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Studies on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations in Teluk Intan, Perak (Malaysia)

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ABSTRACT. A field study was conducted to elucidate the predatory activities of the ant *Oecophylla smaragdina* on the bagworm *Pteroma pendula* in oil palm plantations at Teluk Intan, Perak, Peninsular Malaysia, from November 2010 to August 2011. The ant was found to be prevalent in taller (> 4m) palm stands but absent in shorter ones subject to a comparable regime of chemical pesticides or biological control. Among the taller palms the number of nests per tree ranged from 0 to 13. The abundance level of *P. pendula* was significantly lower in trees occupied by *O. smaragdina* than in unoccupied palms. Similarly, the degree of foliar injury was significantly lower in occupied palms. There was a strong positive correlation between pest density and degree of foliar injury. The number of fruiting bunches, indicative of the palm-oil productivity, was significantly higher in occupied palms. The predatory behaviour of *O. smaragdina* towards *P. pendula* was confirmed by observations in a distinctive chronological sequence. Field experiments showed that *O. smaragdina* preferred to consume pupae over larvae (of all instars), until the extermination of the former. The study confirmed that *O. smaragdina* does not attack or disturb the oil palm pollinator weevil, *Elaeidobius kamerunicus*. The ant species thus shows great promise for biological control in oil palm.

Keywords: oil palms, *Oecophylla smaragdina*, *Pteroma pendula*, foliar injury, predation, biological control, *Elaeidobius kamerunicus*

INTRODUCTION

The Asian weaver ant *Oecophylla smaragdina* (Fabricius) dwells across Southeast Asia as far as India in the west, Taiwan and mainland China in the north and the tropical region of Australia in the south (Ledoux 1950; Stapley 1980; Chen 1981; Van Mele & Cuc 2000; Azuma *et al*. 2006). Weaver ants, including the African species *O. longinoda* (Latreille), exhibit arboreal habits but can sometimes be found foraging on the ground. However, their large polydomous nests are always found in tree canopies (Dejean *et al*. 2007). The ant is known to inhabit many kinds of plant species including domesticated fruit trees such as *Citrus maxima* (Burm.) Osbeck (citrus), *Mangifera indica* L. (mango), *Theobroma cacao* L. (cocoa), *Garcinia* × *mangostana* L. (purple mangosteen), *Lansium domesticum* Corrêa (langsat) and *Syzygium aqueum* (Burm.f.) Alston ("jambu air" or water guava) (Dejean *et al*. 1997; Kenne *et al*. 2003). In Malaysia it is prevalent also in oil palm plantations nationwide, as reported by Wood (1968). Weaver ants have been known to prey on many insect species as well as nectary exudates from plants and sugary secretions produced by homopterans and caterpillars (Blüthgen & Fiedler 2002; Tsuji *et al*. 2004). They are ferocious foragers, attacking almost any organisms that cross their path. It is because of this predatory attribute that the species has been used for biological control of pests by farmers. It is recorded that the indigenous people of South China were using weaver ants to protect their citrus orchards at least since the early centuries of the first millennium A.D. (Huang & Yang 1987), by inserting a nest and promoting colony expansion using bamboo poles connecting the branches of adjacent trees. Peng & Christian (2004) found that *O. smaragdina* effectively controlled the main insect pests of cashew plantations in the Northern Territory of Australia and Papua New Guinea (Peng *et al*. 2004), and the red-banded thrips *Selenothrips rubrocinctus* (Giard) on mango crops in the former territory. During British rule in the Solomon Islands Philips (1940) reported: "Planters, managers and investigators alike have noticed that where *Oecophylla* is present, the trees almost invariably bear well". *Oecophylla smaragdina* is recorded as controlling over 50 varieties of pest insects, from around 12 diverse crops, in tropical areas (Way & Khoo 1992; Peng & Christian 2006).

In Malaysia, huge areas have been planted with oil palm, becoming the major revenue earner for the country since half a century ago. In certain areas the infestation of the leaf fronds by the bagworms *Pteroma pendula* (de Joannis) is serious (Norman & Basri 2007; Cheong *et al*. 2010). It contributes to declining productivity due to damaged leaves caused by the pest, especially during the larval stage when it is actively feeding. In heavily infested areas, the defoliation damage may cause substantial economic loss (Wood *et al*. 1973), sometimes as high as 44% (Basri 1993). The presence of *O. smaragdina* in oil palm plantations (Exélis Moïse Pierre and Azarae Hj Idris personal observations) offers the opportunity to study its predatory behaviours in relation to the bagworm problems.

As context for the present study, the weevil *Elaeidobius kamerunicus* Faust is a very important pollinating agent for the oil palm (Syed *et al*. 1982; Adaigbe *et al*. 2011). Thus it is crucial to establish whether *O. smaragdina* also preys on the weevil, because if this is the case the impact may outweigh the benefits obtained from exterminating *P. pendula*.

The present study was conducted to determine the occupancy patterns of the weaver ants in the study area, to assess the degree of infestation and foliar injury by *P. pendula*, and the productivity of palm trees occupied and not occupied by *O. smaragdina*, to elucidate the ants' predatory behaviour towards the bagworms, and to detect any interference or predation on *E. kamerunicus* by the weaver ants.

Plate 1. *Oecophylla smaragdina* nests in oil palm plantations. Right: brood nest; left: queenright nest. Photos taken by Exélis Moïse Pierre using a Sony T20 digital camera.

