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Insect assemblage and the pollination system in cocoa ecosystems

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ABSTRACT

Objective: An insect survey was carried out in ten farm plots to determine whether there are other tropical pollinators of cocoa which are either unidentified or undescribed, and hence review the pollination system of the crop.

Methodology and results: Ten homogenous farmer managed farm plots were selected. For three consecutive years, a study was carried out to determine the insect species richness and relative abundance in the farm plots during flowering seasons (April to October). It was also to determine which of the insects were pollinators or contributed to the process of pollination of cocoa. Trees used were selected based on availability of flowers. About 2,721 insects belonging to 36 species and 7 orders were recorded. Insect species of the orders viz: Hymenoptera, Diptera, Orthoptera, and Coleoptera were common to all the ten farm plots. These were found on cocoa trees, and on the ground among the cocoa leaf litter. The rest were predominantly aerial or flying insects. The results of focal patch observation indicated that more than half of insect species resident in the cocoa ecosystem did not visit the cocoa flowers. Those which visited did not carry any pollen. Only the ceratopogonid midges (Diptera) showed higher pollinator importance. They were therefore classified as effective pollinators, and hence could be beneficial to the productivity of cocoa. None of the crawling insects ever carried pollen to the stigma. The study showed that the cocoa ecosystem could support diverse insect communities; however, the evolution of the floral structure of cocoa restricts access to all but few pollinators. Cocoa therefore has a specialized pollination system.

Conclusion and application: The study showed that though the cocoa ecosystem could support diverse insect communities the cocoa tree itself has a specialized pollination system. The results therefore suggest that cocoa farmers should be encouraged to incorporate pollinator-friendly practices for sustainable cocoa production.

Key words: Cocoa, pollinators, insect assemblage, *Forcipomyia spp*, pollination system.

INTRODUCTION

The cocoa tree is visited by a myriad of insects, which are viewed as potential pollinators. Some earlier authors (Billes, 1941; Posnette, 1942; Entwistle, 1972; Kaufman, 1973, 1974) had presented some conflicting claims about the pollinator status of other insects other than midges in the ceratopogonid group. Bees, ants, aphids and thrips, found in cocoa flowers have always been considered as potential pollinators or collaborators of cocoa pollination (Entwistle, 1972; Young,

1994), but their distinctive roles had not been clearly established. Kaufman (1975) and Young (1986) had thought that bees were pollinators, and considered euglossine bees to be the original pollinators of cocoa flowers, while midges were facultative alternate pollinators with low pollination efficiency. Kaufman (1975) had observed that three different families of Hymenoptera viz: Apidae, Megachilidae, and Halictidae gather pollen from *T. cacao* in Ghana, and proposed that the halictine bee, *Lasioglossum sp* was the most efficient pollinator at cocoa canopy level, 3-4m above the ground, pollinating 42% of 107 flowers.
Flower visiting insects provide important ecosystem services such as pollination (Kearns, et al., 1998; Williams, 1995). It is observed that not all flower visitors of any particular plant are its pollinators. Some insects visit with the sole aim of collecting pollen or other floral rewards thus denying the true pollinators these same benefits (Inouye, 1980). Waser *et al* (1996) have observed that the ecological prediction of plant reproductive successes and population dynamics of pollinators involves consideration of flower visitors outside the plant's pollination syndrome, as dramatic specialization could occur in some pollination systems. "Although pollinators are vital to plant reproduction, non-pollinating (or poorly pollinating) insects may also be important in the ecosystem function" (Kevan, 1999). Globally, an estimated 1500 species of insects are known to be associated with cocoa (Entwistle, 1972), but considering the overwhelming available evidence that *Forcipomyia spp* is the main pollinators of cocoa throughout cocoa growing regions of the world, claims about other potential pollinators need to be corroborated. A study therefore was carried out to examine the species richness and relative abundance of insects associated with cocoa trees in ten farmer managed plots, and their ecological significance in terms of contribution to pollination of the cocoa flowers. It is essential to acquire a sound knowledge of the pollination system of cocoa (Brew and Boorman, 1993) in order to achieve maximum pollination which is necessary for optimum yield (Mabett, 1989), and to make a substantial contribution to agriculture and conservation, thus yielding multiple benefits (Rodger *et al* 2004). The study therefore sought to answer the following research questions:
a) What are the insect species associated with the cocoa trees in the study area?
b) Which of them provide pollination as an ecological service to the cocoa trees?

