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Spatial distribution of insect assemblage in cocoa farms in relation to natural forest

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ABSTRACT

Objective: An insect survey was carried out on the hypothesis that cocoa farm ecosystems closer to intact forest will have higher insect assemblage than farms distant away.

Methodology and results: About 2,721 individual insects belonging to 36 species and 7 orders were recorded. Insect species of four of the orders viz: hymenoptera, diptera, orthoptera, and coleoptera were common to all the ten farm plots. The results showed strong negative effect of distance of the farm plots to the Bobiri forest on spatial distribution of insect assemblage both in species richness and abundance (F = 221.92, $p < 0.001$). The number of insect taxa decreased linearly with distance to the forest ($y = 0{\cdot}524–0{\cdot}013x$), however, the effect of distance to the forest on the species richness was relatively consistent among years. Insect species richness and abundance depended significantly on the proximity of farms to the Bobiri forest ($p < 0.012$). More species of insects were sampled in farm plots which were closer to the forest. The effect of distance to the forest on insect distribution was also highly significant ($p < 0.001$). Closeness to the forest significantly predicted insect composition and structure ($p < 0.05$). Among all the insect species the ceratopogonids or midges (Order: Diptera) and the ants (Order: Hymenoptera) were found in all the ten farms.

Conclusions and application of findings: The study showed that agro-ecosystems that maintain similar microclimate to that of the natural forest can provide abundance and diversity of food, nesting-sites, and hiding places for resident insects. The study shows that different insect taxa resident in the cocoa ecosystem contribute both directly and indirectly to the productivity of cocoa and as such proper attention should be paid to cocoa agro-ecosystems.

Key words: Cocoa, spatial distribution, insect species, ceratopogonids (midges), natural forest

INTRODUCTION

Insects, together with other invertebrates, make up more than 75% of global species diversity (Hammond, 1992; Kim, 1993; Stork, 1997). They are a diverse group that shows enormous variations in their seasonality, size, mobility, trophic level, life history strategy, and requirements for habitats (Southwood *et al*., 1979). The diversity of both species and life forms therefore make insect communities an important part of terrestrial ecosystems (Steffan-Dewenter and Tscharntke, 2002). Over 1500 species of insects are known to be associated with the cocoa alone throughout its geographical range (Entwistle, 1972).

Despite increasing interest in the potential of traditional cocoa ecosystems for supporting biodiversity, there has been much less research on biodiversity in cocoa than in coffee. Only a few papers have reported patterns of biodiversity in general within cocoa agroforestry systems (Faria *et al*., 2006; Harvey *et al*. 2006). In the absence of more data on cocoa, information gained through biological studies in coffee are used to develop hypotheses about the potential role of traditional cocoa plantations in biodiversity conservation (Greenberg, R., unpublished). Few studies on insects in the cocoa ecosystems, however, focused on a limited set of insect species such as ants, and rarely examined the insect communities on the same plots (Room, 1971; Brew, 1984). Other complementary studies also focused mainly on their distribution in the forest habitat as index of their importance (e.g. Ings and Hartley, 1999; Elek *et al*., 2001; Bus de Warnaffe and Duffrene, 2004). Steffan-Dewenter and Tscharntke (2002) have indicated that arthropods in farms may reflect the total species composition in the forest. Therefore to a large extent the closeness or otherwise, of a farm to the forest, could determine the species composition. Such insect studies however, are uncommon.

An insect survey was carried out with the aim to understanding the ecological significance of the farm locations in relation to the forest. Specifically, it was to determine whether the composition of insect assemblages in the cocoa ecosystem is affected by their distance of farm to natural forest. The objectives of this study were to determine what insect species were in the cocoa farms, the composition and structure of change of insect assemblages as distance to the forest increases.

