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DIVERSITY AND ACTIVITY OF INSECT NATURAL ENEMIES OF THE BAGWORM (Lepidoptera: Psychidae) WITHIN AN OIL PALM PLANTATION IN PERAK, MALAYSIA

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ABSTRACT

Bagworms (Lepidoptera: Psychidae) are one of the important leaf-eating pests of oil palm in Malaysia and Indonesia. Crop losses, due to the extensive defoliation by a serious bagworm attack are inevitable. The establishment and propagation of the bagworm's parasitoids, depend very much on species of flowering plants as sources of nectar. Cassia cobanensis*, was proven suitable due to its attractiveness to most bagworm parasitoids. A study to assess the diversity of bagworm's natural enemies (hymenopterous parasitoids and reduuvid predatory bugs) on the* C. cobanensis *plant and within the undergrowth of the oil palm planting block was evaluated by sweep net and sticky trap sampling. Environmental parameters such as light intensity, temperature and relative humidity were also recorded during the sampling to determine their possible range of influence towards the activity of the insect natural enemies. The Shannon-Wiener diversity index of insect natural enemies occurring on the* C. cobanensis *plant was 2.32. Among the dominant parasitoids observed on* C. cobanensis *plants are chalcids (*Brachymeria lugubris *and* Brachymeria carinata*) and braconids (*Dolichogenidea metesae *and* Apanteles aluella*), besides the reduuvid predator,* Cosmolestes picticeps*. In contrast, within the oil palm planting block, the undergrowth within the non-harvesting path only recorded a much lower diversity index of 1.09 and 1.12 each, in a block with* C. cobanensis *at the roadside and without, respectively. However,* C. picticeps *was shown to be much more dominant within both oil palm planting blocks, up to two- to three-fold, with much lesser numbers of hymenopterous parasitoids (less than five individuals). This indicates the important contribution of* C. cobanensis *plant towards enriching the diversity of the parasitoids, which are normally not found within the oil palm block, due to much less intense sunlight. In terms of insect activity, they are significantly more active in the moderate or medium light intensities (<8000 fc), medium humidity levels (50%-69%) and medium temperatures (30°C-34°C).*

Keywords: bagworm, *Pteroma pendula*, natural enemies, diversity, environment, oil palm.

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INTRODUCTION

Bagworms (Lepidoptera: Psychidae) are one of the important leaf-eating pests of oil palm in Malaysia and Indonesia. Crop losses, due to the extensive defoliation by a serious bagworm attack are inevitable. A moderate defoliation of about 10%-13% may cause a crop loss of about 33%-40% (Basri, 1993). Parasitoids play an important role in regulating bagworm numbers. The propagation and establishment of the insect natural enemies depend on some suitable species of flowering plants as sources of nectar. Basri *et al*. (1999) confirmed that flowering plants prolong the life span of the adult parasitoids in the laboratory. Among all beneficial plants, *Cassia cobanensis* (Fabaceae) is deemed most suitable for propagation in oil palm estates due to its easy establishment and maintenance. Ho (2003) has confirmed that *C. cobanensis* and *Euphorbia heterophylla* (Euphorbiaceae) are comparable in terms of being attractive to parasitoids in the field. However *C. cobanensis* has the competitive edge, of which it is easier to propagate and need not be successively replanted at every three months as with *E. heterophylla*. A more recent study (Nor Sarashimatun *et al*., 2011), has shown that *C. cobanensis* is second best to *E. heterophylla* in terms of attractiveness to bagworm parasitoids, followed by *Turnera subulata* (Passifloraceae), *Antigonon leptopus* (Polygonaceae), *Vitis japonica* (Vitaceae) and *Turnera ulmifolia* (Passifloraceae).

An inventory of insect natural enemies affecting the bagworms and nettle caterpillars in oil palm has been documented previously (Norman *et al*., 1996; 1998). This current study intends to assess the diversity of insect natural enemies of the bagworm, found occurring on the beneficial plant (*C. cobanensis*) and within the oil palm planting block. At the same time, the range of environmental parameters which influence the activities of these natural enemies within the oil palm ecosystem are also studied.

MATERIALS AND METHODS

An oil palm plantation infested with the bagworm, *Pteroma pendula* was selected at Telok Intan, Perak, Malaysia. Two oil palm planting blocks were selected: one having three groves of the beneficial plant, *C. cobanensis* planted at the roadside, while another, without *C. cobanensis* planted at its vicinity, was used as a control. Each block was about 5 ha, with palm age of 3-4 years old at the start of the study.

Sweep net samplings were conducted on the *C. cobanensis* groves, by sweeping four times above the grove quickly and turning the opening from side to side, to capture the insects within the beneficial plant. This method of sampling is replicated three times in a completely randomised design (CRD). Samples were taken at around 9.00 am and 12 noon, for two consecutive days, in each sampling period. Environmental parameters such as light intensity (foot-candles, fc), temperature (°C) and relative humidity (% RH), were recorded during the sampling period.

A square sticky trap, made from plywood and painted yellow, was covered with a plastic sleeve and sprayed with polybutene gum (Brand: NEOPEACE-F101 - Polybutene - 16% w/w) on both surfaces to capture free flying insects above the *C. cobanensis* grove. The sticky trap was placed at about 1.5 m above the ground, in the middle of the beneficial plant grove and left in the field for two days. The traps were replicated three times in a CRD among the *C. cobanensis* groves. The plastic sleeve was collected and replaced the following morning (9.00 am). This was done for two consecutive days.