MATERIALS AND METHODS

The biophysical characteristics of the study area: the study location called Kubease in the Ejisu-Juaben District of the Ashanti Region of Ghana (Fig. 1), lies between latitudes 6^0 44' and $6^0$40' North and longitudes $1^0$15' and $1^0$22' West (source: Gold Coast Survey Field Sheet No.129, Scale 1:62,500), and it is about 180 to 240 m above sea level. The natural forest belongs to the Triplochiton-Celtis Association of the Tropical Moist Semi-Deciduous Formation (Hall and Swaine, 1981). The area has an annual average temperature of 26.5 (± 2.09) ˚C, relative humidity of 86.1 (± 12. 6) %, and a mean monthly rainfall ranging between 19.1-235.1mm. The area experiences a bimodal rainfall distribution, with peaks in June and September. The first and second growing seasons typically last from mid March to mid July and from mid August to end of November, respectively, separated by a short dry spell of about four weeks in July. The major dry season starts in mid-November and lasts until end of March. The climate is marked by high incidence of solar radiation and relatively little variation in day length.

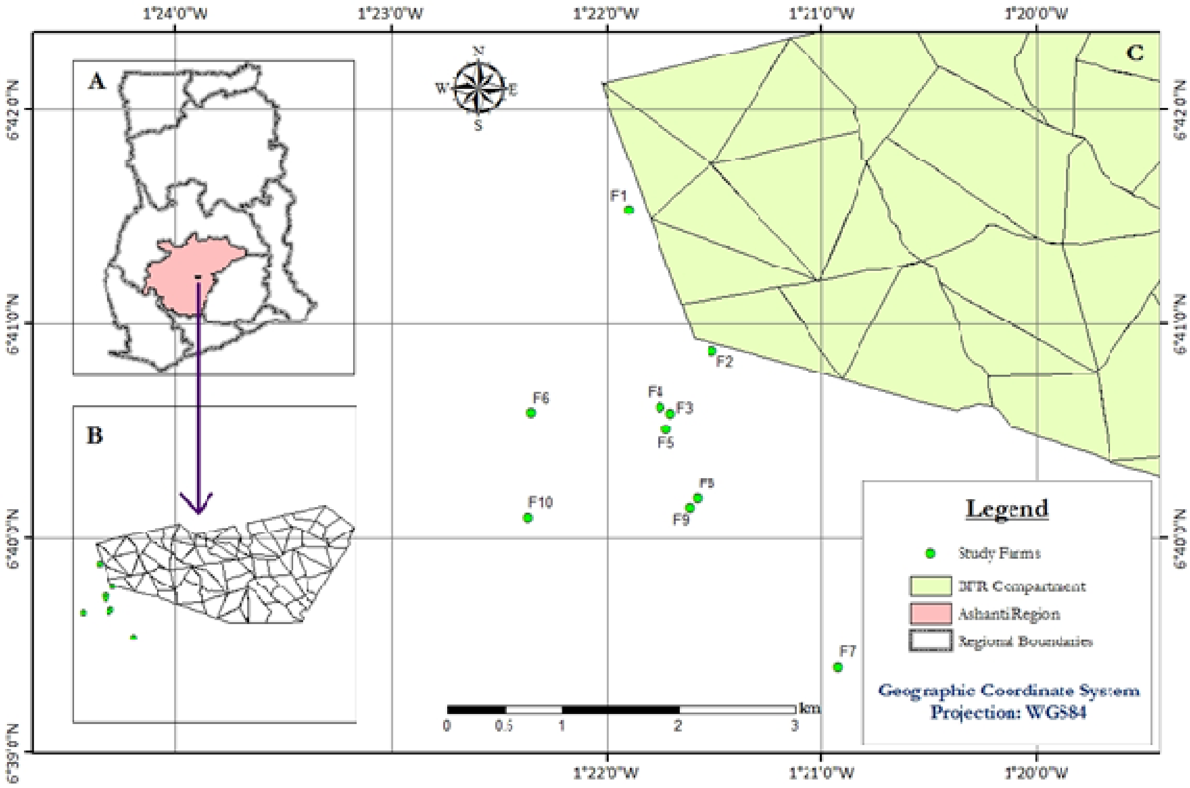

Figure 1: Location of farm plots in relation to the Bobiri Forest at Kubease in the Ejisu-Juabeng District.

Field Procedures: Insect surveys were carried out in the ten homogenous farm plots during the flowering seasons (April to October) of three consecutive years (2006, 2007 and 2008) to determine the insect species richness, their relative abundance, and determine whether they are pollinators or contribute to the process of pollination of cocoa. Trees used were selected based on availability of flowers. For each day, two of the six techniques below were employed in sampling the insects between 06.00 and 18.00 h in each study farm:

Insects sampling methodologies: A hand-height flower/ insect collection protocol of the Cocoa Research Institute of Ghana was followed (Brew, 1984). For every 15 min per tree (n=30) 100 cocoa flowers were randomly handpicked in a top-down fashion 24 h after opening. The insects were caught by clapping flowers swiftly between a 2.5 cm tube and its stopper.