MATERIALS AND METHODS

The Biophysical Characteristics of the Study Area: Kubease in Ejisu-Juabeng district, Ashanti Region of Ghana, lies between latitudes 6^0 44' and $6^0$40' North and longitudes $1^0$15' and $1^0$22' West and about 220m above sea level. The natural forest belongs to the Triplochiton-Celtis of the Tropical Moist Semi-Deciduous Formation (Hall and Swaine, 1981). The area has an annual average temperature of 26.5 (± 2.09) ^{O}C, relative humidity of 86.1(± 12. 6) %, and a mean monthly rainfall ranging between 19.1-235.1mm, with the peak of rainfall being in June. The area experiences a bimodal rainfall pattern: the major season (April to July) and the minor season (September to November). There are clear seasonal fluctuations of wet and dry seasons, but these may be short, dry periods when rain does not fall. The climate is marked by high incidence of solar radiation and relatively little variation in day length

Field Procedures: Ten homogenous (monoculture) cocoa farms were selected based largely on accessibility and willingness on the part of the farmers. The farms were between 20-25 years and were still productive. On the average the cocoa varieties in this area belonged to the Upper Amazon (67. 6%) and Hybrid (32.4%). Varieties grown were Upper Amazon and hybrids. Farms were ten to twenty five years old with varying plantain/banana intercrop distribution.

Insect surveys were carried out in the ten farm plots during the flowering seasons of three consecutive years (2006, 2007 and 2008) to determine the insect species richness and assess their numbers in relation to distance to the intact forest. To determine the effect of distance on the insect assemblages four 'distance treatments' to the forest edge from each of the farm plots were considered: 96-171 m (farm plots 1 and 2), 280-290 m (farm plots 3, 4 and 5), 670-1,340m (farm plots 6, 7, and 8) and 1,710-1,730m (for farm plots 9 and 10). Inter-farm plot distances varied widely ranging from 20 meters between farm plots 3 and 4 to 1,410m between farm plots 1 and 2. The study was therefore based on the assumption that the various insect groups stayed in their respective farm plots, and that there were no corridor-effects. For every two weeks the following five techniques were employed in sampling the insects between 06.00 and 18.00 hrs in each study farm plots:

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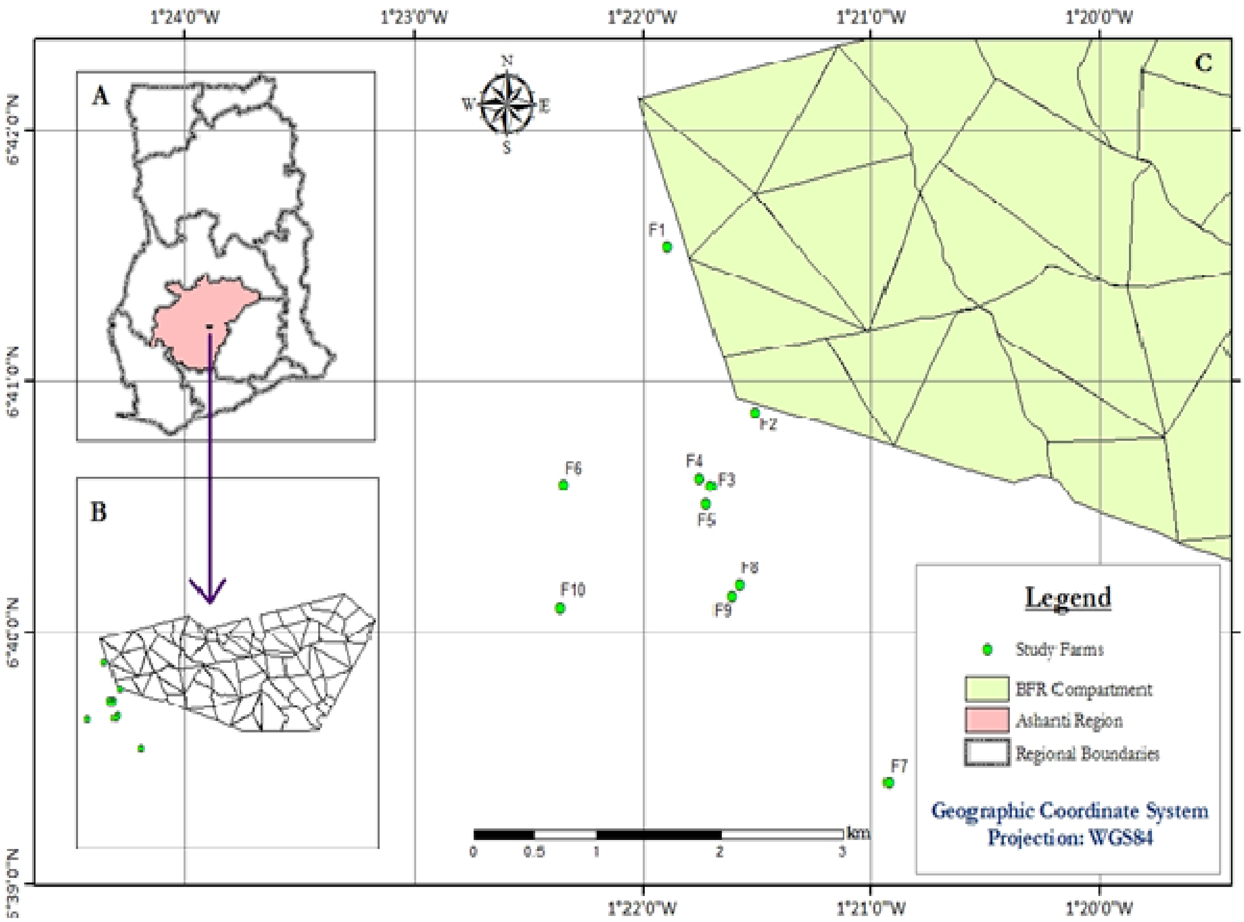