MATERIALS AND METHODS

Study site

The study was conducted at the Malaysia Palm Oil Board (MPOB) plantation in Teluk Intan, Perak, Peninsular Malaysia: geographical coordinates 4° 2' 0" N, 101° 1' 0" E. The total size of the plantation is 1000 ha and it is divided into 36 administrative blocks of various sizes and ages. The area experiences a typical Malaysian tropical climate with a uniform temperature round the year, with daily air temperature ranging from 21^{o}C to 35^{o}C. Relative humidity is high, ranging from a mean daily minimum of 54 % to a mean daily maximum of 94 %. Winds generally affect seasonal rainfall, with the main important seasonal features the North-East monsoon blowing from October to February and the North-West monsoon from May to September.

Field survey for occupancy studies on *O. smaragdina*

The study was conducted from November 2010 to August 2011. For the purpose of this study five blocks of short (1.5 to 2.5 m) palm trees and five blocks of tall (>4 m) palm trees were selected at random for sampling. The taller ones comprised older palms (7-13 years old) and the shorter ones were younger palms (3-4 years old). Each block may contain an average of 1000 palms. In each block 50 trees were randomly sampled, with adjacent trees excluded whenever they fell into the random sample. A minimum distance was applied only in this case, to avoid sampling immediate neighbouring trees. Thus a total of 500 palm trees were sampled: 250 from each size category. These were distinctively different in physiognomic appearance, with the younger palm trees shrubby in appearance and without any interconnecting fronds, while the older ones (4-8 m and above) have an obvious trunk and overlapping canopies, enabling easy expansion of ant colonies within occupied blocks.

No management operations were carried out during our study duration (heavy aerial spraying of the biological pesticide *Bacillus thuringiensis* Berliner was part of the management regime, but was done shortly after the present study). There is no record of chemical insecticide spraying operations for the last two years in either tall or short palm trees. Occupancy was assessed by direct observation, using the naked eye to detect the presence of all kinds of nests and individual ants of all castes. There are three types of nests: queenright nests, "brood nests," and "pavilions" (Lim 2007) or "barracks nests" (Hölldobler 1983) (see Plate 1). Where necessary, especially on older and taller palm trees, observation was aided by using a pair of binoculars. A palm tree was considered occupied by *O. smaragdina* if during the field survey there was one or more nest (of any type) or one or more foraging individual.

Field survey on the pest intensity/ density level and foliar injury by *P. pendula*

A survey was conducted to assess the pest density as well as the degree of frond damage/injury on each selected palm tree. One frond from each palm, at a 45° angle to the trunk, was examined to quantify the infestation. For tall trees the fronds were cut (Hartley 1977). The degree of infestation of *P. pendula* was categorised into 5 levels of intensity: Level 0 = total absence; Level 1 = 1-10 individuals of larvae per frond; Level 2 = 11-20 individuals of larvae per frond; Level 3 = 21-30 individuals/ frond and Level 4 = > 30 (Wood 1971; Krishnan 1977; IRHO 1991; Basri 1993). These categories were formulated based on preliminary sampling of *P. pendula* infestation in the study area to determine the abundance range (lumping all phases of the life cycle). A total of 250 tall palm trees not occupied by *O. smaragdina* were randomly sampled for *P. pendula* infestation. If an occupied palm tree was selected, another random number was taken. The results were compared to infestation intensity of only the total number of tall palm trees occupied by *O. smaragdina*. These data were obtained simultaneously while sampling for the occupancy of the ants. Since there were no short palm trees observed to be occupied by *O. smaragdina* (see below), comparison of infestation with and without them could not be made on short trees.

Assessment of the degree of foliar injury was made on the same palm trees selected for the infestation and occupancy studies. The assessment of foliar injury was made on a per-palm basis. The total number of palm trees of each level of damage was counted. The degree of damage was categorised into five Levels. Level 0 = All fronds are green and healthy. No noticeable injury from a distance, corresponding to 0% frond injury. Level 1 = Fronds with small cut holes (eaten by *P. pendula* larvae), showing signs of minor desiccation at the tips. Less than 5% of fronds are injured. Level 2 = Fronds with obvious and numerous desiccated leaflets (brownish in colour). 6-33% of fronds are injured. Level 3 = Serious frond injury, with 34-66% defoliation and desiccation, exhibiting numerous and obvious holes. Level 4 = Almost all fronds are severely injured with characteristic dried and burnt look, resulting in a severe plantation dieback (see Plate 2).

Chi-square tests were conducted to see if there was any significant difference between the occupied and unoccupied palms with respect to *P. pendula* infestation and foliar injury. Correlation analysis, using Spearman coefficient r_s, was performed between the levels of pest infestation and foliar injury.

