tipulidae	*Tipula* sp	13	7	45	65	0.21	0.05	0.78
Hemiptera	Aphidae	*Toxopotera aurantii*	117	233	55	405	1.9	1.72	0.95
	Cicadelidae	*Cicadelid* sp	16	22	20	58	0.26	0.16	0.35

Order	Family	Species	Number of Insects				Proportions from each Farm		
			Farm 1	Farm 2	Farm 3	Total (F1+F2+F3)	F1	F2	F3
							(#/total)/100	(#/total)/100	(#/total)/100)
	Coreidae	*Pseudotheraptus devastus*	0	6	6	12	0	0.04	0.1
	Membracidae	*Membracid* sp	3	0	4	7	0.05	0	0.07
	Pentatomidae	*Bathycoelia thalassina*	0	1	2	3	0	0.01	0.03
	Psyllidae	*Tyora tessmanni*	83	236	173	492	1.35	1.74	2.99
Hymenoptera	Apidae	*Apis* sp	0	1	1	2	0	0.01	0.02
	Braconidae	*Braconid* sp	12	14	7	33	0.2	0.1	0.12
		Cotesia sp	72	150	134	356	1.17	1.11	2.32
	Chalcididae	*Brachymeria* sp	3	7	5	15	0.05	0.05	0.09
	Evanidae	*Evanid* sp	2	0	5	7	0.03	0	0.09
	Formicidae	*Bothroponera* sp	61	64	23	148	0.99	0.47	0.4
		Camponotus sp	7	26	18	51	0.11	0.19	0.31
		Crematogaster sp	152	334	108	594	2.47	2.47	1.87
		Odontomachus sp	6	100	0	106	0.1	0.74	0
		Oecophylla longinoda	417	650	34	1101	6.78	4.8	0.59
		Pheidole megacephalus	13	394	7	414	0.21	2.91	0.12
		Pheidole sp	208	2248	147	2603	3.38	16.6	2.54
		Polyrachis sp	4	15	27	46	0.07	0.11	0.47
		Tetramorium sp	5	283	106	394	0.08	2.09	1.83
		Tetraponera sp	8	9	25	42	0.13	0.07	0.43
	Helictidae	*Helictid* sp	0	2	0	2	0	0.01	0
	Ichneumonidae	*Ophion* sp	20	13	72	105	0.33	0.14	1.25
		Xanthompimpla sp	22	40	53	115	0.36	0.3	0.92
	Megachilidae	*Megachile* sp	2	3	0	5	0.21	0.02	0
	Platygastridae	*Platygastrid* sp	0	0	1	1	0	0	0.02
	Pompilidae	*Pompilid* sp	7	13	62	82	0.11	0.1	1.07
	Sphecidae	*Sceliphron* sp	41	50	68	159	0.67	0.37	1.18

Order	Family	Species	Number of Insects				Proportions from each Farm		
			Farm 1	Farm 2	Farm 3	Total (F1+F2+F3)	F1	F2	F3
							(#/total)/100	(#/total)/100	(#/total)/100)
		Sphecid sp	34	25	31	90	0.55	0.18	0.54
	Vespidae	*Polistes* sp	3	2	11	16	0.05	0.01	0.19
		Vespid sp	3	1	4	8	0.05	0.01	0.07
Isoptera	Termitidae	*Macrotemes* sp	15	4	72	91	0.24	0.03	1.25
Lepidoptera	Hesperidae	*Hesperid* sp	21	19	155	195	0.34	0.01	2.68
	Noctuidae	*Noctuid* sp	0	1	0	1	0	0.01	0
	Nymphalidae	*Nymphalid* sp	0	3	0	3	0	0.02	0
Mantodea	Mantidae	*Mantid* sp	1	0	2	3	0.02	0	0.03
Neuroptera	Chrysopoidae	*Chrysopa* sp	4	11	4	19	0.07	0.08	0.07
Orthoptera	Acrididae	*Acrida* sp	6	4	2	12	0.1	0.03	0.03
	Gryllidae	*Gryllus* sp	46	49	37	132	0.75	0.36	0.64
Phasmatodea	Phasmatidae	*Phasmatid* sp	0	0	2	2	0	0	0.03
Thysanoptera	Thripidae	*Frankliniella* sp	2567	5269	1765	9601	41.77	38.91	30.53
TOTAL			**6146**	**13541**	**5782**	**25470**	**100**	**100**	**100**

Appendix 2. Insect Orders, Families, and individual species abundance in coloured pan traps at 3.0 m.

