AN ECOLOGICAL STUDY OF *PTEROMA PENDULA* (LEPIDOPTERA: PSYCHIDAE) IN OIL PALM PLANTATIONS WITH EMPHASIS ON THE PREDATORY ACTIVITIES OF *OECOPHYLLA SMARAGDINA* (HYMENOPTERA: FORMICIDAE) ON THE BAGWORM

EXELIS MOISE PIERRE

FACULTY OF SCIENCE

UNIVERSITY OF MALAYA

KUALA LUMPUR

2013

An Ecological Study of *Pteroma pendula* (Lepidoptera: Psychidae) in Oil Palm Plantations with emphasis on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on the bagworm

EXELIS MOISE PIERRE

SGR 100001

DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

INSTITUTE OF BIOLOGICAL SCIENCE

FACULTY OF SCIENCE

UNIVERSITY OF MALAYA

KUALA LUMPUR

2013

To my Family and Teachers

UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Exélis Moïse Pierre (Passport No: 03ID40407)

Registration Matric No: SGR 100001

Name of Degree: Master of Science Biology

Title of Project Paper/Research Report/Dissertation/Thesis:

An ecological study of *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations with emphasis on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on the bagworm

Field of Study: Ecology and Agricultural Biotechnology (Population Ecology of Agricultural Insect Pests)

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work:

(2) This work is original:

(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purpose and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work:

(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work:

(5) I hereby declare that all and every rights in the copyright to this Work are owned by myself, henceforth shall be owner of the copyrights of this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of myself having been first had and obtained.

(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by University Malaya.

Candidate's Signature Date

Subscribed and solemnly declared before,

Witness's Signature Date

Name:
Designation:

ABSTRACT

A study entitled "An ecological study of *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations with emphasis on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on the bagworm was conducted at the MPOB Research Plantation at Teluk Intan, Perak, Malaysia from 11.11.2010 to 31.01.2013. The main objectives of the study was to assess the infestation of *P. pendula* and investigate a correlation between pest density fluctuations with abiotic factors in the study area and to elucidate *O. smaragdina* occupancy pattern and its predatory behaviours towards *P. pendula* as well as assessing the productivity of palm trees occupied and not occupied by the weaver ants.

Results of the survey showed that there was an infestation of the bagworm with peak outbreak from October to November 2010 which coincides with the ending of the dry season (Pearson correlation coefficient $r = 0.474$, $p < 0.05$).

O. smaragdina shows a high preference for tall trees where 92% of sampled palms were occupied with a Preference Index (P_i) of 1.84 but avoid short palms where none were occupied ($P_i = 0$). Forty percent of the occupied palms harbours nests of various types ranging from 1-13 nest per palm with an average of 3.98 ±1.74 and uniquely the number was always odd. The weaver ants exhibited a bimodal foraging circadian cycle with two peaks: midday (12:00 h-15:00 h) and around dusk (17:30 h-18:30 h).

O. smaragdina showed a moderate positive correlation of foraging activity with increase in air temperature ($r=0.874$, $p < 0.001$). However it is negatively correlated to relative humidity ($r = -0.921$, $p < 0.001$). The attack tactic deployed by *O. smaragdina* towards the bagworm larva can be simplified into four main stages: Foraging and detection of prey; physical attack & securing of prey; piercing and releasing of formic acid and finally the lifting of paralyzed prey followed by transporting it to the nest. *O. smaragdina* shows no aggressive behavior towards *Elaeidobius kamerunicus*, the principal pollinators for oil palm.

O. smaragdina had a high preference for pupae ($P_i = 1.73$) over larvae ($P_i = 0.13$) when the former was in abundance within the cut-off period of 90 minutes ($U = 0$; $P < 0.01$). A log-rank test demonstrated a statistically significant difference in survival ability between pupae and larvae (for equivalence death rates $X^2 = 3.42$, d.f =1; $P = 0.06$).

The degree of infestation by the bagworm was significantly different between the occupied and unoccupied palms ($X^2 = 406.30$, d.f = 4, $p < 0.001$). Among the tall occupied palms, none were infested to Level 3 and 4 with 84% not infected at all (Level "0"). But 40% of the tall unoccupied palms were infested to Level 3 and 25% to Level 4. For the short unoccupied palms 31% were infested to Level 2 and 28% to Level 3 with only 2.2% showed no evidence of infestation. The degree of foliar injury is significantly less severe for the occupied palms ($X^2= 439.2$), d.f = 4, $p < 0.001$). There is positive correlation between the level of infestation and the degree of foliar injury ($r_s= 0.952$; d.f = 48; $P < 0.01$) in occupied palms and unoccupied palms ($r_s= 0.848$; d.f = 48; $P < 0.01$).