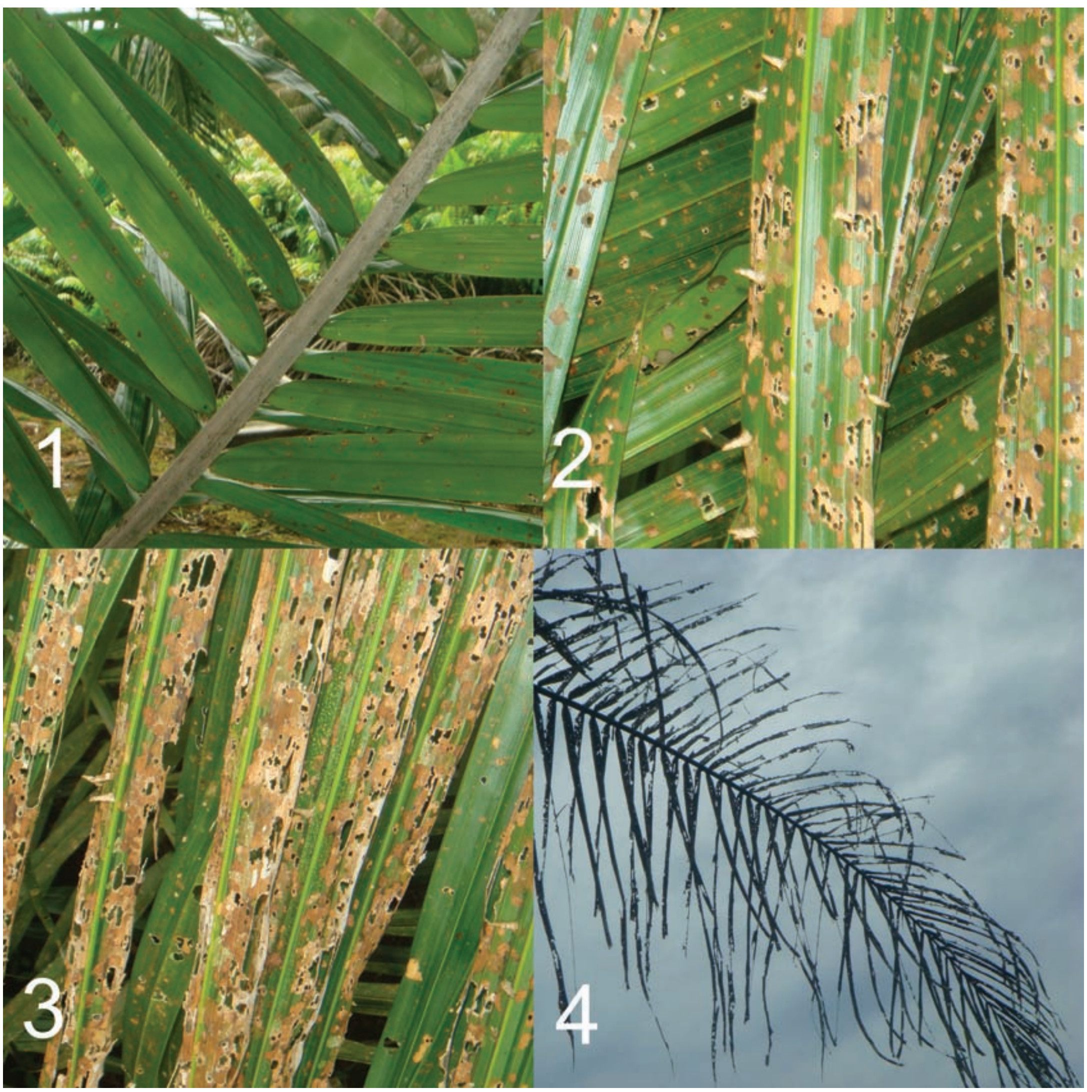

Plate 2. Foliar injury affecting oil palm trees: the number represents foliar injury of Level 1-4 respectively. Photos taken by Exélis Moïse Pierre using a Sony T20 digital camera.

Assessment of productivity

Productivity in this study was indicated by the number of either developing fruit bunches (DFBs) or fresh fruit bunches (FFBs) per palm tree. The measure of FFB productivity used was the number produced per palm-tree sampled. The higher the number, the higher was the productivity. Palm trees were selected at random during the field survey conducted for another study with different purposes. For each palm tree sampled, either occupied or unoccupied by *O. smaragdina*, the sum of the number of DFBs and that of FFBs was recorded. Size and weight of DFBs or FFBs was not taken into consideration. For the purpose of graphical presentation productivity was categorised into four levels: Level 1 (not productive), with <5 DFBs/FFB per palm; Level 2 (moderately productive), with 6-10 DFB/ FFBs per palm; Level 3 (productive), with 11-15 DFB/ FFBs per palm; and Level 4 (highly productive), with >15 DFB/FFBs per palm tree. The second element was the total weight of FFB harvested in respective blocks surveyed (not provided here by MPOB). The actual number of DFB/FFBs was used for the statistical analysis with the non-parametric Mann-Whitney U-test.

Field observation and experiment on the predatory behaviour of *O. smaragdina* on *P. pendula*

The premise that *O. smaragdina* preyed on *P. pendula* was investigated by intensive field observations on a 24-hour basis for a total of 72 hours (3 replicates) in the five occupied blocks. In each row, all occupied trees were observed for 1 hour. However, in occupied oil-palm trees, there was no significant presence of bagworms and many ants, making predation impossible to monitor at the time of the present study. Consequently field experiments were carried out by artificially creating encounters between small nests of *O. smaragdina* (comprising about 50 ants) and *P. pendula*. Observations were first carried out in typical field conditions, then again during artificial field predation experiments for more accuracy and easier monitoring, with fewer ants to follow (*N*=50/per experimental nest) on a single palm frond. The trials were done on a 24-hour basis, beginning at 12:00 h, 17:00 h (10 replicates each = 20) and 19:30 h (10 replicates each = 30). The ants were taken from other host trees, namely *Syzygium aqueum* (see Plate 3). In other words, the weaver ants in these experiments were not known to have been exposed to oil palm as a host or to bagworms as prey. The experimental nest was placed on a pre-selected frond. On the same frond, 15 individual *P. pendula* larvae and 15 pupae were placed simultaneously 30 cm away from the nest. Then, every 5 minutes, the number of pupae or larvae taken was summed until 90 minutes after the release of the prey, with the aid of a Panasonic SDR-S71 video camera with 78x advanced optical zoom and night vision system (Fig. 1). Twenty replicates were made. In this experiment, there was a need to determine the cut-off time when most of the pupae or larvae had been taken. A preference index (P_i) was calculated for the two prey items. $P_i = U_i/A_i$, where U_i is the percentage of items taken for each category and A_i the percentage of available resources (bagworms) for each category. The index ranged from 0 to 2, where < 1 indicates avoidance, 1 = no preference and > 1 is a degree of preference.

Fig. 1. Experimental setting. Recording predation experiments using Panasonic video recorder.