Within each of the two planting blocks, sweep net sampling was also conducted at the non-harvesting path (sweeping four times while walking along the path) and replicated three times at random within the oil palm planting block. At the same time, three sticky traps were also placed randomly at the path. Samples were gathered similarly as conducted on the *C. cobanensis* plant. Data was collected quarterly from 2008 to 2010.

In these sampling, it was deduced that the sweep net captures resemble the resident population within the non-harvesting path or within the *C. cobanensis* plant. Whereas, sticky trap captures should resemble the activity of the insects as they were caught while hovering and flying around the beneficial plant or among the non-harvesting paths within the oil palm planting block.

All samples were brought to the laboratory for sorting and identification of common bagworm parasitoids and predators to bagworms and nettle caterpillars following Norman *et al.* (1996; 1998). Shannon-Wiener biodiversity indices were calculated using the online programme at https://www.easycalculation.com/statistics/shannon-wiener-diversity.php

RESULTS

Diversity of Insect Natural Enemies in the Oil Palm Ecosystem

***Cassia cobanensis* plant**. *Figure 1* shows the overall diversity of insect natural enemies occurring on the *Cassia cobanensis* plant, collected by both sweep net and sticky traps. The Shannon-Wiener diversity index was 2.32. For the hymenopterous parasitoids, there were three species each from the families Ichneumonidae (*Spinaria spinator* and *Paraphylax varius*), Eulophidae (*Tetrastichus* sp., *Sympiesis* sp. and *Pediobius imbreus*) and Chalcididae (*Brachymeria lasus*, *B. carinata* and *B. lugubris*); two species from the family Braconidae

(*Dolichogenidea metesae* and *Apanteles aluella*) and one species each from the families Eurytomidae (*Eurytoma* sp.), Eupelmidae (*Eupelmus catoxanthae*), and Ceraphronidae (*Aphanogmus thylax*). Apart from parasitoids, the two common species of predators (Hemiptera: Reduviidae) captured were *Sycanus dichotomus* and *Cosmolestes picticeps*.

It was observed that within the *C. cobanensis* plant, chalcids (*B. lugubris* and *B. carinata*) appeared to be much more dominant, followed by the braconids (*A. aluella* and *D. metesae*) (*Figure 1*). There were three species of parasitoids (*E. catoxanthae, P. imbreus* and *B. lasus* found on the *C. cobanensis* plant (*Figure 1*) but not detected in the oil palm planting blocks (*Figures 2* and *3*). *S. dichotomus* was also found only on the *C. cobanensis* plant (*Figure 1*).

***Within oil palm block with* Cassia cobanensis *at the roadside*.** It was noted that within the oil palm planting block, even with having Cassia groves at the roadside, the Shannon-Wiener index of diversity has reduced to 1.10, compared to 2.32 on the *C. cobanensis* plant. *Figure 2* shows that there were two species of hymenopterous parasitoids from the family

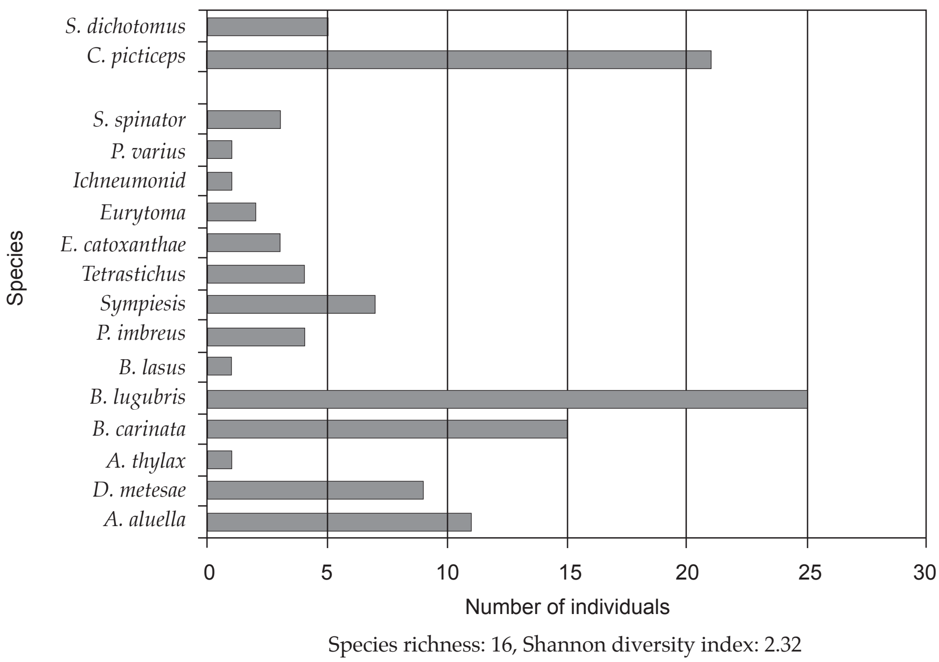


Figure 1. Biodiversity of bagworm natural enemies on Cassia cobanensis *plant, at a plantation in Telok Intan, Perak, Malaysia.*