Figure1: Distribution of farm plots in relation to the Bobiri Forest at Kubease in the Ejisu-Juabeng District.

Insects sampling methodologies: A hand-height flower insect collection protocol of the Cocoa Research Institute of Ghana was followed (Brew, 1984). For every 15 minutes per tree 100 cocoa flowers were randomly handpicked in a top-down fashion 24 hours after opening. The insects were caught by trapping the flowers swiftly between a 2.5 cm tube and its stopper. Arboreal insects were sampled using sweep-net (*d*=30 cm). For each sample insects were captured by three sweeps of the net made in a figure of eight between the ten cocoa trees within each farm plot following the method of Klein *et al*. (2002). Each farm sampling was done three times every 2 weeks. The catch was then aspirated into storage vials. Adult flying insects fluttering around bark of cocoa trunks and between bark of trees on the farm were captured by an aspirator or putter and placed in test-tubes with ethanol. Following the procedure of Potts *et al.,* (2005) pan traps consisting of three different colors of plastic bowls (blue, white and yellow) of 20cm in diameter, containing 80% full of water mixed with several drops of detergent solution were placed in the open ground with no tree canopy directly overhead, and at distances of 5 meters apart on sunny days. The traps were left on the farms for 2 days per treatment, and care was taken to avoid insect rot.

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. Thus, all the farms were treated within ten days during the flowering seasons. The micro-environmental factors i.e. temperature, and humidity, were measured using Data logger Hobo Pro temp/relative humidity three times per habitat unit under standardized conditions. The light intensity per study site was measured with Digital light meter (Extech model 401025) 0-2000 Foot Candle (Fc) range, under standardized conditions (on the ground and on sunny days, local time 09.00 a.m. The percent canopy cover of cocoa tree stands was estimated using a Spherical Densiometer©; a concave mirror divided into squares (produced by R.E. Lemmon Forest Densiometers, U.S.A).