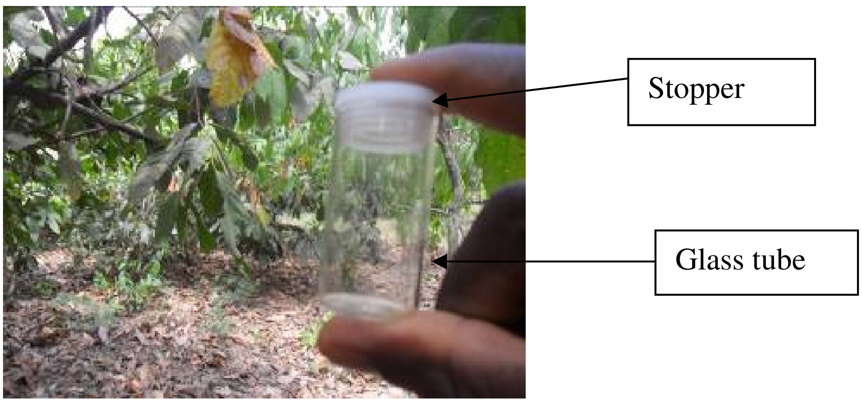

Plate 1: Tube with stopper used in the study

Arboreal insects close to the cocoa trees were sampled using sweep-net (*d* =30 cm). Insects were captured by three sweeps between the ten cocoa trees within each farm plot following the method of Klein *et al.* (2002). The catch was then aspirated into storage vials. Insect samples were rendered immobile by placing them in a cold chest for some few minutes before sorting out. Following the procedure of Potts (2005) pan traps consisting of three different colours of plastic bowls (blue, white and yellow) of 20cm in diameter, containing water (about 80%) mixed with several drops of detergent solution were placed in the open ground with no tree canopy directly overhead, and at distances of 5 m apart on sunny days.

Plate 2: Pan Traps with detergent used in the insect sampling

The traps were left on the farms for 2 days per treatment, and care was taken to avoid insect rot. This was the only sampling method that was used in both dry and wet seasons of the year. Adult flying insects fluttering around bark of cocoa trunks, including cocoa pods, and those resting festooned between buttresses of large shade trees were caught by sucking the air . around them, and placed in test-tubes containing ethanol using the manual aspirator. Samples were treated like those by sweep net. The Pirbright light trap which operated with 12 V bulb, built-in fan and 13 plates battery (Brew, 1984) was employed in further sampling of the insects overnight (7pm -6am)

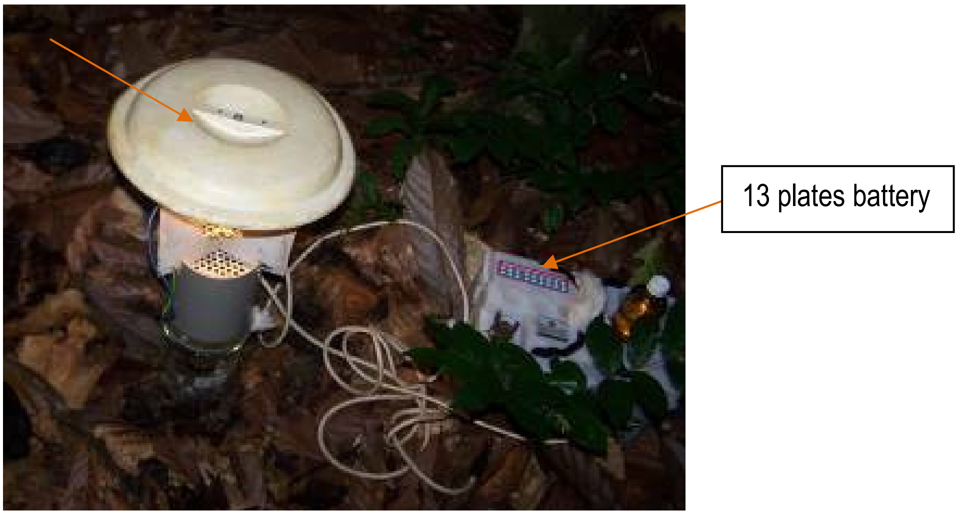

Plate 3: The Purbright light trap (arrowed) used for insect sampling.