Order	Family	Species	Height (3.0 m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
Blattodea	Blattidae	*Blattid* sp	1	3	3	0	3	1	0	2	0
Coleoptera	Chrysomelidae	*Aulacophora* sp	0	6	4	1	0	0	0	0	0
		Chrysochus sp	29	21	32	7	4	7	19	8	10
		Chrysomelid sp	26	16	16	13	8	5	42	20	32
	Cantharidae	*Cantharid* sp	0	0	6	1	0	2	0	0	2
	Nitidulidae	*Carpophilus* sp	1	1	0	1	0	0	0	1	3
	Curculionidae	*Curculionid* sp	1	1	3	0	1	1	1	0	1
	Styphalinidae	*Styphalinid* sp	1	2	1	2	0	1	1	0	0
Diptera	Culicidae	*Aedes* sp	43	6	8	8	103	30	15	30	80
	Asilidae	*Asilid* sp	0	0	0	0	0	0	1	0	0
	Calliphoridae	*Calliphora* sp	1	0	5	0	0	0	2	4	0
	Ceccidomyidae	*Ceccidomyid* sp	4	5	11	3	3	5	5	0	1
	Cerambycidae	*Cerambycid* sp	0	0	0	0	0	2	0	0	0
	Tephritidae	*Ceratitis* sp	0	0	3	0	1	0	0	0	0
	Chironomidae	*Chironomus* sp	1	0	0	0	0	0	0	0	0
	Stratiomyiidae	*Dictylometopa* sp	0	6	0	0	0	0	0	0	0
		Hermetia sp	2	0	0	0	0	3	0	0	3
		Plecticus posticus	1	2	3	0	0	0	1	0	1
		Stratiomyiid sp	0	0	1	0	0	0	0	0	0
	Drosophilidae	*Drosophila* sp	9	2	4	3	0	1	0	4	1
	Ephydridae	*Ephydra* sp	6	3	8	5	1	0	4	2	0
	Ceratopogonidae	*Forcipomyia* sp	22	50	21	19	13	28	19	8	15
Diptera	Lauxanidae	*Lauxanid (1)* sp. 1	4	7	1	1	0	0	0	0	0
		Lauxanid (2) sp. 2	2	7	8	3	1	5	4	2	1
		Lauxanid (3) sp. 3	7	4	2	35	15	9	13	43	4
		Lauxanid (4) sp. 4	0	0	0	7	0	1	2	5	0
		Lauxanid (7) sp. 7	4	0	0	1	0	1	2	2	0
	Phoridae	*Megaselia* sp	0	1	3	0	0	0	0	0	0
	Membracidae	*Membracid* sp	1	0	0	0	0	0	0	0	0
	Micropezidae	*Micropeza* sp	0	3	0	0	0	0	0	0	0
	Muscidae	*Musca* sp	1	1	0	0	0	0	0	0	0
	Mycetophillidae	*Mycetophilid* sp	7	0	2	1	0	0	0	4	0
	Neridae	*Nerius* sp	0	1	1	2	1	12	0	1	6
	Ptycopteridae	*Ptycoptera* sp	1	2	3	0	0	0	0	0	0
	Sciaridae	*Sciarid* sp	0	0	1	0	0	1	0	0	0
	Tipulidae	*Tipula* sp	1	1	1	0	0	0	1	0	0