The productivity of DFB/FFB is significantly higher for the occupied palms ($z \geq 4.16$, $p < 0.0003$) compare to shorter unoccupied palms. Similarly, the difference between tall occupied and tall unoccupied palms was highly significant at $P < 0.002$ ($U=1$). Based on

the finding of this study, *O. smaragdina* holds a promising potential as biological control agent for the bagworm pests particularly against the increasing concern for sustainable oil palm industries.

ABSTRAK

Satu kajian bertajuk "An ecological study of *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations with emphasis on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on the bagworm" telah dijalankan di Ladang Penyelidikan Lembaga Minyak Sawit Malaysia (MPOB) Teluk Intan, Perak Malaysia dari 11.11.2010 hingga 21.1.2013. Objektif utama kajian adalah untuk menilai serangan serta menyiasat korelasi antara variasi tahap serangan ulat bungkus *Pteroma pendula* dengan faktor abiotik di kawasan kajian dan untuk mengkaji corak penghunian *Oecophylla smaragdina* dengan tabiat pemangsaannya terhadap *P. pendula* serta menilai produktiviti pokok kelapa sawit yang dihuni dan yang tidak dihuni oleh kerengga tersebut.

Hasil tinjauan menunjukkan terdapatnya serangan ulat bungkus dengan puncak letusan dari Oktober 2010 hingga November 2010 yang bertepatan dengan musim kering (Koefisien Korelasi Pearson $r = 0.474$, $p < 0.05$).

O. smaragdina menunjukkan kecenderungan yang tinggi kepada pokok tinggi di mana 92% dari palma yang disampel didapati dihuni dengan Index Keutamaan(P_i) 1.84 tetapi menolak palma rendah di mana tidak satu pun pokok dihuni ($P_i = 0$). Empat puluh peratus dari palma yang dihuni mempunyai sarang dari pelbagai jenis yang berjulat dari 1-13 dengan purata 3.98 ±1.74 dan uniknya bilangan sarang senantiasa bernombor ganjil. Kerangga mempamerkan kitaran circadian bimodal pemburuan dengan dua puncak: tengah hari (12:00 h-15:00 h) dan ketika senja (17:30 h-18:30 h).

O. smaragdina menunjukkan korelasi positif sederhana aktiviti pemburuan dengan kenaikan suhu udara ($r=0.874$, $p < 0.001$). Walau bagaimanapun ia berkolerasi secara negatif dengan kelembabpan bandingan ($r = - 0.921$, $p < 0.001$). Taktik serangan yang digunakan oleh *O. smaragdina* terhadap larva ulat bungkus boleh dipermudahkan kepada empat peringkat utama: Pemburuan dan pengesanan mangsa; serangan fizikal dan penawanan mangsa; penembusan kutikel dengan mandibel dan pembebasan asid formik dan akhirnya mengangkat mangsa yang lumpuh dan mengangkutnya ke sarang. *O. smaragdina* tidak menunjukkan kelakuan agresif terhadap *Elaeidobius kamerunicus*, ia itu pendebunga utama untuk sawit.

O. smaragdina mempunyai kecenderungan yang tinggi terhadap pupa ($P_i = 1.73$) daripada larva ($P_i = 0.13$) dalam keadaan larva masih banyak dalam had 90 minit ($U = 0$; $P < 0.01$). Ujian log-pangkat menunjukkan perbezaan yang signifikan secara statistik bagi keupayaan survival di antara pupa dan larva (untuk kadar kematian bersamaan $X^2 = 3.42$, d.f =1; $P = 0.06$).

Tahap serangan ulat bungkus adalah berbeza secara signifikan di antara palma yang dihuni dan yang tidak dihuni ($X^2 = 406.30$, d.f = 4, $p < 0.001$). Di kalangan palma tinggi yang dihuni, tiada yang di serang ke Tahap 3 dan 4 dengan 84% tidak diserang sama sekali (Tahap "0"). Walau bagaimanapun 40% dari palma tinggi yang tidak dihuni diserang ke Tahap 3 dan 25% ke Tahap 4. Bagi palma rendah yang tidak dihuni, 31% di serang ke Tahap 2 dan 28% ke Tahap 3 mana kala 2.2% tidak menunjukkan sebarang kesan serangan. Tahap kecederaan dedaun adalah kurang teruk secara signifikan bagi palma yang dihuni ($X^2= 439.2$), d.f = 4, $p < 0.001$). Terdapat korelasi positif diantara

tahap serangan dengan tahap kecederaan dedaun (r_s= 0.952; d.f = 48; $P < 0.01$) di antara palma yang dihuni dengan palma yang tidak dihuni (r_s= 0.848; d.f = 48; $P < 0.01$).