The various sampling methods were employed to ensure that as much as possible all the types of insects were sampled. To obtain unbiased data, each day was dedicated to a farm, but the order was varied. To determine the pollination system of the Amazonia cocoa a focal patch observation (Frankie et al., 2002; Potts, 2005) was undertaken to observe the regular floral insect visitors and assess their pollinator activity. Insect visitors to the 1-m section of selected cocoa trees (n=30) were carefully recorded. This was done for 10 min at four periods during the day (6am-8am; 10am-12am; 13pm-15pm; 16pm-18pm). Visiting insects were later captured using the putter and the flowers they visited gently removed and further observed under laboratory conditions. A "visit" was defined as an insect landing on a flower and collecting floral reward (Ricketts, 2004). In all a total of 200 observations were done in five months (May-September, 2008). A further investigation was undertaken in the field to determine whether crawling insects were involved in the pollination of the cocoa flowers. Ten trees which were infested with psyllids and ants were selected. Fifty freshly opened flowers per tree were tagged, and grease-banded at their base. An equal number of flowers were tagged but not grease-banded to serve as control. The grease was to prevent any crawling insect from reaching the flowers. For three months (May-July, 2008) flowers were observed for setting every ten days following Brew (1984). The activities of insects that visited the flowers were carefully observed. Those that carried pollen from the stamens to the stigma were noted.

Identification of Insect: All the insects captured were identified to the morphospecies level and were stored temporarily in vials containing 70% ethanol. Insects that eluded identification were coded for later identification. Further identification was done using reference collection at the insectary of Cocoa Research Institute of Ghana. When identification was not possible because of missing parts or if there was uncertainty, insects were classified as "not identifiable" and left out of the analysis. Due to taxonomic difficulties, the identification of the midges was limited to the genus. Total number of individual insect and species for each of the 10 farm plots were then recorded.

Statistical Analysis: The catch from all the various replicate sites for the entire sampling period were pooled together for analysis of the abundance and diversity in the ten cocoa farms. Species frequency data was tested for Poisson distribution as described by Clarke and Cooke (1992), and square root

($\sqrt{X + 0.1}$) transformed.

ANOVA was carried out and the means separated by Tukey's (*w*) test for pairwise comparison at α= 0.05 level.

Pollen deposition per flower was used as proxy for pollination services (Kremen et al., 2004). Flower set was used to estimate pollination under the field conditions. Pollinator importance was calculated as the product of pollination efficiency and visitation frequency of a given pollinator (Bloch et al., 2006). The pollination efficiency of different insect visitors was measured by the number of pollen grains deposited by a single pollinator species on the stigma lobes under a light microscope under 400x magnification, while the visitation frequencies was estimated by counting visits/ abundance of foraging insects. Two variables were also estimated: i) species richness i.e. number of morphospecies per census per farm plot, and ii) total visit frequency rate (by all potential pollinators) expressed as number of visit x $10mins^{-1}$ x $flower^{-1}$. Only insect visitors contacting the stigma (i.e. those actually or potentially performing pollination) were included in this analysis. All analysis was performed with the Statistical Analysis System (SAS version 9.0, SAS Institute, 2005) and SPSS version 17 and were considered at an overall significance level of α=0.05.

RESULTS

Insect Assemblages in the Cocoa farms: A total of 2,721 insects belonging to 36 species and 7 orders were recorded through the systematic sampling from the ten study farm plots over the two flowering seasons (Table 1). About 40% of the insect species were crawling insects belonging to the orders Coleoptera and Hymenoptera. They were found on cocoa trees (arboreal), and on the ground among the cocoa leaf litter. The rest were predominantly aerial or flying insects. The Dipterans constituted 46.52% (N=1, 266) of insects resident in the cocoa farms, following the Hymenopterans 48.32% (N=1,315), with the least abundant insects being the Hemipterans 0.78% (N=21) (Table 2). The distribution showed a log normal distribution, indicating large, mature and varied insect communities (Magurran, 2004).

Table 1: Abundance, Diversity and Distribution of Insects sampled in 2006/2007/2008 Flowering Period in the ten Farms. Number of individual insects.