Identification of Insects: All the insects captured were identified to the morphospecies level and cross-checked using reference collection at the Cocoa Research Institute of Ghana insectary. 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: All analysis was performed with the Statistical Analysis System (SAS version 9.1, SAS Institute, 2005). The catch from all the various sites for the entire period were pooled together for analysis of the abundance and diversity of the insect species. The four distance blocks were considered as replicates. Data was square root transformed. The number of species found on the farm plots was estimated by the first order Jacknife estimator for species richness (Boulinier *et al.,* 1998; Hughes *et al.,* 2002). Species abundance and patterns between-farms was examined using β or differentiation diversity's formula $\beta w = (S/\alpha)-1$, where S = the total number of species recorded in the system and α = the mean species richness. The effect of increased distance to the forest on insect communities of the farm plots was assessed using generalized linear model (GLM). Distance was considered as a fixed effect and farm plot, year and two- and three-way interactions as random effects.

RESULTS

Insect assemblage diversity and composition in the cocoa ecosystem: A total of 2,721 individual insects belonging to 36 species and 7 orders were recorded through the systematic sampling from the ten study farm plots over the three flowering seasons (Table 1). The dipterans constituted 46.52% (N=1, 266) of insects resident in the cocoa farms, followed by hymenopterans with 46.45% (N=1, 264). The least abundant insects being the hemipterans 0.78% (N=21) (Table 1).

Table 1: Diversity and abundance of insects in the study farms

Order	No. of insect species	No. of individuals (in %)
Hymenoptera	17	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)**

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

Insect species of four of the orders viz: hymenoptera, diptera, orthoptera, and coleoptera were common to all the ten farm plots. The distribution showed a log normal distribution, indicating large, mature and varied natural insect communities (Magurran, 1988). Some of the insect species, for example, *Anoplocnemis curvipes* (order: Hemiptera) and *Gideona klots* (order: Lepidoptera) were singletons (i.e. species with only one individual collected in a particular farm throughout the sampling periods). However, most were either doubletons or found in their numbers. The hymenopterans sampled during the study consisted mainly of ants, and bees, and was the order with most varied insect species. They were followed by the order Diptera and Lepidoptera. More species of insects were sampled in farm plots which were closer to the forest than the other farms (Table 2).

Table 2: Species richness and Diversity of insects in the cocoa farm plots

Farm Plot	Species Richness	Shannon Diversity
1	36	2.70
2	36	2.84
3	26	2.90
4	26	2.94
5	30	2.97
6	26	2.98
7	25	2.99
8	24	3.00
9	26	3.00
10	20	3.00

The richness and/or diversity refer to the number of taxonomic groups and were expressed in absolute terms (Beck and Schulze, 2000).

Multivariate analysis (MANOVA) indicated significant differences in the insect communities according to the farm plot locations in the four distance blocks and insect assemblage (Table 3): distance block (96-171m) F=3.99, p=0.01, assemblage F=3.45, p=0.01; distance block (280-290m) F = 3.63, p= 0.01, assemblage F= 3.23; distance block (670-1,340m) F= 4.10, p= 0.01, assemblage F =2.94; distance block (1,710-1,730m) F = 2.83, p= 0.01, assemblage F= 2.74.

Table 3: Generalized linear model applied to dependent variable estimated from insect assemblage within the distance block treatments.

Dependent Variable	Transformation	Error Distribution	Generalized Linear Model		
			DF	*F*	*P*
Distance Block 1	Square root	Normal	1	3.99	0.01
Assemblage				3.45	0.01
Distance Block 1	Square root	Normal	2	3.63	0.01
Assemblage				3.23	0.01
Distance Block 1	Square root	Normal	2	4.11	0.01
Assemblage				2.94	0.01
Distance Block 1	Square root	Normal	1	2.83	0.01
Assemblage				2.74	0.01

Distance Blocks: *1*-96-171m; 2- 280-290m; *3*-670-1,340m; *4*-1,710-1,730m

On species by species basis ants (all species together) represented most of the non-pollinating hymenopterans in the ten cocoa farms and constituted *ca* 45.28% of total individuals collected when all the insects were pooled together. Thus, the abundance of ants was higher in numbers and pervasive in distribution. Among the dipterans the *Forcipomyia spp,* (biting midges) the most dominant individuals constituted *ca* 25.1% of all the insect species altogether, followed by *Cecidomyiids* (gall midges) *ca* 17.16%. Butterflies (order: Lepidoptera) made up to 2.09%. All the other insect species, viz: coleopterans, hemipterans, and orthopterans were obtained in virtually insignificant numbers. The heteropterans *Distantiella theobroma* and *Bathycoelia thalassina* which are known pests of cocoa were also found on the trunks and pods. The bees (order: hymenoptera) constituted *ca* 3.71%.