Produktiviti DFB/FFB (tandan buah baru/tandan buah segar) adalah tinggi secara signifikan bagi palma yang dihuni ($z \geq 4.16$, $p < 0.0003$) antara pokok tinggi dan pokok yang rendah. Palma tinggi yang dihuni adalah lebih produktif secara signifikan daripada palma tinggi yang tidak dihuni ($U= 1$; $P < 0.002$).
Berdasarkan kajian ini, *O. smaragdina* mempunyai potensi besar sebagai agen kawalan biologi terhadap perosak ulat bungkus lebih-lebih lagi disaat-saat ke prihatinan kepada industri sawit yang mampan meningkat.

ACKNOWLEDGEMENTS

I am grateful to my supervisor **Associate Prof. Datuk Dr Azarae Hj Idris** for his support, guidance and advices since long years ago and particularly during my Master Degree present study at University of Malaya, Kuala Lumpur. **Datuk Dr Azarae** taught me important aspect on applied ecology and judicious caution on the statistical analysis related to the design of the nature of sampling methods used along their final applications for sound and credible scientifically acceptable results. I have also the pleasure to give my special thanks to both ex and present General Director of the Malaysian Palm Oil Board (MPOB), in the person of **Datuk Dr Mohd Basri Wahid** and **Datuk Dr Choo Yuen May**, respectivelyfor granting me permission and trust for conducting a major part of my ecological study in the institution laboratories and field oil palm station in Teluk Intan, Perak. Their continuous moral support and directives coupled with sound advices were always of tremendous benefit for the betterment and success of such challenging project. I thank **Dr Norman Kamaruddin** and **Dr Ramle Muslim** for providing me access to their respective laboratories in the Biology Department of MPOB. Both have been overall key instrumental experts and consultant during both laboratory and field research study, investing a lot of their times (Dr Norman in particular) and sharing confidential technologies in their respective field of entomology, ecology and mycology/biotechnology.

I also extend gratitude to **Mr. Othman Arshad** for parasitoids identification along ant's taxonomy and field samplings, **Mr. Tunku Akhirudin Tunku Aris** who provided continuous attention and knowledge with valuable experience sharing (field samplings), **Puan Hajijah Shamsuddin**, **Noor Hasan Mohd Yob** (specially for field samplings), **Mat Tahir Bong Ruziz** for several interesting technical discussions and applications both in laboratory and field. Special thanks to **Ngadiran Bin Dowree**, **Mohd Farizwan Bin Mohd Ismail** and **Muhammad Rashidi Bin Abdul Rahim** from the Institute of Biological Sciences University Malaya for being my field support team research.

Finally, I am indebted to my wife **Puan Nurmastura Binti Abdul Rashid** from the Ministry of Education Malaysia who helped on computer applications software's, for her love and support with my beloved daughter **Fatimah Zahra Moïse Pierre Exélis** throughout all this period always. My special thought and thanks is extended also to my respectable and honorable mother **Madame Exélis Nelly Raymonde Marie** descendant of the "Lords of Amour D'Abadie of L'Urbes France" whom prayers have given me strength and inspiration during my life time. My father **Mr. Exélis Emile François Angelo** also always took a personal responsibility for my education with financial and moral support. And to the Most Merciful and Beneficent Only One God (Allah) whom all the praises belong to Him Alone, I'm grateful for the breath given to me by Him always.

Research in this thesis was funded by the University of Malaya with scholarship provided in the form of a special scheme service for staffs and grants project No. PS320-2010B, PV078/2011B and RG-187/12 SUS (UMRG).

TABLE OF CONTENTS

	Page
Abstract	i - ii
Abstrak	iii - iv
Acknowledgements	v - vi
Table of contents	vii - x
List of figures	xi - xii
List of plates	xiii - xiv
List of tables	xv
List of abbreviations	xvi - xvii

CHAPTER 1: GENERAL INTRODUCTION

1.0	General Introduction	1
1.1	The Oil Palm Industry in Malaysia	1
1.2	Agricultural Pests and Biological Control Management	5
1.3	Oil Palm Pest, Disease and the Bagworm Problem in Malaysia	7
1.4	*Oecophylla smaragdina* as a Potential Biological Control Agent in Oil Palms	9
1.5	Objectives of the Study	11