Order	Family	Species	Height (3.0 m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
Hemiptera	Cicadelidae	*Cicadelid* sp	2	4	5	1	0	0	0	2	0
	Coreidae	*Pseudotheraptus devastus*	0	0	4	0	0	0	0	0	0
	Aphidae	*Toxoptera aurantii*	1	33	8	1	4	5	2	2	0
	Psyllidae	*Tyora* sp	12	33	38	6	9	6	2	1	3
Hymenoptera	Apidae	*Apis* sp	0	0	1	0	0	0	0	0	0
	Chalcididae	*Brachymeria* sp	1	0	1	0	0	0	1	0	0
	Braconidae	*Braconid* sp	2	2	1	3	1	0	1	0	0
		Cotesia sp	1	1	4	0	0	1	0	0	0
	Coccinelidae	*Coccinelid* sp	0	0	0	0	0	0	0	0	1
	Helictidae	*Halectid* sp	0	0	0	0	0	0	0	2	0
	Ichneumonidae	*Ophion* sp	1	4	9	1	0	0	0	0	3
		Xanthopimpla sp	2	5	5	1	0	1	1	0	2
Hymenoptera	Megachilidae	*Megachile* sp	0	0	0	1	0	0	1	2	0
	Formicidae	*Oecophylla longinoda*	13	27	5	59	15	0	91	77	9
		Phediole megacephalus	0	0	0	1	1	0	0	0	0
		Pheidole sp	3	115	15	9	80	2	0	17	12
		Tetramorium sp	0	99	19	1	8	12	0	2	1
		Tetrponera sp	0	0	0	0	0	5	0	1	0
		Polyrachis sp	0	3	2	0	0	5	0	0	4
		Crematogaster sp	7	51	5	34	12	2	3	7	14
		Camponotus sp	0	1	2	0	0	10	0	0	2
		Bothroponera sp	0	0	0	0	0	0	1	0	0
	Vespidae	*Polistes* sp	1	0	0	0	0	0	0	0	0
	Pompilidae	*Pompilid* sp	0	3	2	0	0	2	0	0	5
	Sphecidae	*Sceliphron* sp	3	7	0	0	2	4	1	0	0
		Sphecid sp	1	4	9	3	0	0	0	1	1
Isoptera	Termitidae	*Macrotermes* sp	0	0	6	0	0	9	6	1	3
Lepidoptera	Hesperidae	*Hesperid* sp	2	2	31	2	1	8	2	1	2
Mantodea	Mantidae	*Mantid* sp	0	0	1	0	0	0	0	0	0
Neuroptera	Chrysopoidae	*Chrysopa* sp	2	3	2	0	1	0	1	1	1
Orthoptera	Acrididae	*Acrida* sp	1	0	0	1	1	0	0	0	0
	Gryllidae	*Gryllus* sp	0	1	0	0	1	0	0	0	0
Thysanoptera	Thripidae	*Frankliniella* sp	249	571	268	270	525	309	492	2645	431
TOTAL			**480**	**1120**	**595**	**508**	**815**	**496**	**738**	**2899**	**654**

Appendix 3. Insect Orders, Families, Genus and individual species abundance in coloured pan traps at 1.5m.

Order	Family	Species	Height (1.5m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
Blattodea	Blattidae	*Blattid* sp.	4	3	2	1	3	2	2	2	1
	Cantharidae	*Canthariđ* sp.	4	1	4	3	0	0	5	0	2
	Nitidulidae	*Carpophilus* sp.	3	2	2	0	0	0	1	0	0
	Carabidae	*Carabid* sp.	0	0	0	1	0	0	0	0	1
Coleoptera	Chrysomelidae	*Aulacophora* sp.	3	0	2	0	1	0	0	0	0
		Chrysochus sp.	57	8	44	21	12	8	24	11	34
		Chrysomelid sp.	15	8	9	12	1	6	44	8	26
	Curculionidae	*Curculionid* sp.	0	0	6	0	1	0	0	1	4
		Hadramphus spinepennis	0	0	1	0	0	0	0	0	0
	Styphalinidae	*Styphalinid* sp	2	0	0	0	0	0	0	1	1
Diptera	Culicidae	*Aedes* (larvae) sp.	96	73	143	100	114	96	136	208	17
	Asilidae	*Asilid* sp.	0	0	0	1	0	0	0	0	0
	Calliphoridae	*Calliphora* sp.	2	1	0	0	0	0	2	3	1
	Ceccidomyidae	*Ceccidomyid* sp.	6	4	5	3	2	5	0	1	23
	Tephritidae	*Ceratitis* sp.	2	0	0	0	0	0	1	3	0
	Cerambycidae	*Cerambycid* sp.	0	0	1	2	0	2	0	0	0
	Diopsidae	*Diasemopsis* sp.	0	0	0	0	0	1	0	0	2
	Drosophilidae	*Drosophila* sp.	33	5	7	5	1	5	8	4	12
	Ephydridae	*Ephydra* sp	3	6	0	4	0	3	7	0	3
	Ceratopogonidae	*Forcipomyia* sp.	28	23	30	26	29	24	15	22	18
	Stratiomyiidae	*Hermetia* sp.	0	1	3	1	0	0	1	0	0
		Plecticus posticus	1	2	7	0	1	0	0	4	2
	Lauxanidae	*Lauxanid* sp. 1	1	0	0	0	0	0	0	0	2
		Lauxanid sp. 2	34	4	1	2	1	11	6	2	3
Diptera	Lauxanidae	*Lauxanid* sp. 3	5	1	0	20	6	3	8	13	2
		Lauxanid sp. 4	0	0	0	6	1	0	1	1	1
		Lauxanid sp. 5	0	2	1	0	1	0	0	0	0
		Lauxanid sp. 6	3	0	0	0	0	0	0	0	0
		Lauxanid sp. 7	0	0	1	0	0	0	0	0	0
	Phoridae	*Megaselia* sp.	1	7	0	0	2	1	0	0	3
	Membracidae	*Membracid* sp.	2	0	0	0	0	0	0	0	0
	Micropezidae	*Micropeza* sp.	1	2	3	0	1	0	0	0	1
	Muscidae	*Musca domestica*	11	2	3	1	0	3	4	0	1
	Mycetophillidae	*Mycetophilid* sp.	1	2	2	2	1	0	0	1	1
	Neriidae	*Nerius* sp.	2	4	0	4	12	9	2	3	5
	Ptycopteridae	*Ptycoptera* sp.	7	0	3	0	0	0	0	0	0
	Sarcophagidae	*Sarcophaga* sp.	1	0	0	0	0	1	1	0	0
	Sciaridae	*Sciarid* sp.	0	5	2	0	0	1	0	0	0