Insect Taxa	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	Total
Order: Hymenoptera											
Family: Formicidae											
Polyrhachis viscose (Mayr)	25	20	15	10	5	12	14	10	5	12	128
Polyrhachis decemdentata (Mayr)	8	5	5	2	2	3	2	1	2	2	32
Polyrhachis weissi (Bolton)	11	3	1	2	2	4	10	5	4	1	43
Polyrhachis militaris (Bolton)	10	12	0	5	5	7	5	4	2	4	54
Polyrhachis laboriosa (Forel)	50	55	20	16	14	45	20	11	11	10	252
Polyrhachis lestoni (Bolton)	4	21	1	2	3	4	10	1	2	7	55
Camponotus acvepimensis (Mayr)	28	23	6	14	2	1	1	4	1	2	82
Bothroponera pachyderma (Santschi)	17	15	4	0	0	10	6	31	22	0	105
Bothroponera silvestrii (Emery)	20	19	11	5	5	11	10	2	4	1	88
*Oecophylla longinoda (*Latreille)	15	13	1	0	1	0	0	0	2	0	32
Cremastogaster africana (Emery)	14	16	0	12	15	0	4	4	3	0	68
Cremastogaster depressa(Latr).	52	45	15	11	3	0	4	6	4	5	145
Cremastogaster clariventris(Mayr.)	44	40	11	5	4	1	0	4	1	0	110
Pheidole megacephala (Fabricius)	4	6	0	1	2	1	7	0	9	8	38
Family: Apidae											
Apis mellifera adansonii	2	0	0	1	5	2	1	0	0	0	11
Family: Meliponinae											
Hypotrigona araujoi (Michener)	5	2	1	1	3	2	1	1	2	0	18
Family: Vespidae											
Polistes marginalis	1	1	1	0	0	0	1	0	0	0	3
Order: Hemiptera											
Family: Pentatomidae											
Chlorochroa sayi (Stål)	2	0	1	0	5	0	0	2	1	1	12
Family: Coreidae											
Anoplocnemis curvipes (Nymph)(Fabricius)	1	1	0	0	0	1	1	0	0	0	4
Dysdercus spp	2	2	1	0	2	0	0	0	0	0	5
Order: Lepidoptera											
Bebearia congolensis (male)	5	4	0	1	2	1	0	0	0	0	13
Euphaedra janetta (male)	6	3	1	0	1	1	0	0	0	0	12
Euphaedra medon (male)	3	5	0	0	2	0	0	0	0	0	10
Euphaedra medon medon(female)	2	1	0	0	0	0	1	0	0	0	4
Bebearia absesa abesa(male)	4	2	0	0	1	1	0	0	0	0	8
Gideona klots (moth)	1	1	1	0	0	0	1	1	1	0	6
Pterocarpus spp	2	1	0	0	1	0	0	0	0	0	4
Order: Orthoptera											
Family: Acridae											
Heterachis guineensis	8	4	1	1	1	2	1	2	3	2	25
Order: Diptera											
Drosophila spp	60	11	15	20	11	16	5	25	17	10	190
Cecidomyiid spp	51	37	36	54	33	42	51	56	55	52	467
Forcipomyia spp	70	45	81	50	55	45	91	55	21	65	578
Musci domestica	2	5	1	1	6	7	2	5	1	1	31

Order: Coleoptera										
Carabid sp	3	4	2	2	1	2	3	2	1	1	21
Apogonia sp	2	1	3	1	1	2	2	1	1	2	16
Order: Heteroptera											
Distantiella theobroma Distant	3	8	0	1	0	0	1	0	0	1	14
Bathycoelia thalassina Scumacher	9	4	1	6	0	8	3	2	1	3	37
Grand Total of species											2721

Table 2: Summary of Diversity and Abundance of insects in the 10 farm plots.

Order	No. of insect species	No. of individuals	% of the total no. of insects
Hymenoptera	10	1264	46.45
Hemiptera	3	21	0.78
Lepidoptera	7	57	2.09
Orthoptera	1	25	0.93
Diptera	4+	1266	46.52
Coleoptera	2	37	1.36
Heteroptera	2	51	1.87
Total		2721	100.00

(+) Due to taxonomic challenges, all midges were grouped under their generic names.

Focal patch observation: Insects Visitation to Cocoa flowers: More than half (*ca* 52.81%) of the insects belonging to 26 species from all the orders (except the order Heteroptera) did not visit the cocoa trees at the time of observation; 10.4% (N=2721) arboreal insects were found on the cocoa trees, but not on the flowers (Table 3). The regular visitors observed largely belonged to Hymenoptera and Diptera. The hymenopteran visitors included the stingless bee *Hypotrigona aurajoi* (Michener), *Camponotus acvapimensis* (Mayr), *Cremastogaster depressa* (Emery), *Pheidole megacephala* (Fabricius) (Figure 2), while the dipterans were gall midges, *Cecidomyiids spp.,* and the biting midges, *Forcipomyia spp.* It was noted that the midges accounted for about 97% (N=2721) of all visitors to the cocoa flowers. The number of midges found to visit the flowers between 0600 and 0900 h was high compared to that between 1500 -1700 h. The other insect visitors to the cocoa flowers commenced their visitation later than the midges (i.e. after 0700 h).

Table 3: Classification of sampled Insect species based on their visitation to the cocoa trees at Kubease

Visitation Status	Number of Species	Order(s)	% Total no. insect (N=2721)
Non-visiting insects	26	6 orders	52.81
Tree visiting insects	2	Hymenoptera	10.4
Flower visiting insects	7	Diptera, Hymenoptera	46.04
Visit of pollinator importance	2	Diptera	38.4