The preference analysis was confined to the period from the moment the experiment started until the cut-off time. The difference in survival rate between pupae and larvae was statistically calculated using the log-rank test, by determining its chi-square value obtained from the predation trial done for the 20 replicates in the field.

To determine the impact of *O. smaragdina* on the weevil *Elaeidobius kamerunicus*, observation was made on the spikelets when both weevil and weaver ant were present. Each spikelet was continuously observed for up to 1 hour during the peak times of ant activity in the day (12:00-15:00 h and 18:00-19:00 h). Three types of behaviour related to attack were monitored and recorded: 1) Attack approach; 2) Attack posture; 3) Physical attack. If any of these behaviours was recorded, then it would be considered that *O. smaragdina* does prey on or disturb the weevil. A total of 25 samples were made. All observations were carried out following only natural occasional interactions between the beetles and the ants. Spikelets exhibiting intense pollinator activity in the flowers were selected for the experiment. Video and photographic recordings were made and analysed further in the laboratory for confirmation (see Plate 3).

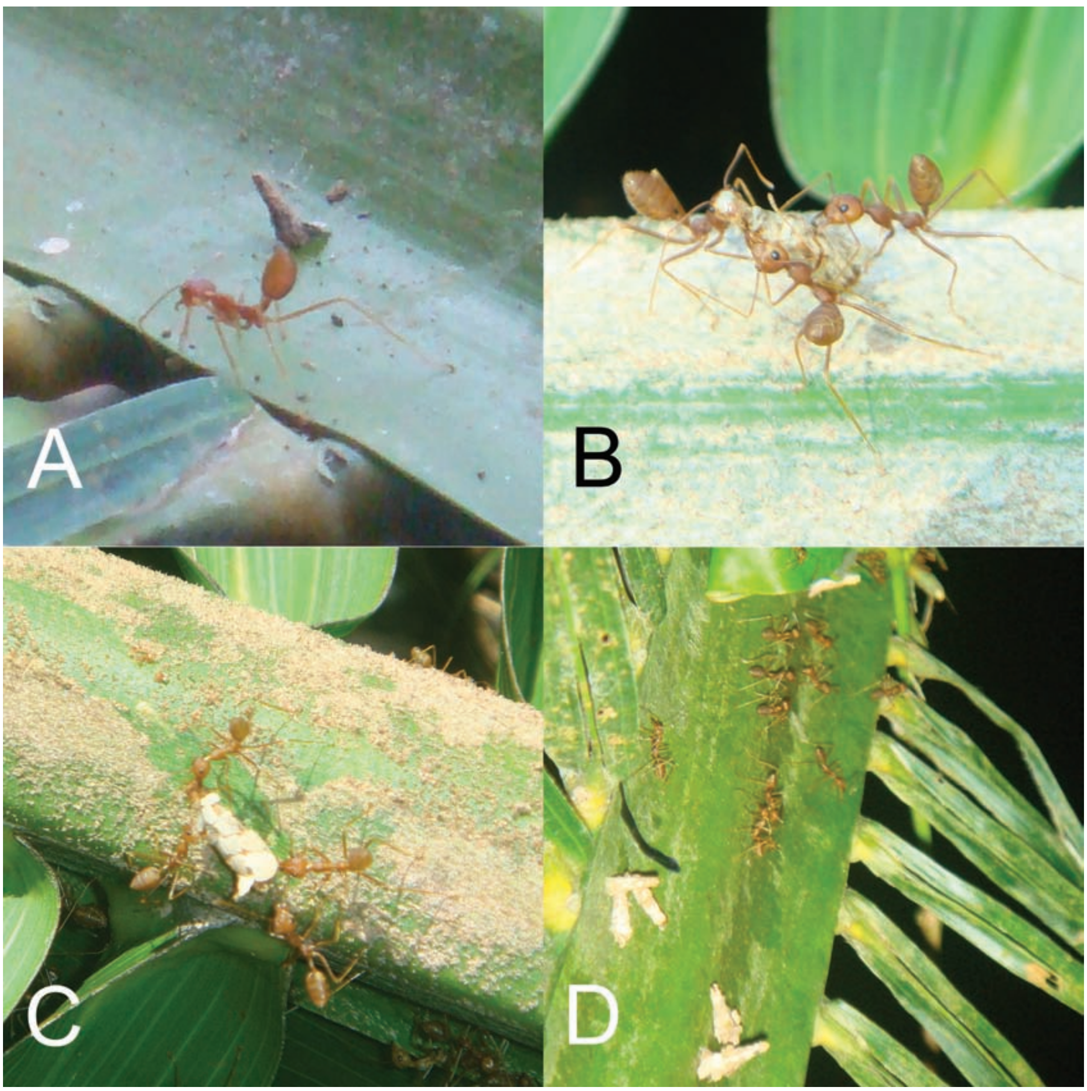

Plate 3. Artificially provoked night encounters between *P. pendula* and *O. smaragdina*. A. Detecting prey from a distance, with aggressive stance (Phase 1). B. Ants show 90-degree gaster elevation and bite while spraying formic acid (Phase 2). C. Neutralising pest pupa before lifting (Phase 3). D. Nocturnal predation with exposed larvae approaching nest. Photos taken by Exélis Moïse Pierre using a Sony T20 digital camera.

RESULTS

Occupancy on sampled trees

No weaver ants were found to occupy the short palm trees (Occupancy 0%, *N*=250). Among the tall palms, 230 trees (92%) were occupied by *O. smaragdina* (Fig. 3) with 20 trees (8%) unoccupied. Of the 230 occupied palm trees, 100 (40%) were observed to contain nests, of various types. These contained an average of 3.98 ±1.74 (mean ± SD, range 1-13) nests per tree. The ants exhibited polydomous nesting behaviour, as reported by other authors (Debout *et al*. 2007), with multiple nests in a single palm tree (Plate 1), and multiple queens were sometimes observed in the main nest, suggesting polygyny (Exélis Moïse Pierre and Azarae Hj Idris pers. obs.); further study is needed to confirm this. Overall, we had 230 occupied and 270 unoccupied oil palm trees.