Order	Family	Species	Height (1.5m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
	Tipulidae	*Tipula* sp.	2	0	3	0	2	36	3	0	0
Hemiptera	Pentatomidae	*Bathycoelia thalassina*	0	0	0	0	0	0	0	1	2
	Cicadelidae	*Cicadelid* sp.	7	1	2	1	0	2	0	0	1
	Coreidae	*Pseudotheraptus* sp .	0	0	1	0	0	0	0	0	0
	Aphidae	*Toxoptera aurantii*	17	32	17	1	40	1	3	21	4
	Psyllidae	*Tyora tessmannisp*	22	54	58	3	3	0	6	6	1
Hymenoptera	Apidae	*Apis* sp	0	0	0	0	1	0	0	0	0
	Chalcididae	*Brachymeria* sp	0	2	0	0	0	2	1	0	1
	Braconidae	*Braconid* sp.	1	1	1	0	2	1	0	0	0
		Cotesia sp.	14	4	14	1	0	4	0	1	4
	Evanidae	*Evanid* sp.	0	0	1	0	0	0	1	0	0
	Ichneumonidae	*Ophion* sp.	7	0	3	0	0	2	2	0	2
Hymenoptera	Ichneumonidae	*Xanthopimpla* sp.	3	5	15	1	0	2	0	0	1
	Megachilidae	*Megachile* sp.	0	0	0	0	0	0	0	1	0
	Orusidae	*Orusid* sp.	0	1	0	0	0	0	0	0	0
	Phasmatidae	*Phasmatid* sp.	0	0	0	0	0	1	0	0	0
	Vespidae	*Vespid* sp.	0	0	1	0	0	0	0	0	2
		Polistes sp.	1	1	2	0	0	6	0	0	1
	Pompilidae	*Pompilid* sp.	1	3	6	0	0	10	2	1	6
	Sphecidae	*Sceliphron* sp.	14	2	9	2	1	1	2	4	4
		Sphecid sp.	6	1	1	7	0	5	1	1	2
	Formicidae	*Crematogaster* sp.	14	18	18	9	65	9	13	53	3
		Odontomachus sp.	0	3	0	0	0	0	0	0	0
		Camponotus sp.	3	5	2	0	0	2	0	1	0
		Tetramorium sp.	0	11	18	0	26	12	1	12	14
		Oecophylla longinoda	67	47	6	17	23	5	87	36	2
		Phediole megacephalus	0	0	0	0	4	1	0	6	0
		Polyrachis sp.	0	0	4	0	4	2	0	0	1
		Pheidole sp.	8	73	9	13	77	33	9	104	9
		Tetraponera sp.	2	0	1	0	0	2	0	0	2
		Bothroponera sp	1	0	0	1	0	0	1	1	0
Isoptera	Termitidae	*Macrotermes* sp.	4	0	5	0	0	21	4	1	7
Lepidoptera	Hesperidae	*Hesperid* sp.	4	2	12	6	1	61	0	0	6
Mantodea	Mantidae	*Mantid* sp.	0	0	0	0	0	0	0	0	1
Neuroptera	Chrysopoidae	*Chrysopa* sp.	1	1	0	0	0	0	0	2	1
Orthoptera	Acrididae	*Acrida* sp.	1	1	0	1	0	1	1	0	0
	Gryllidae	*Gryllus* sp.	0	1	0	0	1	1	0	0	0
Thysanoptera	Thripidae	*Frankliniella* sp.	213	300	109	283	357	74	729	449	318
TOTAL			**741**	**736**	**600**	**564**	**800**	**478**	**1134**	**989**	**562**