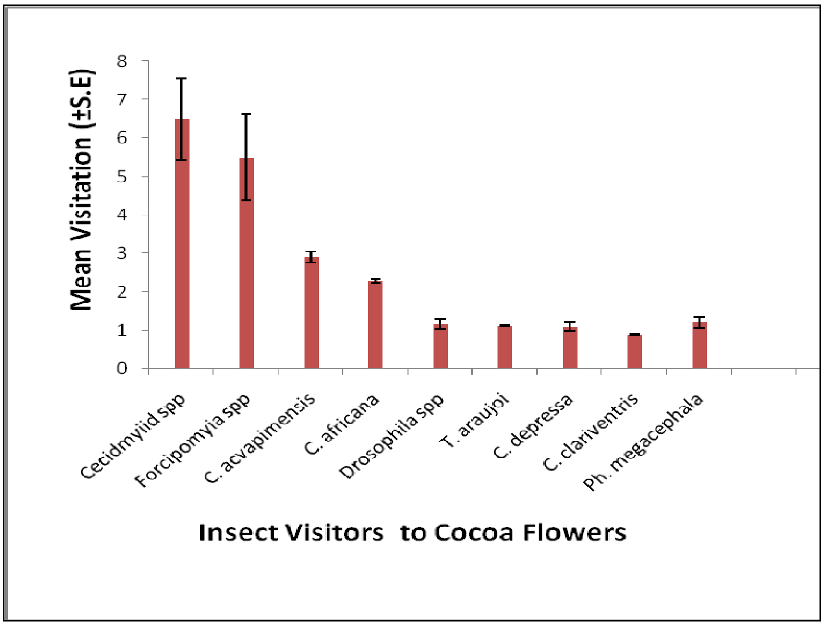

Figure 2: Frequency of visit by all insects.

Generally, there were significant differences in the visitation frequencies of the insect visitors. The ceratopogonids visited more than other visitors including: all species of ants, *Drosophila spp* and *H. araujoi* ($F_{1,30}$= 28.79, P <0.05) (Table 4). However, among the ceratopogonids the visitation frequency of the gall midge *Cecidomyiids spp* was higher (6.5 ± 1.1) than that of the biting midge, *Forcipomyia spp* (5.2 ± 0.09) per flower per 10 min observation (Figure 2). The visitation frequency of the other visitors were not significant (P = 0.05) (Table 4).

Source of variation	Df	SS	MS	F
Ceratopogonids				
Visitation frequency	5	102.5	20.5	3.55
Visitor x flower interaction	7	1,210.58	172.94	28.79**
Residual	35	202.17	5.78	
Total	47	1,515.25		
Other visitors				
Visitation frequency	3	3.14	1.05	0.801
Visitor x Flower interaction.	5	31.65	6.33	7.93 ns
Residual	15	19.72	1.31	
Total	23	54.51		

**p < 0.05; ns=non-significant

Visitation frequency, however, varied significantly between species (P < 0.05), between months (P <0.05) and times of the day (P < 0.001). While the visitation of the midges increased during the rainy season, and greatly reduced in the dry season, visits by *Drosophila spp* were constant throughout the study period. The numbers of the ants *C. acvapimensis, C. africana, C. depressa, C. clariventris, P. megacephala* increased during the minor rainy seasons in September each year. Table 5 indicated that pollination still occurred in the field even though none of the crawling insects could enter the flowers, and that there was no significant difference (P>0.05) in percentage flower set between the banded and unbanded flowers.

Table 5: Average fruit set of grease banded flowers and unbanded (control) flowers.

Treatment	Number of Flowers	Fruit set (%)[a]
Grease-banded flowers	1,800	8.7
Unbanded flowers (control)	1,800	7.7
T		1.4
P		0.09

Differences were tested with *t*-test with one-tailed probability.
[a] Arcsine square-root transformed prior to analysis.

Pollinator efficiency and importance of Insects. : Laboratory examination of flowers revealed that the presence of the microdipterans i.e. *Forcipomyia spp,* and the Cecidomyiids*,* aided deposition of mass of pollen on the stigmas of the flowers. Even though fewer number of *Forcipomyia spp.* visited the flowers they appeared to be more important pollinators than the gall midges as they deposited greater number of pollen grains per mm^3 (60.1 ± 13, n = 500) per visit (Figure 3). The pollinator importance of the *Hypotrigona* bee, however, could not be assessed as their visit was sporadic. The rest of the visitors did not deposit any pollen on the stigmas.