Effect of distance to the forest on insect distribution: The results showed strong negative effect of distance of the farm plots to the Bobiri forest on spatial distribution of insect assemblage (Tables 2 and 4) both in species richness and abundance (F = 221.92, p < 0.001). The number of insect taxa decreased linearly with distance to the forest (y = 0·524–0·013x), however, the effect of distance to the forest on the species richness was relatively consistent among years. More species of insects were sampled in farm plots 1 and 2 which were closer to the forest than the other farms (Table 4).

Table 4: Spatial Distribution of insect assemblage in the 10 farm plots

Farm group	Farm plot Number	Distance block from the forest (m)	Richness	Abundance
1	1 and 2	96 - 171	1.55 ± 0.13	621.5 ± 36.5
2	3, 4 and 5	280 - 290	0.91 ± 0.25	441.2 ± 11.4
3	6, 7, and 8	670 - 1,340	0.85 ± 0.05	340.1 ± 19.34
4	9 and 10	1,710 - 1,730	0.81 ± 0.11	325.3 ± 27.51

Farm plots 1 and 2 within the distance range of 96-171m had most species of insects with averaged species richness 1.55 (± 0.13), and had all the insects species (Table 4). The two farm plots (9, 10) within the distance block 1,710-1730m from the forest recorded the lowest the species richness with averaged species richness 0.81 (± 0.11) (Table 4). Similarly, the insect abundance linearly declined with increase in distance to the forest (y = 0·682–0·013x) (Table 4). Thus, insect species richness and abundance depended significantly on the proximity of farms to the Bobiri forest ($p < 0.012$). However, the dipterans, particularly the midge species richness and abundance were not predicted by distance to the forest ($p < 0.001$). The six taxa of insects were fairly distributed among the ten cocoa farm plots ($p < 0.001$) and the effect of distance to the forest on insect distribution was also highly significant ($p < 0.001$). Closeness to the forest significantly predicted insect composition and structure ($p < 0.05$). For example, butterflies (order: Lepidoptera) were found in farms closer to the forest than those farther away ($r^2 = 8.53$, $p = 0.01$), and farm plot1 had more insect species than farm plot 2 (*t*-test, $p = 0.01$) though they were within the same distance range. Among all the insect species the ceratopogonids or midges (Order: Diptera) and the ants (Order: Hymenoptera) were the most pervasively distributed insect groups in the area. They were found in all the ten farms similar in both species richness and abundance across all farms. Farm plot10 had the lowest insect assemblage having the least numbers of insects and diversity.