CHAPTER 2: SURVEY AND ASSESSMENT OF *P. pendula* INFESTATION IN THE STUDY AREA

2.0 Introduction 12

2.1 Objectives 13

2.2 Methodology 13

2.2.1 Study Area 13

2.2.2 The Systematic Census on *P. pendula* Infestation 17

2.2.3 Comparative Study on the Presence of all Type of Defoliators 22

2.2.4 Recording of Meteorological Parameters 23

2.3 Results 23

2.3.1 Comparative Presence of Lepidopterans Defoliators 23

2.3.2 Monthly fluctuation of infestation density of *P. pendula* and Correlation between Rainfall and Relative Humidity with Infestation Density 28

2.4 Discussion 38

2.4.1 Comparative Presence of Lepidopteran Defoliators 38

2.4.2 Correlation between pest density fluctuations with Rainfall and Relative Humidity 39

2.5 Conclusion 42

CHAPTER 3

3.0 STUDIES ON THE PREDATORY ACTIVITIES OF *Oecophylla smaragdina* ON *Pteroma pendula* 44

3.1 Introduction 44

3.1.1. The Asian weaver ants 44

3.1.2 Taxanomical note 46

3.1.3. Biological control 47

3.2 Objectives 54

3.3 Methodology 55

3.3.1 Occupancy patterns of *O. smaragdina* on palm trees 55

3.3.2 Predatory Behaviour of *O. smaragdina* towards *P. pendula.* 59

3.3.2.1 Active Foraging Bouts 59

3.3.2.2 Attacking Tactic 60

3.3.2.3 Prey Preference Experiment 62

3.3.3 Assessment of Infestation by *P. pendula* on Occupied and Unoccupied Palms with *O. smaragdina* 65

3.3.4 Assessment of Foliar Injury by *P. pendula* on Occupied and Unoccupied Palms with *O. smaragdina* 66

3.3.5 Assessment of Productivity of palm on Occupied and Unoccupied by *O. smaragdina* 67

3.3.6 Verification on interference of *O. smaragdina* activities on pollinator Weevil *Elaeidobius kamerunicus* 69

3.4 Results

3.4.1 Occupancy patterns of *O. smargdina* on sampled palms trees 69

3.4.2 Observation on the Predatory Behaviors of *O. smaragdina* on *P. pendula* 71

3.4.2.1 Active Foraging Bouts (Peaks) 72

3.4.2.2 Attacking Tactic – Analysis of Sequential Acts 75

3.4.2.3 Prey Item Preference 81

3.4.3 Assessment of the degree of Infestation by *P. Pendula* on Occupied and Unoccupied Palms with *O. smaragdina* 83

3.4.4 Assessment of the degree of Foliar Injury caused by *P. pendula* on 84

Occupied and Unoccupied Palms with *O. smaragina*

3.4.5 Assessment of the Productivity of palm Occupied and 86

Unoccupied with *O. smaragdina*

3.4.6 Evaluation on Impact of *O. smaragdina* activities on the pollinator weevil

Elaeidobius Kamerunicus 88

3.5 Discussion 90

3.5.1 Occupancy pattern of *O. smaragdina* on palm trees 90

3.5.2 Observation on the Predatory Behaviors of *O. smaragdina* on *P. pendula* 91

3.5.2.1 Active foraging bouts 91

3.5.2.2 Predation strategy of *O. smaragdina* on *P. pendula* 92

3.5.3 Assessment of the degree of infestation and foliar injury caused by *P. pendula*, with

the productivity of palms occupied and unoccupied with *O. Smaragdina* 93

3.5.4 Evaluation on Impact of O. smaragdina activities on the pollinator weevil 93

Elaieidobius kamerunicus

3.6 Conclusion 94

CHAPTER 4: GENERAL DISCUSSION AND CONCLUSION

4.1 General Discussion 96

4.2 General Conclusion 105

REFERENCES 107

APPENDICES 119

LIST OF FIGURES

		Page
Figure 1.1a.	Natural Forest and Oil Palm land Coverage in Malaysia. Source: Forestry Department Malaysia, MPOB and Department of Agriculture	3
Figure 1.1b.	Malaysian palm oil production and export from 1964-2006. Source: http://news.mongabay.com/2007/0515-palm_oil.html	3
Figure 2.2.1a.	Map of Peninsular Malaysia showing the Location of the Study Area at Teluk Intan, Perak	14
Figure 2.2.1b.	Ground Plan of MPOB Oil Palm plantation in Teluk Intan. (Source: MPOB station Teluk Intan, Perak).	16
Figure 2.2.2a.	Diagrammatic representation of how the census on *P. pendula* infestation was carried out in the study area.	18
Figure 2.2.2b.	Layout of sampling plots.	19
Figure 2.2.2c.	Phyllotaxy of Oil Palms (Hartley, 1977).	20
Figure 2.3.1.	Frequency percentages of 5 bagworm species sampled in the study area. As depicted by the pie-chart, *P. pendula* is most dominant species.	27