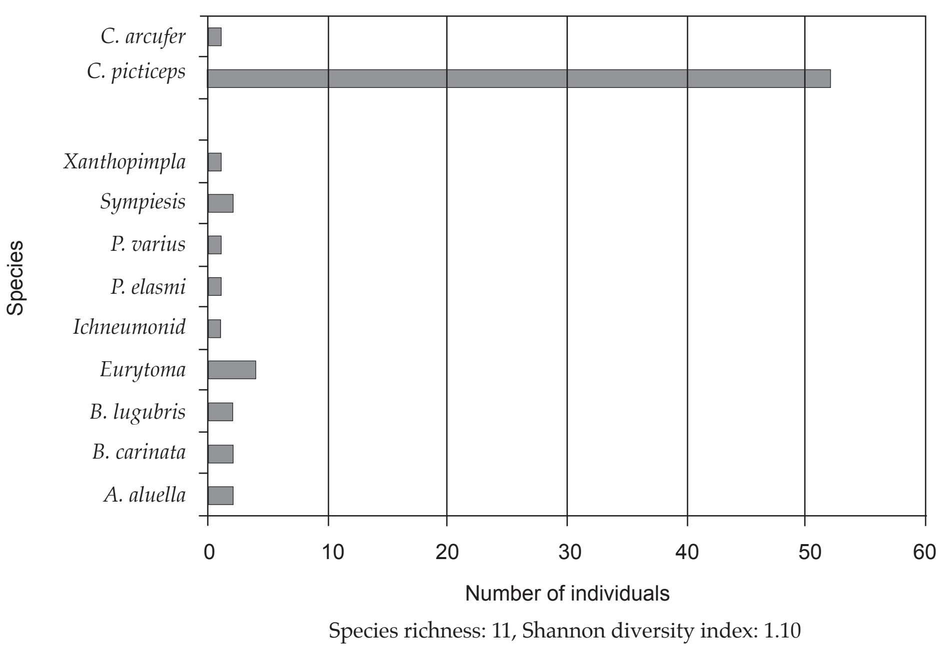


Figure 2. Biodiversity of bagworm natural enemies within the oil palm block (with C. cobanensis *at the roadside) at Telok Intan, Perak, Malaysia.*

Ichneumonidae (*Xanthopimpla* sp. and *Paraphylax varius*), two species each from Eulophidae (*P. elasmi* and *Sympiesis* sp.) and Chalcididae (*B. lugubris* and *B. carinata*) and one species each from Eurytomidae (*Eurytoma* sp.) and Braconidae (*A. aluella*). The dominant insect within the area was the reduuvid predator, *C. picticeps*. This species was captured more than one-fold than those on *C. cobanensis* (*Figures 1* and *2*). A clerid predator, *Callimerus arcufer* was also captured. *Eurytoma* sp. was captured more frequently than others, with number of parasitoids not exceeding five individuals for each species (*Figure 2*). *Xanthopimpla* sp. *P. elasmi* and *C. arcufer* were found in this block which were not detected on the *C. cobanensis* plant (*Figures 1* and *2*).

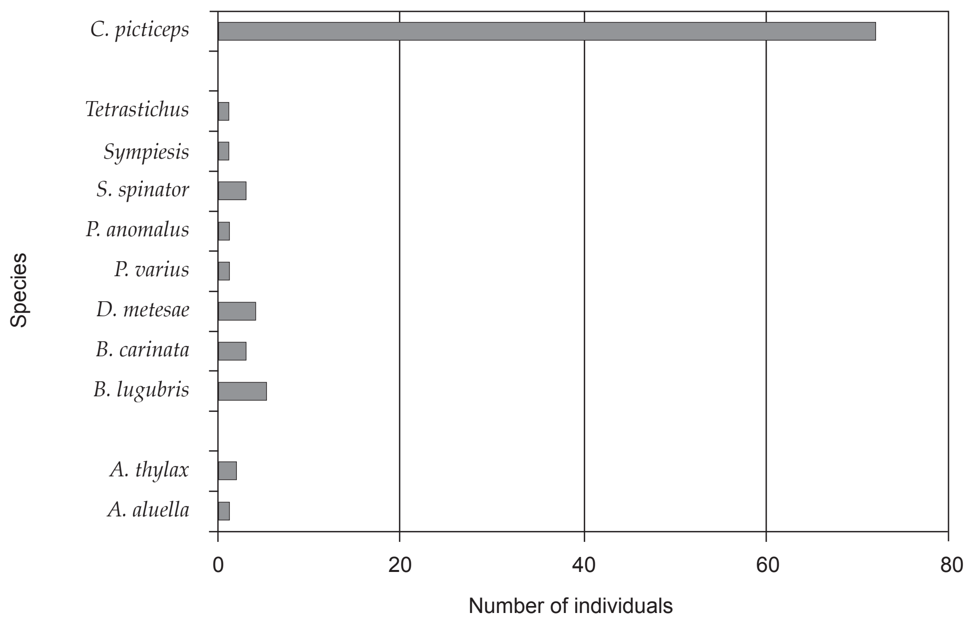
***Within oil palm block without* Cassia cobanensis *at the roadside (control)*.** The captures of insect parasitoids in the oil palm planting block without any nearby presence of *C. cobanensis* plants was also low (less than five individuals per species). Only three species of parasitoids appeared to be captured more frequently than others (*B. lugubris*, *D. metesae* and *S. spinator*). However, the reduviid predator was also dominant, with more than two-fold the number captured on *C. cobanensis* plant (*Figure 3*). The Shannon-Wiener diversity index (1.12) is almost similar to the planting block having the Cassia plant at the roadside (1.10). Similarly, it was also relatively much lower than recorded on the *C. cobanensis* plant (2.32). In terms of parasitoid species composition, there were three species of Eulophidae (*Tetrastichus* sp., *Sympiesis* sp. and *P. anomalus*), two species each of Chalcididae (*B. lugubris* and *B. carinata*), Braconidae (*D. metesae* and *A. aluella*), Ichneumonidae (*S. spinator* and *P. varius*) and one species of Ceraphronidae (*A. thylax*).