Degree of *P. pendula* pest density. Fig. 2 shows the number of sampled palm trees for the occupied and unoccupied category with the different degrees of infestation by *P. pendula*. The degree of infestation was significantly different between the occupied and unoccupied palms ($X^2 = 406.30$, d.f. = 4, $P < 0.001$). Among the occupied palms, none were infested to Levels 3 or 4, with 210 palms (84%) not infected at all (Level 0). Only 15 palms were infested to Level 1, and 5 to Level 2. For the short unoccupied palms, only 6 (2.2%) of the 250 sampled showed no evidence of infestation. The majority were infested to Level 2 (31%) or Level 3 (28%). Among tall unoccupied palms, no trees had Level 0 pest density; most had pest densities of Level 2 (30%), 3 (40%) or 4 (25%).

Degree of foliar injury. The degree of foliar injury due to *P. pendula* pest attack was investigated and compared between palm trees occupied and unoccupied by *O. smaragdina* (see Fig. 3). There was a significant difference in the degree of foliar injury between palms occupied by weaver ants and those unoccupied ($X^2 = 439.2$, d.f. = 4, $P < 0.001$). Of the 230 occupied palm trees sampled, 210 (91.3%) showed no sign of foliar injury. The fronds of these were in a healthy state. The remaining 20 palms (8.7%) showed injury to either Level 1 or Level 2. None showed injury to Level 3 or 4. On the other hand, only 5 (1.8%) of the 270 samples of unoccupied palms were healthy (Level 0) whereas 61.1% had injury to Level 2 or 3, and 18% were extremely injured (Level 4). A Spearman's correlation analysis between the degree of *P. pendula* pest density and degree of foliar injury found a high positive correlation for both occupied ($r_s = 0.952$; d.f. = 48; $P < 0.01$) and unoccupied palms ($r_s = 0.848$; d.f. = 48; $P < 0.01$, both one-tailed tests).

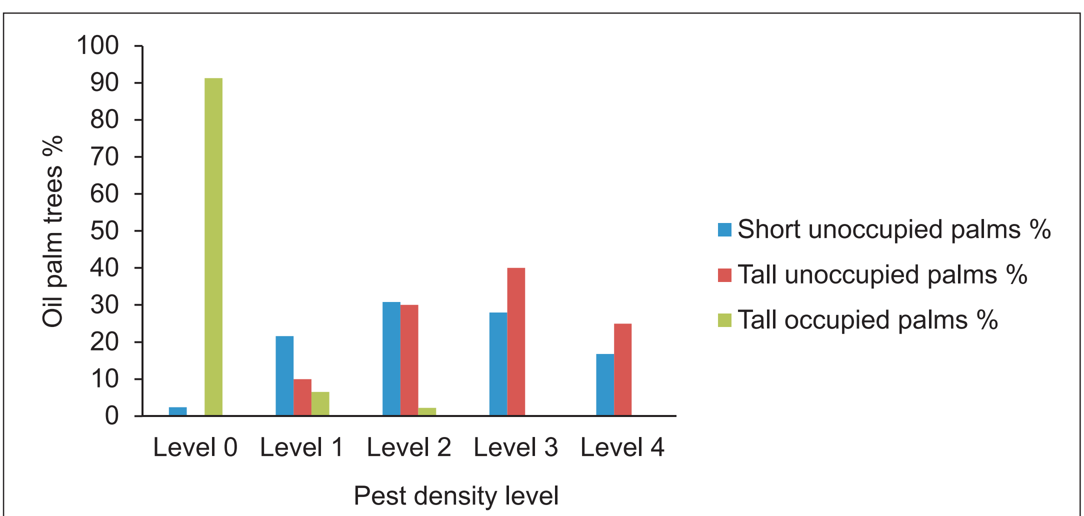

Fig. 2. Degree of pest density of *Pteroma pendula* on palms occupied and unoccupied by *Oecophylla smaragdina*. 'Tall' palms were > 4 m.