DISCUSSION

The results demonstrated that the cocoa farms have the potential to support insect diversity and act as more effective refugia for some tropical forest organisms. In this study not only the composition of insect assemblage in the farms could decreased as distance to the forest increased, but also the structure of the insect assemblage could be altered. According to Hunter (2002) insects dwell within complex ecosystems and interact with other taxonomic groups and the abiotic environment. The presence of these insects in the cocoa farms probably might be due to certain factors favorable to the insect species viz: microhabitat conditions which include temperature, humidity, light intensity and food availability. The presence of decaying matter-wood, banana stems, cocoa leaf litter, and cocoa pod husks (at the pod-breaking points) on the farms might have provided a variety of microhabitats which accommodated the different insect species such as the pollinators of cocoa. The temperature range (20-25^{0}C) and relative humidity range (41-98.5%) appeared suitable for the insect species. Similar studies by Levings and Windsor, (1982) indicated that microclimate played important role in insect distribution, diversity, and abundance. Some authors (Nair, 1984; Beer, 1987) have contended that the tree crowns virtually merge thus create self-shade which could ameliorate the direct and extreme impact of the solar radiation on the soil surface, resulting in conducive micro-environment. It was observed that parts of the farm plots that were exposed to direct sunlight were drier and warmer and had less number of insects. Food availability for the insects could result in the presence of certain insects. For example, Perfect and Snelling (1995) observed that coleopterans and some hymenopterans could be important sources of proteins for ants. Miyaji *et al*. (1997) also observed that the larvae of some Lepidopterans and Coleopterans feed on the fresh leaves just after their emergence, whiles adult of Hemipterans also feed on mature leaves. This led to leaf-fall and subsequently, decomposition of cocoa leaf litter. The relative proportions of insect species as suggested by the result (Fig. 2) suggest that the various insect communities resident in the cocoa farms potentially respond differently to the heterogeneity of its environment (Kareiva, 1994; Dauber *et al.,* 2003).

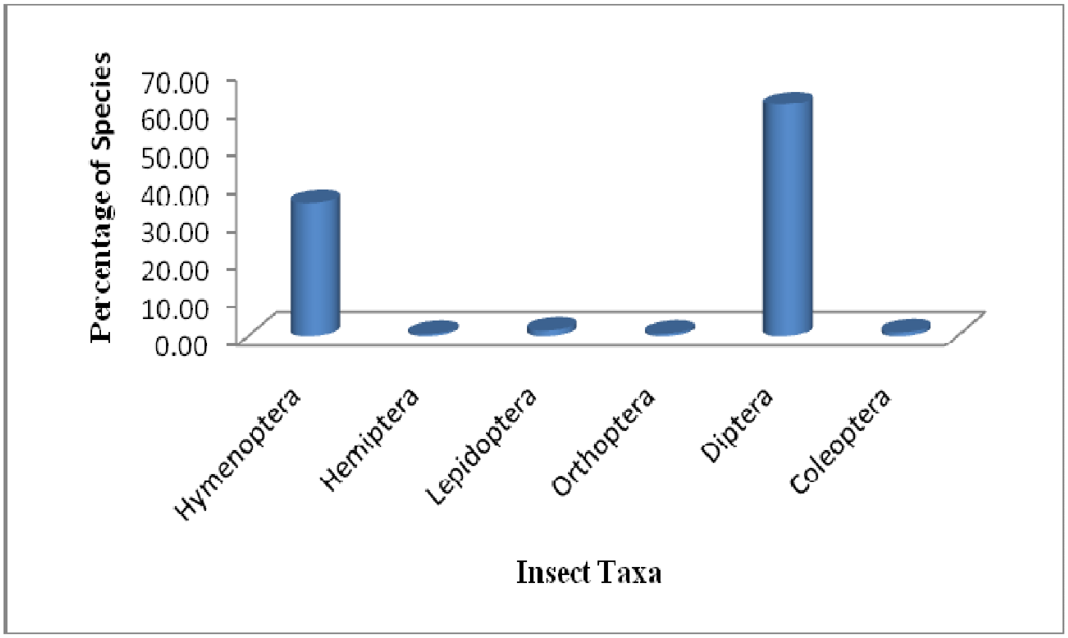

Figure 2: Relative Abundance and Diversity of Insect Species in the Cocoa Ecosystem at Kubease, Ejisu-Juaben District. Sampling was done for three flowering seasons.

The low patronage of the coleopterans, hemipterans and orthopterans in the cocoa ecosystem may be mainly due some agricultural practices. Studies by Wilson *et al*. (1999) showed that beetles are affected by monoculture practices instead of mixed farming. Orthoptera are known to lay eggs at or near the ground surface and make 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. This might also account for the low numbers in the samples.