Effects of Environmental Parameters on Activity of Natural Enemies

***Insect activities in relation to light intensity (fc)*.** With sticky traps, the activities of most insect natural enemies were observed highest between light intensities of 2000-4999 fc (*Table 1*). Activities by insects were significantly lower at high light intensities (>8000 fc) (*Table 3*).

The braconid, *A. aluella* seem to be more active at lower light intensities of between 2000-3000 fc (*Table 1*). A significant correlation (r^2= 0.84, $p<0.05$) was detected for the captures of *A. aluella* using sticky traps (indicating activity) with light intensity. Similarly, although ichneumonids can be active over a broad range of light intensities (1000-13 000 fc), *P. varius* seems to be more active in lower light intensity between 2000-3000 fc. *S. spinator* seems to be active in less intense sunlight, between 2000-4000 fc (*Table 1*). *D. metesae* on the other hand, appeared to have periodic activities between 300-1000 fc, 3000-4000 fc and 6000-7000 fc. Chalcids (*B. lugubris*) appeared active between 2000-3000 fc while *B. carinata* seem to be active at 1000-2000 fc and 3000-4000 fc (*Table 1*). Eulophids (*P. anomalus, P. imbreus, Sympiesis* and *Tetrastichus*) were observed more active at higher light intensities of between 4000-5000 fc (*Table 1*).

By using sweep net, most of the natural enemies were caught at the lower range of light intensity



Species richness: 12, Shannon diversity index: 1.12

*Figure 3. Biodiversity of bagworm natural enemies within the oil palm block (*without C. cobanensis *at the roadside) at Telok Intan, Perak, Malaysia.*

TABLE 1. DISTRIBUTION OF NATURAL ENEMIES' ACTIVITY (sticky trap) ALONG VARIOUS LIGHT INTENSITIES

		No. of individuals captured by sticky traps										
		Light intensity (fc)										
Species	Order	300-999	1 000-1 999	2 000-2 999	3 000-3 999	4 000-4 999	5 000-5 999	6 000-6 999	7 000-7 999	8 000-8 999	9000-9 999	10 000-13 000
A. aluella	Braconidae	0.00	1.00	7.00	0.00	6.00	4.00	5.00	1.00	1.00	0.00	0.00
D. metesae	Braconidae	2.00	0.00	1.00	2.00	1.00	1.00	2.00	0.00	0.00	0.00	0.00
S. spinator	Braconidae	0.00	0.00	2.00	2.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
A. thylax	Ceraphronidae	0.00	0.00	0.00	1.00	2.00	0.00	1.00	0.00	1.00	0.00	0.00
B. lugubris	Chalcididae	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B. carinata	Chalcididae	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
C. arcufer	Cleridae	0.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
P. imbreus	Eulophidae	0.00	1.00	2.00	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
P. anomalus	Eulophidae	0.00	0.00	1.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
Sympiesis	Eulophidae	0.00	0.00	1.00	0.00	2.00	0.00	1.00	0.00	0.00	0.00	0.00
Tetrastichus	Eulophidae	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00
E. catoxanthae	Eupelmidae	0.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Eurytoma	Eurytomidae	0.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
B. oxymora	Ichneumonidae	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G. bunoh	Ichneumonidae	0.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Ichneumonid	Ichneumonidae	0.00	1.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P. varius	Ichneumonidae	0.00	0.00	2.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
Xanthopimpla	Ichneumonidae	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. picticeps	Reduviidae	1.00	1.00	2.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00
S. dichotomus	Reduviidae	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 2. DISTRIBUTION OF RESIDENT NATURAL ENEMIES (sweep net) ALONG VARIOUS LIGHT INTENSITIES

		No. of individuals captured by sweep net							
		Light intensity (fc)							
Species	Family	1 000-1 999	2 000-2 999	3 000-3 999	5 000-5 999	6 000-6 999	7 000-7 999	8 000-8 999	9 000-9 999
A. alluela	Braconidae	3	0	0	0	0	0	0	0
A. psychidivorus	Braconidae	0	0	0	0	0	1	0	0
D. metesae	Braconidae	4	0	0	0	0	0	0	0
B. carinata	Chalcididae	0	0	0	0	0	0	2	3
B. lugubris	Chalcididae	4	1	0	0	1	0	4	3
Sympiesis	Eulophidae	1	0	0	0	0	0	2	0
Tetrastichus	Eulophidae	3	1	0	0	0	0	0	0
E. catoxanthae	Eupelmidae	1	0	0	1	0	0	0	0
Eurytoma	Eurytomidae	2	2	0	0	3	1	1	2
B. oxymora	Ichneumonidae	2	0	0	0	0	0	0	0
C. picticeps	Reduviidae	3	0	4	0	0	1	1	3

(1000-1999 fc), possibly indicating less active at these range of light intensities (*Table 2*). However, further analysis indicates that light intensity has no significant effect on the resident population (*Table 3*).

Insect activities in relation to relative humidity (RH). With sticky traps, the activities of the insect natural enemies were observed higher at medium humidity levels of between 60%-79% RH (*Table 4*). These include all three species of braconids (*A. aluella, D. metesae* and *S. spinator*), chalcids (*B. carinata*), most eulophids (*P. imbreus, Sympiesis* and *Tetrastichus*) and ichneumonids (*G. bunoh* and *P. varius*). Insect activities are shown to be significantly higher ($p<0.05$) at the medium range of humidity levels (50-69%) (*Table 6*).