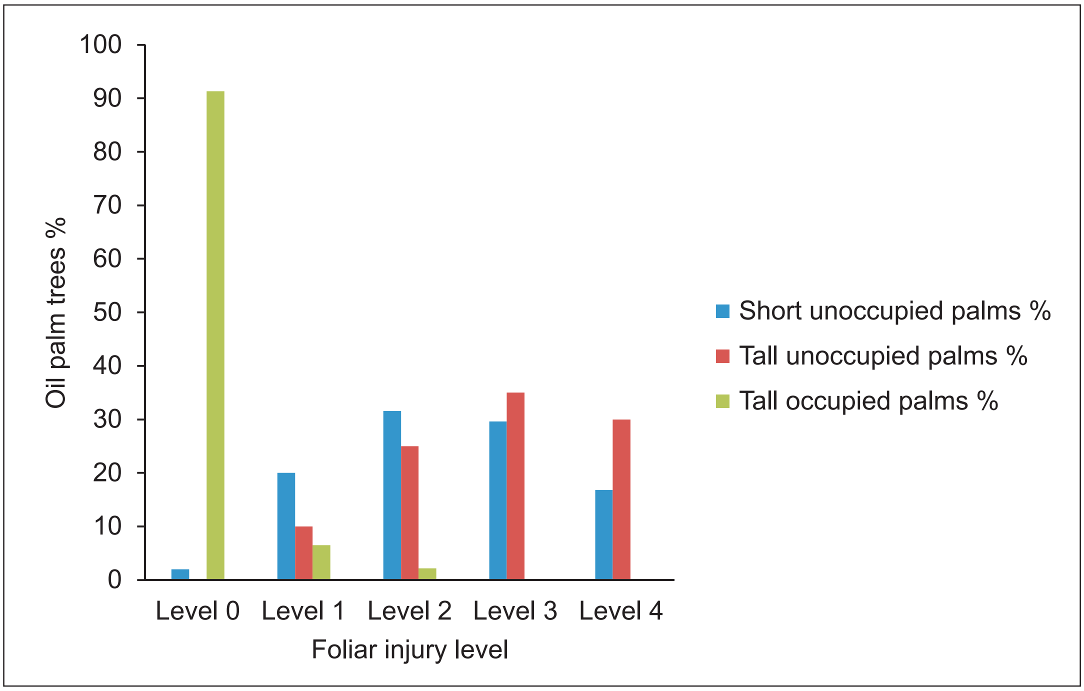

Fig. 3. Foliar injury levels in palms occupied and unoccupied by *Oecophylla smaragdina*.

Number of DFB/FFBs: The combined number of developing fruit bunches (DFBs) and fresh fruit bunches (FFBs) per palm tree is shown in Fig. 4. There was a significant difference between tall-occupied and short-unoccupied palms ($z \geq 4.16$, $P < 0.0005$; Mann Whitney U test for large samples). All tall-occupied palms were either productive (65%) or very productive (35%). Most tall-unoccupied palms were moderately productive (85%), with a low percentage productive (10%) and a few not productive (5%). Among the short-unoccupied trees, 55% were either not productive or moderately productive while 44.8% were either productive or very productive. The results are presented for occupied taller/older trees (N=230), unoccupied taller palms (N=20) and unoccupied shorter/ younger palms (N=250).

Predatory behaviours

A. Sequence of an attack: To ascertain the ant's predatory activity on *P. pendula*, this study also examined the chronological sequence of an attack. The sequence or phases of attack could be simplified into three main stages. Stage 1 was when the ant identified a prey (larva or pupa of *P. pendula*) from a distance and this was characterised by the gaster being raised at a 90° angle. Then the ant moved toward the prey, bit it (Stage 2) and subsequently directed formic acid onto the prey (Stage 3; this is distinctively recognisable, with the elevated gaster arching forwards). The prey is thus neutralised and lifted (Stage 4), to finally be brought to the nest (Stage 5).

B. Preference for prey items: Preliminary field observation showed that *O. smaragdina* would attack the pupae of *P. pendula* first before attacking the larvae (various instars), although both were present in the vicinity. To confirm this, a field experiment was conducted as outlined above.

Fig. 5 shows the cumulative number of prey items taken over time for 20 replicates of experiments. From the graph it can be seen that by 90 minutes 100% (15) of the pupae had been taken. Thus, the cut-off time for the experiment was set at 90 minutes. The results of the experiment were subjected to a statistical test (Mann Whitney U-test) to determine whether

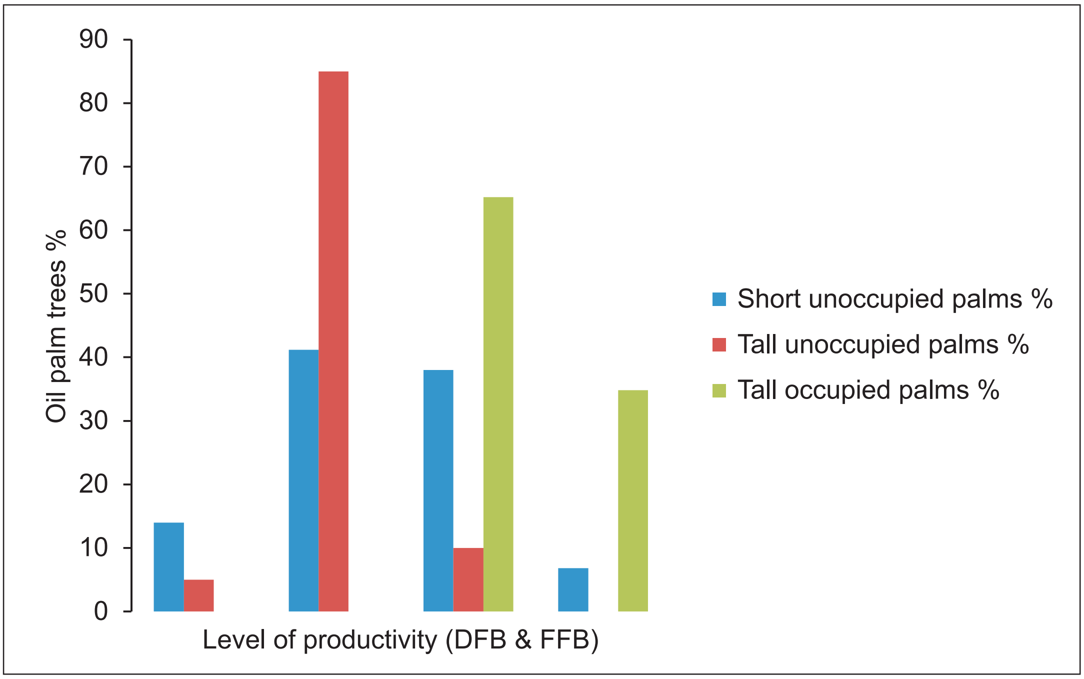

Fig. 4. Number of fruit bunches in tall (> 4m) and short palms, respectively occupied and unoccupied by *O. smaragdina.*