The insect assemblage on the whole, exhibited a relative decline with the distance from the forest edge. Proximity of farms to the forest was a major determinant in the variation of species richness and abundance (Table 2). Farm plot 1 which was the closest to the forest was most abundant and diverse in species. Insect species in the farm plots close to the forest might be a reflection of what is in the forest. The observation is consistent with earlier findings which have shown that the diversity and abundance of several taxa in agricultural landscapes decline significantly with increasing distance from native habitats (Rickets *et al.,* 2001; Perfecto and Vandermeer, 2002; Luck and Daily, 2003; Ricketts, 2004). Distance from natural or semi-natural habitats has been found to have negative effects on species richness and abundance of crop pollinators in America (Kremen *et al*., 2004; Ricketts, 2004), Asia (Klein 2003) and Europe (Free, 1993). The cocoa ecosystem studied was by and large a monocultural system and therefore could not be a satisfactory surrogate for the reserve forest in terms of plant or flower diversity. This could also determine the spatial distribution of the insect communities in relation to the forest. Although no movement of any particular insect was observed in this study its possibility as a significant factor cannot be discounted.

The species of the order, diptera, was present in significant proportions and thus dominated the cocoa ecosystem by their numbers, though not by their sizes. Prominent among them are the midges which constitute little-studied, non-charismatic, but ecologically important insect species that make up most of the biodiversity in the cocoa ecosystem. It was observed that the spatial distribution of midges did not correlate with increase in distance to the nearby forest.

The hymenoptera was dominated by ant species which formed the bulk of the insect biomass. Studies by various workers (Leston, 1973; Room, 1971, 1975; Majer *et al.,* 1994) point to the fact that in general, ants tend to dominate the abundance and species richness of the arthropod fauna of many tropical ecosystems, including cocoa plantations. The non-effect of distance observed in the study may in part be the result of adaptability of ants to diverse ecological conditions.

In relative proportion the lepidopterans (butterflies) sampled in the farms were greatly dispersed in the farms. Butterflies are known to be affected by habitat heterogeneity in terms of plant/floristic diversity (Steffan-Dewenter and Tscharntke, 2000; Schulze *et al*., 2001). A combination of factors therefore might be responsible for the presence of the butterflies. The self-shade due to the canopy cover of cocoa trees (mentioned above) coupled with the relatively low wind speed could be conducive to the butterflies. Other studies have shown that butterfly diversity and species composition change predictably in response to changes in vegetative structural diversity and microhabitat characteristics such as temperature and moisture (Estrada *et al.,* 1997; Hamer *et al.,* 1997). The question at stake was why were the butterflies present mostly in the farms close to the forest? Studies by Chai (1990) showed that species with stouter bodies are stronger on the wing, and hence could attain height while slender-built species do not reach high flight speeds, but have a superior manoeuvrability. The body design of the butterflies was not studied quantitatively but apparently in this sampled guild slender-built species (e.g., *Euphaedra janetta, Bebearia congolensis*) were more prevalent. These were more likely to live closer to the forest. They could therefore rank as bio-indicators of the non-closeness to the forest. On the whole, the results show that large fluctuations in insect populations are associated with conversion of land use to agriculture (Williams, *et al* 2001). Many authors, Sayer and Whitmore (1991); Verhaagh (1991); Perfecto *et al.* (2003) have indicated that tropical agro-ecosystems are more important for the conservation of biological diversity than previously thought, and that management practices in agro-ecosystems can have an impact on the biological diversity. This is possibly because natural areas are usually embedded in a matrix of natural and managed lands. The data agrees with and confirms earlier studies that the cocoa ecosystem makes a unique contribution to the conservation of fauna biodiversity (Power, A. G and Flecker, A. S *unpublished*).

CONCLUSIONS

The study showed that agro-ecosystems that maintain similar microclimate to that of the natural forest can provide abundance and diversity of food, nesting-sites, and hiding places for resident insects. Proximity of farms to the forest largely determined the variation of insect species richness and abundance. The important outcome of this study is that different insect taxa resident in the cocoa ecosystem contribute both directly and indirectly to the productivity of cocoa and as such proper attention should be paid to cocoa agro-ecosystems.

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