Insects tend to rest at the ground covers at higher humidity levels; hence, more individuals were

TABLE 3. MEAN NUMBER OF INSECTS CAPTURED PER INSECT SPECIES UNDER VARIED LIGHT INTENSITIES

	Mean number of insects captured per species		
	Low (300-3 999 fc)	Medium (4 000-7 999 fc)	High (8 000-10 000 fc)
Activities of insect (sticky trap captures)	2.55[a]	2.70[a]	0.50[b]
Resident population (sweep net captures)	2.80[a]	0.70[a]	1.90[a]

Note: Means with the same letter within the same row are not significantly different (ANOVA, Wilcoxon Mann-Whitney, p=0.05).

TABLE 4. DISTRIBUTION OF NATURAL ENEMIES' ACTIVITY (sticky trap) ALONG VARIOUS RELATIVE HUMIDITIES

		No. of individuals captured by sticky traps					
		Relative humidity (%)					
Species	**Family**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**
A. aluella	Braconidae	0.00	0.00	4.00	13.00	9.00	1.00
D. metesae	Braconidae	0.00	0.00	0.00	5.00	3.00	1.00
S. spinator	Braconidae	0.00	0.00	0.00	4.00	2.00	0.00
A. thylax	Ceraphronidae	0.00	0.00	2.00	3.00	1.00	0.00
B. lugubris	Chalcididae	0.00	0.00	0.00	1.00	1.00	0.00
B. carinata	Chalcididae	0.00	1.00	0.00	2.00	0.00	0.00
C. arcufer	Cleridae	0.00	0.00	0.00	2.00	2.00	0.00
P. imbreus	Eulophidae	0.00	1.00	0.00	4.00	3.00	0.00
P. anomalus	Eulophidae	0.00	0.00	2.00	1.00	2.00	0.00
Sympiesis	Eulophidae	0.00	1.00	0.00	2.00	1.00	0.00
Tetrastichus	Eulophidae	0.00	0.00	0.00	2.00	1.00	0.00
E. catoxanthae	Eupelmidae	0.00	0.00	0.00	1.00	1.00	1.00
Eurytoma	Eurytomidae	0.00	1.00	0.00	1.00	0.00	1.00
B. oxymora	Ichneumonidae	0.00	0.00	0.00	0.00	1.00	0.00
G. bunoh	Ichneumonidae	0.00	0.00	0.00	3.00	0.00	0.00
Ichneumonid	Ichneumonidae	0.00	0.00	0.00	1.00	3.00	0.00
P. varius	Ichneumonidae	0.00	0.00	0.00	3.00	2.00	0.00
Xanthopimpla	Ichneumonidae	0.00	0.00	0.00	1.00	0.00	0.00
S. dichotomus	Reduviidae	0.00	0.00	0.00	1.00	1.00	0.00
C. picticeps	Reduviidae	1.00	2.00	4.00	12.00	3.00	0.00

captured by sweep nets. Braconids like *A. aluella* and *D. metesae* seem to be resting at very high humidities of between 80%-90% RH (*Table 5*). However, chalcid species like *B. carinata* and *B. lugubris* appeared resting between 60%-70% RH. Eulophids like Sympiesis seem to be resting at medium (50%-60% RH) humidities, while *Tetrastichus*, at higher (70%-80% RH) humidities (*Table 5*). It was also confirmed that significantly higher ($p<0.05$) insect population are resting at the highest range of humidity (70%-89%) (*Table 6*).

Similarly, the abundance of predators (*i.e.* *C. picticeps*) in sticky traps indicated higher activities between 60%-70% RH and consequently, most of them were also caught by sweep net, at the same humidity levels (*Table 5*).

Insect activities in relation to temperature (°C). In terms of natural enemies captured by sticky traps, a majority of the insect families were found more active between 30°C-34°C, with the exceptions of chalcids (*B. carinata*) and reduviid (*C. picticeps*), being more active at the higher range of 35°C-39°C (*Table 7*). In general, significantly lower ($p<0.05$) activities occurred at both the lower or higher temperatures from this range (30°C-34°C) (*Table 9*).

TABLE 5. DISTRIBUTION OF RESIDENT NATURAL ENEMIES (sweep net) ALONG VARIOUS RELATIVE HUMIDITIES

		No. of individuals captured by sweep net					
		Relative humidity (%)					
Species	Family	40-49	50-59	60-69	70-79	80-89	90-99
A. psychidivorus	Braconidae	0.00	0.00	1.00	0.00	0.00	0.00
A. alluela	Braconidae	0.00	0.00	0.00	0.00	3.00	0.00
D. metesae	Braconidae	0.00	0.00	0.00	2.00	2.00	0.00
B. carinata	Chalcididae	0.00	1.00	4.00	0.00	0.00	0.00
B. lugubris	Chalcididae	0.00	3.00	4.00	3.00	3.00	1.00
Sympiesis	Eulophidae	0.00	2.00	1.00	1.00	0.00	0.00
Tetrastichus	Eulophidae	1.00	0.00	0.00	2.00	1.00	0.00
E. catoxanthae	Eupelmidae	0.00	0.00	0.00	0.00	1.00	0.00
Eurytoma	Eurytomidae	1.00	2.00	1.00	5.00	2.00	0.00
B. oxymora	Ichneumonidae	0.00	0.00	0.00	1.00	0.00	1.00
C. picticeps	Reduviidae	0.00	1.00	3.00	6.00	1.00	1.00

TABLE 6. MEAN NUMBER OF INSECTS CAPTURED PER INSECT SPECIES UNDER VARIED RELATIVE HUMIDITIES

	Mean number of insects captured per species		
	Low (30%-49%)	Medium (50%-69%)	High (70%-89%)
Activities of insect (sticky trap captures)	0.35[a]	3.70[b]	2.00[ab]
Resident population (sweep net captures)	0.20[a]	2.10[ab]	3.30[b]

Note: Means with the same letter within the same row are not significantly different (ANOVA, Wilcoxon Mann-Whitney, p=0.05).