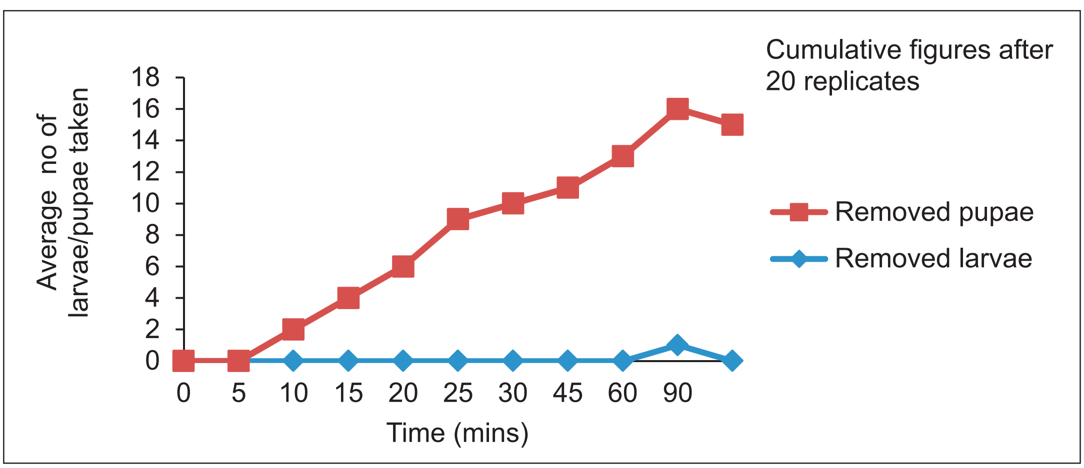

Fig. 5. The average cumulative number of larval and pupal *P. pendula* prey taken by *O. smaragdina* ants in the predation-preference evaluation experiment.

there was a significant difference between the two prey types in the proportion taken within that cut-off time period. It was shown that there was a highly significant difference between the larvae and the pupae in the proportion taken ($U = 0$; $P < 0.01$). This showed that *O. smaragdina* had a high preference for pupae over larvae when the former was in abundance. The ants took an average of 10 minutes to remove two pupae. Once all pupae were taken, ants continued to predate on those remaining and still exposed larvae on the frond surfaces, with the rachis being used as an effective highway to move faster across the multitude of leaflets, spreading over a whole tree when necessary (see Plate 3 and 4).

The removal of moving larvae (Instars I to IV) was time-consuming and demanded greater cooperation among individual ants than that of pupae. On average a total of 27% of larvae were taken over a seven-hour period during the night. Compared with diurnal activity night predation was less active, and more opportunistically dependent on prey larvae approaching the nest, when they were detected by major guard workers (see Plate 3). The sequence of attacks can be summarised as follows: searching for bagworm prey, detection (by contact during night-time, visually during daytime), recruitment, attack by biting, holding prey, spraying of formic acid at prey, lifting and finally transportation to the nest for storage.

A pairwise comparison of the number of prey taken by ants with 90 minutes was done between larvae and pupae, by a survival analysis conducted on the experimental data using a log-rank test (StatsDirect). The survival rate was lower for pupae, though the difference was not quite statistically significant (for equivalence death rates $X^2 = 3.42$, d.f. = 1; $P = 0.06$). The preference index P_i calculated at 90 minutes after releasing the prey was 1.73 and 0.13 for the pupae and larvae respectively. This shows that *O. smaragdina* had a high preference for pupae compared to the larvae when the former was in abundance.

Evaluation of the impact of *O. smaragdina* on *Elaeidobius kamerunicus*

During the 24-hour observations on 25 palms where there was concurrent presence of *O. smaragdina* and *E. kamerunicus* but no *P. pendula*, none of the three attacking behaviours (as outlined under methods) were seen. After observations of the weevil pollinator *E. kamerunicus* in the presence of *O. smaragdina* around male and female flowers, there was never evidence of the weaver ant going on the spikelets, let alone attacking the weevil. *Oecophylla smaragdina* did not exhibit any aggressive behaviour toward the weevil at any moment during observations of the weaver ants' predation activity on *P. pendula*, made on 25 palms from 07:00 h to 20:00 h.

DISCUSSION

This study suffers from confounding variables: most of the trees occupied by *O. smaragdina* were also taller and older than most of the unoccupied trees. Further studies are needed to conclusively separate the effect of ant occupancy and that of the palm-tree size. But though the sample of tall unoccupied trees was small, it suggests weaver-ant presence, not tree size, was the main determinant of pest infestation, damage and productivity. Other field surveys carried out on oil palm plantations in Peninsular and East Malaysia have shown positive occupancy of ants in short younger palms (only in palms with fruit bunches) (Exélis Moïse Pierre, unpublished data). In the present study, it was observed from censusing that tall palms (N=50) that were unoccupied when surveyed in April 2011, which had low or moderate productivity compared with tall occupied trees, recovered from infestation within few months of being occupied in August 2011 (Exélis Moïse Pierre, unpublished data). DFB and yield in FFB increased satisfactorily. Generally most of the palms within occupied blocks looked healthier than those that were unoccupied. Tall palms unoccupied by *O. smaragdina* serve, within an occupied plantation block, as territorial boundaries between different colonies.

All palms bordering respective plantations blocks exhibited the highest foliar injury (Exélis Moïse Pierre, pers. obs.). The pest density of the defoliator *P. pendula* was more pronounced on roadside trees exposed to dust. One report demonstrated that parasitoid natural enemies of the pest develop higher mortality rates from roadside dust exposure. The interior of the plantation blocks provided better shelter and nutritious resources due to the denser vegetation (Ho 2002, unpublished data from a PhD study). In that location, palm trees were therefore more vulnerable to foliar damage from pest defoliators.