Appendix 4. Insect Orders, Families, Genus and individual species abundance in coloured pan traps at 0.0 m.

Order	Family	Species	Height (0.0m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
Blattodea	Blattidae	*Blattid* sp.	12	6	0	6	3	5	0	6	1
Coleoptera	Cantharidae	*Cantharid* sp.	3	3	18	0	2	2	0	0	1
	Carabidae	*Carabid* sp.	2	1	2	2	0	4	2	1	3
	Nitidulidae	*Carpophilus* sp.	2	5	3	0	0	1	0	0	0
	Cerambycidae	*Cerambycid* sp.	0	0	0	7	0	0	0	0	0
	Chrysomelidae	*Aulacophora* sp .	1	0	6	0	1	0	0	0	0
		Chrysochus sp.	14	14	18	8	0	10	19	10	11
		Chrysomelid sp.	15	11	6	19	6	3	48	9	9
	Curculionidae	*Curculionid* sp.	1	0	0	0	0	2	3	4	2
	Scarabidae	*Scarabid* sp.	4	19	6	5	11	2	3	7	13
	Styphalinidae	*Styphalinid* sp.	1	7	1	7	0	2	2	2	2
Diptera	Culicidae	*Aedes* (larvae) sp.	183	290	301	119	272	321	77	318	309
	Asilidae	*Asilid* sp.	1	0	0	0	0	0	0	0	1
	Calliphoridae	*Calliphora* sp.	11	9	4	3	1	0	6	14	0
	Ceccidomyidae	*Ceccidomyid* sp.	8	4	7	7	13	11	2	5	4
	Tephritidae	*Ceratitis* sp.	0	1	0	0	0	0	0	5	0
	Chironomidae	*Chironomus* sp.	0	2	0	0	0	0	0	0	0
	Diopsidae	*Diasemopsis* sp.	1	3	0	0	8	0	1	7	3
	Drosophilidae	*Drosophila* sp.	3	12	14	9	3	4	10	4	10
Diptera	Ephydridae	*Ephydra* sp.	8	5	13	0	3	9	3	30	10
	Ceratopogonidae	*Forcipomyia* sp.	46	64	34	47	21	21	28	53	27
	Stratiomyiidae	*Hermetia illucens*	2	0	0	1	0	0	0	0	0
	Lauxanidae	*Lauxanid* sp. 1	0	1	0	0	1	1	0	0	0
		Lauxanid sp. 2	19	642	25	2	0	0	0	59	7
		Lauxanid sp. 3	1	2	0	5	6	2	5	7	3
		Lauxanid sp. 4	1	12	0	20	32	5	10	26	6
		Lauxanid sp. 5	0	3	5	0	0	0	1	1	0
		Lauxanid sp. 6	2	0	0	0	0	1	0	0	0
		Lauxanid (7) sp. 7	1	1	0	0	0	1	2	1	2
	Phoridae	*Megaselia* sp.	6	3	4	3	0	1	3	1	3
	Micropezidae	*Micropeza* sp.	3	8	1	1	4	0	1	6	1
	Muscidae	*Musca domestica*	7	5	7	1	3	0	3	2	2
	Mycetophillidae	*Mycetophilid* sp	3	0	2	3	0	0	6	2	0
	Neriidae	*Nerius* sp,	3	10	2	0	5	7	2	6	6
	Orusidae	*Orusid* sp.	1	0	1	0	0	0	0	0	0
	Tephritidae	*Perilampsis* sp.	1	0	0	0	0	0	0	0	0
	Stratiomyiidae	*Plecticus posticus*	7	4	3	1	0	0	2	0	3
	Ptycopteridae	*Ptycoptera* sp.	0	3	0	0	0	0	0	0	0
	Sarcophagidae	*Sarcophaga* sp.	6	5	10	1	2	1	2	5	3
	Sciaridae	*Sciarid* sp.	4	0	68	0	1	0	0	0	0
	Stratiomyiidae	*Stratiomyiid* sp.	0	0	1	0	0	0	0	0	0