TABLE 7. DISTRIBUTION OF NATURAL ENEMIES' ACTIVITY (sticky trap) ALONG VARIOUS TEMPERATURES

		No. of individuals captured by sticky traps			
		Temperature (°C)			
Species	Family	25-29	30-34	35-39	40-44
A. aluella	Braconidae	6.00	15.00	4.00	0.00
D. metesae	Braconidae	1.00	7.00	1.00	0.00
S. spinator	Braconidae	0.00	5.00	1.00	0.00
A. thylax	Ceraphronidae	0.00	4.00	1.00	0.00
B. lugubris	Chalcididae	1.00	1.00	0.00	0.00
B. carinata	Chalcididae	0.00	1.00	2.00	0.00
C. arcufer	Cleridae	0.00	3.00	1.00	0.00
P. imbreus	Eulophidae	0.00	8.00	0.00	0.00
P. anomalus	Eulophidae	1.00	3.00	0.00	0.00
Sympiesis	Eulophidae	0.00	4.00	0.00	0.00
Tetrastichus	Eulophidae	0.00	2.00	1.00	0.00
E. catoxanthae	Eupelmidae	1.00	1.00	1.00	0.00
Eurytoma	Eurytomidae	1.00	2.00	0.00	0.00
B. oxymora	Ichneumonidae	0.00	1.00	0.00	0.00
G. bunoh	Ichneumonidae	0.00	3.00	0.00	0.00
Ichneumonid	Ichneumonidae	1.00	3.00	0.00	0.00
P. varius	Ichneumonidae	0.00	3.00	2.00	0.00
Xanthopimpla	Ichneumonidae	0.00	1.00	0.00	0.00
C. picticeps	Reduviidae	0.00	9.00	10.00	1.00
S. dichotomus	Reduviidae	0.00	2.00	0.00	0.00

TABLE 8. DISTRIBUTION OF RESIDENT NATURAL ENEMIES (sweep net) ALONG VARIOUS TEMPERATURES

		No. of individuals captured by sweep net		
		Temperature (°C)		
Species	**Family**	**25-30**	**31-34**	**35-40**
A psychidivorus	Braconidae	0.00	1.00	0.00
A. alluela	Braconidae	3.00	0.00	0.00
D. metesae	Braconidae	3.00	1.00	0.00
B. carinata	Chalcididae	0.00	0.00	5.00
B. lugubris	Chalcididae	5.00	2.00	7.00
Sympiesis	Eulophidae	1.00	1.00	2.00
Tetrastichus	Eulophidae	3.00	1.00	0.00
E. catoxanthae	Eupelmidae	1.00	0.00	0.00
Eurytoma	Eurytomidae	2.00	5.00	4.00
B. oxymora	Ichneumonidae	1.00	1.00	0.00
C. picticeps	Reduviidae	3.00	5.00	4.00

TABLE 9. MEAN NUMBER OF INSECTS CAPTURED PER INSECT SPECIES UNDER VARIED TEMPERATURES

	Mean number of insects captured per species		
	Low (25°C-29°C)	**Medium (30°C-34°C)**	**High (35°C-39°C)**
Activities of insect (sticky trap captures)	0.60^{a}	3.90^{b}	1.20^{a}
Resident population (sweep net captures)	2.00^{a}	1.50^{a}	2.00^{a}

Note: Means with the same letter within the same row are not significantly different (ANOVA, Wilcoxon Mann-Whitney, p=0.05).

Braconids (*A. aluella, D. metesae*) and the eulophid (*Tetrastichus*) appeared resting at lower temperatures between 25°C-30°C. Eurytomids (E*urytoma* sp.) and reduviid (*C. picticeps*) appeared resting between 31°C-34°C while chalcids (*B. carinata, B. lugubris*) and eulophid (*Sympiesis* sp.) resting at higher temperatures of between 35°C -39°C (*Table 8*).

In general, temperature seems to have no direct effect on the resident population (p>0.05). However as mentioned above, there were some indications that more insects were resting at both the cooler (25°C-29°C) and hotter (35°C-39°C) temperatures (*Table 9*).

DISCUSSION

In this current study, the insect natural enemies within the bagworm infested plots were surveyed by sticky traps and sweep nets. The activities of natural enemies can be estimated based on captures of sticky traps as reported by Dreistadt (1998), Idris and Grafius (1998) and Gray (2009), whereas resident insect population can be assumed based on the captures of sweep net as conducted by UC IPM (2010) and Peña *et al*. (2010).

It was shown from this study that sticky traps consistently captured a higher species density of natural enemies compared to sweep net. This is logical, as the traps were left for two consecutive days, compared to sweep net sampling which was periodically done from morning to afternoon. However, for comparison between the two methods, the mean number for each species was calculated.

It was observed that species diversity of the hymenopterous parasitoids and predators were relatively higher on the *C. cobanensis* plant (Shannon-Wiener index, 2.32), compared to the ground covers of the non-harvesting paths (Shannon-Wiener indices between 1.10-1.12) (*Figures 1* to *3*). The hymenopterous parasitoids, which consisted of the families Ichneumonidae, Eulophidae, Chalcididae, Braconidae, Eurytomidae, Eupelmidae and Ceraphronidae have all been recorded as important parasitoids for the bagworms (Norman *et al*., 1996) including one braconid species important for nettle caterpillars (Norman *et al*., 1998). Apart from these parasitoids, two common species of predators (Hemiptera: Reduviidae) were commonly found as general predators for bagworms and nettle caterpillars (Norman *et al*., 1998). It is also necessary from this study to determine any different types of natural enemies emerging from *Pteroma pendula*, so as to complement the earlier studies (Norman *et al*., 1996; 1998).