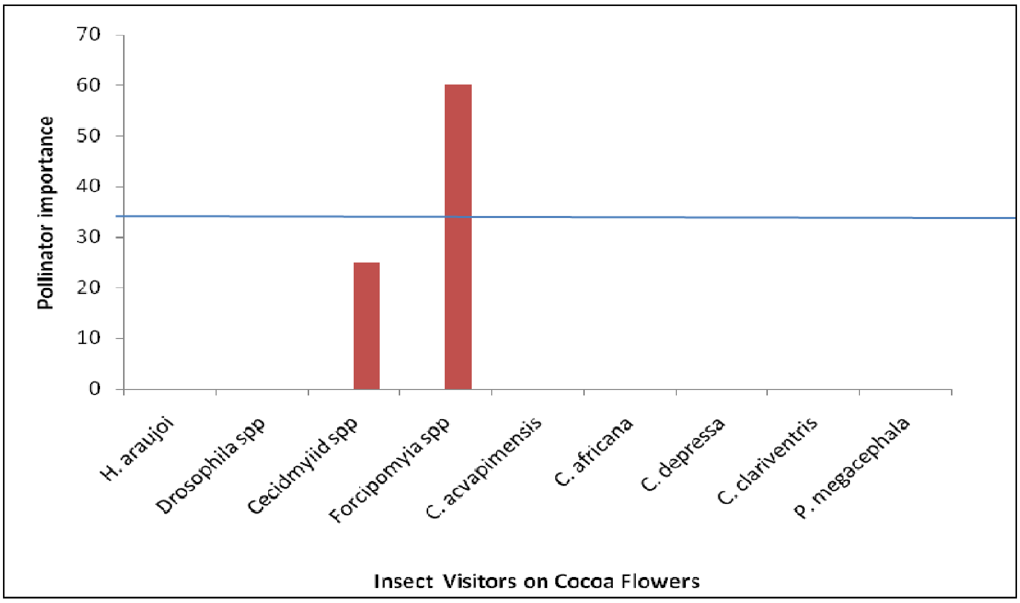

Figure 3: Pollen deposition on pistils as index of pollination importance.

DISCUSSION

Insect Assemblages in the Cocoa farms: The findings indicated that the cocoa ecosystem is a mosaic of insect species (Table 1), and is consistent with the assertion by Hunter (2002) "that insects dwell within complex ecosystems and interact with other taxonomic groups and the abiotic environment". The relative proportions of insect species (Table 2) might reflect their responses to the environmental factors prevalent in the study farms (Kareiva, 1994; Dauber *et al.,* 2003). Earlier studies had indicated that cocoa farms with their diverse shade support great local diversity and act as effective refugia for some tropical forest organisms (Parrish *et al.,* 1998; Zapfack *et al.,* 2002; Bobo *et al.,* 2006). The results also demonstrated that three sets of taxa i.e. Diptera, Hymenoptera, and Lepidoptera were more abundant and more specious, compared to the other three taxa (Coleoptera, Hemiptera, and Orthoptera). Therefore, to discuss the ecological significance of the insect communities in the cocoa ecosystems, emphasis was placed on the populous and more specious groups.

The species belonging to Diptera were present in significant proportions (46.52 %) and thus dominated the cocoa ecosystem numerically. Previous work on cocoa insects (Entwistle, 1972; Kaufman, 1975; Brew, 1984; Young, 1994) was unanimous that the ceratopogonids are the accredited pollinators of cocoa; hence, their presence could be said to be ecologically significant (Mabett, 1989). The hymenoptera were dominated by ant species, the second most abundant insect species (Table 2). Studies by earlier workers (Leston, 1973; Room, 1971; Room, 1975; Majer *et al.,* 1994) pointed to the fact that, in general, ants tend to be the most abundant of the arthropod fauna of many tropical ecosystems, including cocoa plantations. This may account for their being considered as excellent bio-indicators because they are ubiquitously diverse and abundant; and are highly sensitive to environmental variables and respond rapidly to environmental change (Andersen, 1990). The lepidopterans (butterflies) ranked third (2.09%) in relative proportion, and were greatly dispersed in the farms. Butterflies are known to be affected by predation and parasitism (Kruess and Tscharntke, 1994; Zabel and Tscharntke, 1998), habitat heterogeneity in terms of plant/floristic diversity (Steffan-Ingolf and Tscharntke, 2000; Schulze *et al.*, 2001), microhabitat, and generally by habitat fragmentation (Schulze *et al.,* 2001). The cocoa farms studied were largely a monocultural system and therefore could not be a satisfactory surrogate for the reserve forest in terms of plant or floristic diversity. In addition, the morphology of the cocoa flower and the virtual absence of nectar could not be attractive to the butterflies because lepidopterans have shown a positive effect of flower size on visitation, a reflection of their dependency on nectar (Thompson, 2001). A combination of factors therefore might be responsible for the presence of the butterflies in the cocoa ecosystem studied. The self-shade due to the canopy cover, coupled with the relatively low wind speed could be conducive to the butterflies (Estrada et al., 1997; Hamer et al., 1997); and flowers of various plants species available in the surrounding farms and vegetation were visited by the butterflies (Mennechez *et al.,* 2003; Schticking and Baguette, 2003). The low numbers of the coleopterans, hemipterans and orthopterans in the cocoa ecosystem might be due to some agricultural practices. Studies by Wilson *et al.* (1999) showed that beetles are affected by monocultural practices (as in the cocoa farm plots studied) instead of mixed farming. Orthoptera are known to lay eggs at or near the ground surface. This makes them vulnerable to soil disturbance (Marshall and Heas, 1988; Wilson *et al.*, 1999). Residing in the cocoa farms which is under regular farming activities could affect the fecundity and hence the low numbers. Hemipterans though thrive under intensive farming regimes are known to visit periodically especially during the fruiting period.