The study of the use of *O. smaragdina* for biological control is not new; however, this is the first published report on its predatory activities in oil palm plantations on the defoliator bagworms *P. pendula*. The results from this study are an additional testimony of the effectiveness of *O. smaragdina* as a potent agent of biological control, as already proven in Vietnam, China and Northern Australia for various fruit plantations such as *Citrus reticulata* Blanco, *C. sinensis* (L.) Osbeck, *C. aurantiifolia* (Christm.) Swingle and *C. maxima* (Van Mele & Cuc 2000).

Various possible benefits could be derived from these weaver ants in oil palm. Currently in Malaysia, the bagworm problem is tackled using several methods. A synthetic aggregating pheromone, ethyl 4-methyloclanoate, is used to monitor the moth's population and it is mass-trapped with sticky vane traps in West Malaysia, Perak (Norman *et al*. 2009; Norman & Othman 2006). Leguminous cover crops are also planted as a means of control by attracting natural enemies of the bagworms. Recently (May-June 2011), a massive programme for eradication of *P. pendula* was carried out successfully in Perak using heavy aerial spraying of the biological-control agent *Bacillus thuringiensis* (MPOB unpublished data). The establishment of beneficial plants like *Euphorbia heterophylla* L. and *Senna cobanensis* (Britton & Rose) H.S.Irwin & Ba in oil palm plantations led to a significant removal of bagworms, concurrent with an increase in activities of parasitoids such as *Dolichogenidae metesae* (Nixon) in the field (Ho *et al*. 2003). However some of these approaches have ecological and financial drawbacks. The usage of broad-spectrum long-range contact pesticides has brought serious environmental disruption and degradation, causing outbreaks of bagworms. Field ecological studies have demonstrated that fields sprayed with persistent insecticides are ultimately susceptible to outbreaks, and estates were discouraged from spraying (Wood 2002). Substitution to a more integrated pest management programme was considered environmentally friendlier and cheaper compared with conventional approach of exclusively-chemical control (Wood 2002). Therefore *O. smaragdina* could complement as well as supplement existing methods, and is much cheaper and environmentally safer. Apart from the bagworm, *O. smaragdina* is known to prey on several other pest species (Way & Khoo 1992; Peng & Christian 2006). The majority of these pests are also found in oil palm plantations. Thus potential benefits are there to be tapped.

The brood of weaver ant larvae can also be harvested and sold (or eaten) and in this way add a second value to this method of pest control (Offenberg & Wiwatwittaya 2010), as is the case in neighbouring countries, where weaver ant brood are sold at high prices for consumption by humans (Thailand and Philippines) or by song birds and as fish bait (Indonesia) (Van Mele 2009).

One drawback of *O. smaragdina* is that they are highly ferocious, attacking anything that crosses their path. This is a good trait in the light of crop protection but causes nuisance and pain to human workers during pruning and harvesting. It is for this reason that some estate managers resort to burning the ants' nests and exterminating them. Further study is needed to find ways of overcoming or at least reducing the problem. For example, plantation workers might be equipped with anti-ant clothing or use natural insect repellent on their bodies to discourage ants from attacking. Methods to reduce the nuisance of *Oecophylla* bites were provided and compiled from a comprehensive survey done in African and Asian countries, with effective results during the harvesting process (Van Mele 2008, 2009).

The present study found weaver ants only in taller palm trees, aged about seven years or above. The reason was not investigated in this study, but inferring from earlier studies, microclimatic conditions such as temperature and relative humidity may play a role (Wielgoss *et al*. 2010). The distribution of nests found was similar to other studies (Hölldobler & Wilson 1990; Blüthgen & Fiedler 2002). They are polydomous in nature (Hölldobler 1983; Dejean *et al*. 2007) and a single tree could harbour as many as 13 nests. Since not all palm trees in a particular block were occupied by the ants, artificial bridges could be established to facilitate their quick expansion to other trees, as has long been practised in China (Huang & Yang 1987), if this species is to be used as an agent in oil palm estates (Peng *et al*. 2004).

The level of infestation by *P. pendula*, the degree of foliar injury and the productivity differed significantly between occupied and unoccupied palm trees. Since there was no obvious confounding variable (except for the age), infestation of *P. pendula* was reduced because the ants preyed on them. When infestation is low, foliar injury is reduced as well. It follows that when the leaves are not damaged, photosynthetic activities are not impaired and this appears to be why the tree can produce more fruit. At Level 3 and 4 of foliar injury, almost the whole frond is rendered useless for productivity, causing substantial economic loss to the planters (Basri 1993; Basri & Kevan 1996; Basri *et al*. 1988, 2003).

Our results on higher production on ant-occupied trees also support that ants have no negative effect on pollination. Similar results were obtained for other crops like cashew nuts in Australia (Peng *et al*. 2004). *Oecophylla smaragdina* did not prey or disturb the weevil pollinators during our study, in contrast with what has been reported in a rambutan *Nephelium lappaceum* L. orchard in Sumatra (Tsuji *et al*. 2004). In the present study, during experiments carried out on bagworms, it was observed that fast-moving prey (e.g. larvae of all instars) posed difficulties (Exélis Moïse Pierre and Azarae Hj Idris, personal observation) and challenged the ants in two respects: their minuscule size and their intense rapid movement. These may explain the lack of aggressive behaviour towards them by *O. smaragdina*.

CONCLUSION

These findings suggest great potential for use of *O. smaragdina* as a biological agent on oil palm estates: at least as far as the bagworm problem is concerned. The practice could save the industry huge costs and reduce pressure on the environment as well, by incentivising reduction in harmful chemicals and reducing needless loss of forest to oil-palm expansion. It is recommended that further intensive and comprehensive study be conducted, for the good of the industry and the environment.

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