The results showed that within the *C. cobanensis* plant, Chalcididae (*B. lugubris, B. lasus* and *B. carinata*) was more dominant than Braconidae (*D. metesae* and *A. aluella*), and that these two families were more dominant than the other families of Hymenopteran parasitoids (*Figure 1*). This also supports the findings of Naganuma and Hespenheide (1988), which reported on these two predominantly parasitic wasps families visiting the extra floral nectaries of *Baccharis sarothroides* Gray (desert broom). It was also reported by that chalcids eventually 'kicked' the braconids away (Naganuma and Hespenheide, 1988).

On the ground covers within the oil palm planting block, there were lower species diversity (Shannon-Wiener index, 1.10), and lower density of insect natural enemies (*Figure 2*). The families of parasitoids recorded were Ichneumonidae, Eulophidae, Chalcididae, Eurytomidae and Braconidae. *Eurytoma* sp. appeared to be captured more frequently than the others, with no indications of dominance by neither chalcids nor braconids. This possibly indicates that the food sources for these parasitoids were scarce or not available, because the composition of ground covers in the survey area consisted mainly of ferns (*e.g. Nephrolepis biserrata, Stenochlaena palustris*). It was also important to note that within this area, the reduuvid predator, *C. picticeps* and a clerid predator, *Callimerus arcufer* were commonly captured, indicating that these two predators preferred to dwell on the ground covering fern species. Heteroptera (Miridae, Reduviidae) has been recorded dwelling on ferns (Wheeler, 2001; Ballentes, *et al*., 2006). *S. dichotomus*, on the other hand, was only captured among the *C. cobanensis* plant and was not detected in the oil palm planting block. This may indicate the dependency of *S. dichotomus* on the beneficial plant.

Similarly, the low captures of insect parasitoids (less than five individuals per species) within the oil palm planting block, indicates the important and contributory effects of *C. cobanensis* plant as nectar provider to the population of parasitoids. In the absence of this beneficial plant, only three species of parasitoids appeared to be frequently captured, with the reduviid predator gaining dominance (*Figure 3*). As expected, the Shannon-Wiener index of diversity within the oil palm planting block (1.12) was 50% lower than on the *C. cobanensis* plant (2.32).

Using sticky traps, the activities of the insect natural enemies was highest at light intensities of between 2000-4999 fc, with the highest activity recorded between 4000-4999 fc. In contrast, sweep net sampling showed high capture of the natural enemies at the lower range of light intensity (1000-1999 fc). These results suggest that most insect natural enemies are active at medium light intensities and likely to be resting at lower range of light intensities.

The intensity, duration and quality of light have an important influence on the biology and behaviour of most insects (Jervis, 2005). High light intensity seems to increase the general activity of diurnal predators and parasitoids (Jervis *et al*., 2005). For example, the flight and locomotory movements of the Gypsy moth's pupal parasitoid, *Brachymeria intermedia* (Hymenoptera: Chalcididae) increased as temperature and light intensity increased. Significant peaks in activity also occurred during the photo phase (Barbosa and Frongillo, 1977). For *Aphelinus asychis* (Hymenoptera: Aphelinidae), light intensity modified its biological and ecological traits. High light intensity resulted in a shorter developmental duration, higher incidence of females and longer life span of the female parasitoid (Sengonca *et al*., 2008). However, it was reported that this parasitoid can also completely develop and reproduce at low light intensities of 100 and 700 fc.

In general, several species of hymenopteran families (braconid, ichneumonids and chalcids) were found active between 2000-4000 fc. In this study although ichneumonids were found active over a broad range of light intensities (1000-13 000 fc), *P. varius* and *S. spinator* seem to be active in less intense sunlight, between 2000-4000 fc. This supported the findings of Idris and Grafius (1998), which showed that the ichneumonid, *Diadegma insulare* is active in the early morning (0800-1000) and peaked by noon.

In contrast, several species of eulophids were active at higher light intensities between 4000-5000 fc. Eulophids are considered mainly hyperparasitoids (Norman *et al*., 1996), and therefore it is hypothesised that this could be a strategy for these parasitoids to be active at a later part of the day (with higher light intensity), in order to successfully parasitise the primary parasitoids (braconids, ichneumonids and chalcids), which have been actively ovipositing during the earlier part of the day. This current study also supported the previous report by Idoine and Ferro (1990) which indicated that the egg parasitoid eulophid, *Edovum puttleri* are active at around mid-day to the afternoon, *i.e.* between 6-11 hr after sunrise.

The braconid, *D. metesae*, on the other hand, appeared to have periodic activities between 300-1000 fc, 3000-4000 fc and 6000-7000 fc. These periodic activities in different parts of the day, could be a parasitism strategy, in the presence of the competing hyperparasitoids (eulophids).

In general, almost all parasitoids seem to be resting in much lower light intensities (1000-2000 fc). However, some chalcids rest in extreme intense sunlight of more than 8000 fc. Kamm (1990) reported that the alfafa seed chalcids, *Bruchophagous roddi* (Hymenoptera: Superfamily Chalcidoidea, Family Eurytomidae) displayed no preference for baited targets at noon (1200 hr). Preference or activity was not shown at 1-2 hr after sunrise or 1-2 hr before sunset. Kamm (1990) hypothesised that chalcid response/activity was controlled by the polarisation characteristics of sky light. This could probably explain why parasitoids are resting in the early part of morning when the light intensity is low.