Order	Family	Species	Height (0.0m)								
			Yellow			Blue			White		
			F1	F2	F3	F1	F2	F3	F1	F2	F3
	Tachinidae	*Tachinid* sp.	1	0	0	0	0	0	0	0	0
	Tipulidae	*Tipula* sp.	2	1	2	2	0	1	2	3	2
Hemiptera	Cicadelidae	*Cicadelid* sp.	5	10	10	0	0	0	0	5	0
	Membracidae	*Membracid* sp.	0	0	3	0	0	1	0	0	0
	Coreidae	*Pseudotheraptus devastus*	0	3	0	0	1	0	0	2	1
	Aphidae	*Toxoptera aurantii*	74	82	15	3	7	2	15	12	3
Hemiptera	Psyllidae	*Tyora tessmanni*	15	125	50	7	1	16	10	4	1
Hymenoptera	Chalcididae	*Brachymeria* sp.	0	1	1	1	1	0	0	3	0
	Braconidae	*Braconid* sp.	0	5	2	1	1	0	2	2	2
		Cotesia sp.	41	114	88	3	17	6	12	12	13
	Formicidae	*Crematogaster* sp.	36	50	12	9	18	22	27	60	23
		Odontomachus sp.	3	59	0	2	18	0	1	20	0
		Oecophylla longinoda	34	337	2	11	49	1	38	39	4
		Pheidole megacephalus	1	70	2	2	5	0	9	308	4
		Pheidole sp.	76	538	16	34	138	14	56	1106	36
		Tetramorium sp.	0	102	14	0	4	6	3	19	10
		Tetraponera sp.	3	1	13	2	6	0	1	1	2
		Bothroponera sp.	18	35	3	18	7	3	21	21	17
		Camponotus sp	3	14	0	0	2	0	1	3	0
		Polyrachis sp.	2	3	1	2	1	2	0	4	6
	Evanidae	*Evanid* sp.	1	0	3	0	0	0	0	0	1
	Ichneumonidae	*Ophion* sp.	6	7	48	0	0	2	3	1	3
		Xanthopimpla sp.	11	25	26	0	1	1	3	3	0
	Platygastridae	*Platygastrid* sp.	0	0	1	0	0	0	0	0	0
	Vespidae	*Polistes* sp.	0	0	2	0	1	0	1	0	0
		Vespid sp.	3	1	1	0	0	0	0	0	0
	Pompilidae	*Pompilid* sp.	3	5	24	0	0	6	1	1	1
	Sphecidae	*Sceliphron* sp.	10	31	29	4	2	9	5	1	12
		Sphecid sp.	14	9	8	0	3	1	2	6	4
Isoptera	Termitidae	*Macrotermes* sp.	1	0	11	0	1	8	0	1	2
Lepidoptera	Hesperidae	*Hesperid* sp.	1	10	26	1	1	4	3	1	5
	Noctuidae	*Noctuid* sp.	0	0	0	0	0	0	0	1	0
	Nymphalidae	*Nymphalid* sp.	0	1	0	0	2	0	0	0	0
Mantodea	Mantidae	*Mantid* sp.	0	0	0	1	0	0	0	0	0
Neuroptera	Chrysopoidae	*Chrysopa* sp.	0	2	0	0	0	0	0	0	0
Orthoptera	Acrididae	*Acrida* sp.	1	0	0	0	1	1	0	1	0
	Gryllidae	*Gryllus* sp.	21	26	17	9	5	10	15	14	9
Phasmatodea	Phasmatidae	*Phasmatid* sp.	0	0	1	0	0	0	0	0	0
Thysanoptera	Thripidae	*Frankliniella* sp.	133	119	57	78	121	67	120	182	132
Total			**916**	**2,941**	**1,062**	**473**	**814**	**600**	**592**	**2,428**	**735**