Insect Visitors to the Cocoa trees and their Pollinator importance : The results also indicated that despite the wide range of insect species in the cocoa plantations only a small fraction may visit the flowers (Figure 2; Table 4), and a still lower numbers made up of ceratopogonid midges were effective pollinators and hence could be beneficial to the productivity of cocoa (Figure 3). The other insects appeared to enrich the ecosystem by their presence, but might not have direct effect on the cocoa production. It therefore suggests that the abundance of insect species in the cocoa farm was not indicative of their pollinator status. These findings are consistent with findings of earlier studies by Wilson and Thomson (1999), and Johnson and Steiner (2000). Most insect visits did not lead to successful pollination (Olsen, 1997) as was observed in the case of *Cecidomyiids spp.* and *H. aurojoi.* These observations run counter to suggestion by Buide (2006) that visitation rate of insects are related to seed production. The field observations showed that none of the crawling insects found on the cocoa trees provided any pollinating service (Table 5) contrary to earlier report (Kaufmann, 1973), as there was no significant difference (P>0.05) in the number of pollinated flowers. This implies that pollination was not dependent on this class of insects, and therefore they might not be relevant to the reproduction of cocoa (Bloch *et al.,* 2006). The study therefore establishes the fact that crawling insects were not involved in the pollination of the cocoa flowers. The data showed that the *Forcipomyia* spp. midges demonstrated great pollinator importance by their visitation rates and massive (60.1 ± 13) deposition of pollen grains per mm^3 on the stigmas (Figures 2 and 3). Brew (1984) had noted that cocoa flower needed a minimum of 35 pollen grains deposited on the stigma for effective pollination to occur. The study therefore corroborates assertions by earlier authors (Brew, 1984; Bos et al., 2007; Klein *et al.,* 2007; Frimpong *et al.,* 2011) that they are the true and effective pollinators.

Ecological significance of the Insect communities in the cocoa farms : The Amazonia cocoa that was studied was self-incompatible and its reproductive system entirely dependent on insects. Therefore, the non-interaction between some resident insects and the cocoa plant might be as a result of evolution of floral structure of the cocoa plant which requires few specialized insects for reproductive success (Valle *et al.,* 1990; Brew and Boorman, 1993; Machado and Lopes, 2004). Insects that did not interact with the cocoa flowers therefore might not have had the requisite morphological structures to successfully maintain the mutual relationship (Frankie et al., 1983; Brew, 1984). The Amazonia cocoa therefore has what could be considered as having specialized pollination system, in which pollinators belong to just one pollinator class, and are often just a few species of a single insect family, or even genus as suggested by Goldblatt and Manning (2005). Olsen (1997) observed that an insect's foraging strategy, whether specialist or generalist, reflects selection to maximize exploitation of floral rewards. The observed pollinating behavior of the ceratopogonid midges underscores a specialized association (Bystrak and Wirth, 1978; Brew, 1984). However, the degree to which midges are specialized pollinators of cocoa is undetermined (Young, 1986). The significance of this study lies in the fact that the specialization in plant-pollinator relationships as in the case of the Upper Amazon cocoa has implications for conservation biology, since pollinator decline has effect on plant fitness it is important to identify the essential factors of the interaction between plants and their pollinators (Bond, 1995; Allen-Wardell *et al.*, 1998; Kearns *et al.*, 1998; Karrenberg and Jensen, 2000). As cocoa pollination is species-specific, there is the need to determine the suitable environment for the sustenance of its optimum population on the cocoa farms (Kaufman, 1975). This study therefore is an attempt to contribute to the understanding of the role of cocoa ecosystems in the protection of tropical diversity, and this, is a promising avenue for research and management of cocoa ecosystem.

CONCLUSION

The study showed that the cocoa ecosystem could support diverse insect communities; however, the evolution of the floral structure restricts access to all but few pollinators. Hence, cocoa could be said to have a specialized pollination system. From the study it be concluded that contrary to speculations and assertions of earlier authors there are no other cocoa pollinators, which remain unknown or undescribed, and that the abundance of insect species was not necessarily indicative of their pollinator status. The results therefore suggest that cocoa farmers should be encouraged to incorporate pollinator-friendly practices for sustainable cocoa production, as this could help achieve maximum pollination, a necessary condition for optimum yield.

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