Light intensity can also modify biological and ecological traits of insects. For example, high light intensity resulted in a shorter developmental duration, higher incidence of females and longer life span of the female *Aphelinus asychis* (Hymenoptera: Aphelinidae) (Schirmer *et al*., 2008). Aphelinids like *Encarsia formosa* and *Eretmocerus eremicus* parasitised approximately twice as many whitefly hosts at the high light intensity (112–114 W m^{-2}) and long day length (L 16:D 8 hr) treatment than at the low light intensity (12-14 W m^{-2}) and short daylength (L 8:D 16 hr) treatment (Zilahi-Balogh *et al*., 2006). In the oil palm environment, it was observed that parasitoids were more active at the low to medium range of light intensities, and rest during very high light intensities.

Predators also appeared to be active over a broad range of light intensities from 300-13 000 fc but *C. picticeps* was more active between 3000-4000 fc, which is also within the active range among the parasitoids.

Using sticky traps, the activities of most insect natural enemies was observed high at humidities of between 60%-79% RH. Using sweep net, the captures was also high between 70%-89% RH. The parasitoid for *Aphis gossipyi, Aphelinus asychis* (Hymenoptera: Aphelinidae) can completely develop and reproduce at relative humidities of 30% and 60% (Sengonca *et. al*., 2008).

Most of the parasitoids seem to be more active at medium humidity levels of between 60-70 RH, as reflected by the high activity of most insect parasitoids within that humidity levels. These include braconids, chalcids, most eulophids and ichneumonids. Moisture also exerts an influence on the growth and survival of insects. Some species become dormant in the absence of adequate moisture as in the case of the eulophid parasitoid *Sympiesis hyblaea* of the teak defoliator *Hyblaea puera* (Nair, 2007). Parasitism of *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) was good when bred at RH of 70%-80%. In the laboratory, most species are active 40%-60% RH, with lower threshold: 25% RH and higher, 70% RH. In India, low RH (9%-22%) is detrimental to the parasitoid. (Upadhyay *et al*., 2001). On the other hand, sawflies (Hymenoptera: Pamphiliidae) tend to be more active in low RH of 20% (Holusa and Kuras, 2010).

Insects tend to rest at the ground covers, at higher humidity levels, hence more were captured by sweep nets. Braconids seem to be resting at very high humidities of between 80%-90% RH. This could be the fact that it was very early in the morning and the light intensity was too low for their flight activities. However, other parasitoids like eulophids and chalcids were also caught by sweep nets, between 50%-80% RH when most parasitoids are likely to be active. This may suggest that these parasitoids were in abundance and some may be residing at the ground covers. Similarly, the abundance of predators (*i.e. C. picticeps*), which are also highly active between 60-70 RH, were consequently caught by sweep net.

In relation to temperature, almost all the insect natural enemies in this study were active at moderately high temperatures of between 30°C-34°C. There are however some exceptions like chalcids (*B. carinata*) and reduviid (*C. picticeps*) being more active at even higher temperatures of 35°C-39°C. In a temperate country (Spain), it was reported that ichneumonids actively fly at cool temperatures of 25°C-27°C during summer (Mazon *et al*., 2009).

The predatory flower bug *Orius similis* Zheng (Heteroptera: Anthocoridae) has a decreased duration of embryonic and nymphal development as well as total percentage mortality during the development with increasing temperature between 18°C and 30°C (Ahmadi *et al*., 2007). The daily oviposition ranged from 1.0 (18°C) to 6.9 (30°C) eggs per day with *A. gossypii* and *M. persicae* as prey, respectively (Ahmadi *et al*., 2007). Based from the field captures in this current study, the predator, *C. picticeps* seem to be more active at temperatures of between 35°C-39°C. This increase in the predator's activity might be related to oviposition.

Using sweep net, most insect parasitoids were collected between 25°C-30°C, indicating many species (some braconids and eulophids) were not very active at this lower temperature range. Eurytomid could be in abundance as most parasitoids were found active between 31°C-34°C. Some chalcids and eulophids could also be in abundance as they were mostly caught by sweep net within temperatures of between 35°C-40°C.

Temperature had a significant effect on the developmental duration of the aphid parasitoid, *A. asychis* as well as on the percentage and longevity of females, while mortality from mummification to emergence, fecundity and host feeding were only slightly affected (Sengonca *et al*., 2008). This parasitoid can successfully develop and reproduce between 18°C-30°C (Sengonca *et al*., 2008). Parasitism of *T. chilonis* was good when bred at 25°C-28.3°C. Most species were active and fecund at 20°C-29°C, with lower threshold: 9°C and higher, 36°C. Parasitism of *Trichogramma* increased with temperature, reaching a maximum at 20°C-25°C, with more parasitism at higher than lower temperatures (Pavlik, 1993). Very high temperatures (43°C-47°C) were detrimental to parasitoids (Upadhyay *et al*., 2001).

CONCLUSION

This study has shown that the overall diversity of insect natural enemies occurring on the *C. cobanensis* plant was higher compared to the harvesting paths in the oil palm planting block. This suggests the importance of *C. cobanensis* in establishing populations of the bagworm natural enemies, especially the hymenopterous parasitoids, which are potent biocontrol agent for the bagworms. Therefore, it is recommended that the *C. cobanensis* plant should also be planted within the oil palm block, wherever possible, in areas with adequate sunlight, in addition to planting at the roadside. Overall, there are significant increase in natural enemies activities at low to medium light intensities (<8000 fc), medium humidity levels (50%-69%) and medium temperatures (30°C-34°C). This information would provide better understanding on the environment suited and conducive for the diversity and activities of these natural enemies for a long-term, sustainable, control of bagworms.

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