Figure 2.3.2a.	Mean monthly infestation density of *P. pendula* in Block 1A, 2A, 3A, 1B, 2B and 3B in the study area.	29
Figure 2.3.2b.	Mean monthly infestation density of *P. pendula* for combined data from Block 1A, 2A, 3A, B, 2B and 3B.	29
Figure 2.3.2c.	Correlation analysis between mean monthly infestations (live larvae/frond) for *P. pendula* against mean monthly rainfall for the combined data of 6 Blocks	31
Figure 2.3.2d.	Correlation analysis between mean monthly infestations (live larvae/frond) for *P. pendula* against mean monthly relative humidity for the combined data of 6 Blocks.	32
Figure 2.3.2e.	Correlation analysis between mean monthly dead larvae density for *P. pendula* against mean monthly rainfall for data of 6 Blocks.	33
Figure 2.3.2f.	Correlation analysis between mean monthly combined data (dead larvae/frond) of 6 blocks against rainfall.	34
Figure 2.3.2g.	Correlation analysis between mean monthly combined data (dead larvae/frond) of 6 blocks against relative humidity.	34

Figure 2.3.2h.	Regression scatter plot ofaverage number of live larvae/frond against rainfall.	
Figure 2.3.2i.	Regression scatter plot of average number of dead larvae/frond against relative humidity.	
Figure 2.3.2j.	Regression scatter plot of average number of live larvae/frond against relative humidity.	
Figure 2.3.2k.	Regression scatter plot of average number of dead larvae/frond against relative humidity.	
Figure 3.1.1.	Distribution of the two extant species of *Oecophylla*, and fossil sites (numbered 1-7) (Lokkers, 1986, Dlussky et. al. (2008). Extracted from Crozier et al., 2010.	46
Figure 3.3.2.2.	Flow chart of *O. smaragdina* predatory behaviours individually and collectively on various instars larvae and pupae demonstrating major stages of the pest elimination.	61
Figure 3.4.1.	Frequency percentage of occupancy of *O. smaragdina* on sampled short and tall palm trees.	70
Figure 3.4.2.1a.	Two medians of activity peaks in 24 hours circadian rhythms on fronds related to the two Daily temperature peaks lowest level at similar time in oil palm Teluk Intan	73
Figure 3.4.2.1b.	Sigma plot 12 correlation between average foraging ant and relative humidity (%) against time of the day (h)	74
Figure 3.4.2.3.	The average cumulative number of larval and pupal *P. pendula* prey taken by *O. smaragdina* in the prey preference experiment.	82
Figure 3.4.3.	Degree of Infestation of *Pteroma pendula* on occupied and unoccupied palms.	84
Figure 3.4.4.	Degree of Foliar Injury in Occupied and Unoccupied Palms.	86
Figure 3.4.5.	Productivity of Occupied and Unoccupied Palms	88

LIST OF PLATES

		Page
Plate 1.2.	Photograph showing young oil palm plantation in Teluk Intan, Perak.	6
Plate 2.2.1.	Photograph of young oil palm plantation (3-4 years old) in the study area. The terrain is generally flat with underlying deep peat soil.	15
Plate 2.2.2.	Adjustable harvesting pole Model 4.5 F (45 pin) used for the destructive sampling of bagworms in the study area. Photo taken with digital camera Sony DSC-WX3.	21
Plate 2.3.1 (A-I)	Photographs of nettle caterpillars and bagworms found in study area at MPOB oil palm plantations,Teluk Intan, Perak.	26
Plate 2.3.1j.	Abaxial view of a Cryptic apparatus of *Mahasena corbetti* on oil palm frond. Photographer/Camera: Photo taken by Exélis Moïse Pierre using a Sony T20 digital camera. February 2011.	28
Plate 3.1.3a.	Captured laying eggs wingless maternal queen massively surrounded and protected by major workers.	53
Plate 3.1.3b.	Multiple winged virgin queens (A) with a single one (B) exhibiting green colour type from brood nest type.	54
Plate 3.3.1a (A-B).	Queen right nest A heavily guarded by major workers and brood nest B showing much modest presence of guards.	57
Plate 3.3.1b.	Pavilions or barrack type of nest, smaller in size at lower palm frond.	58
Plate 3.3.2.3a.	Experimental setting. Recording predation experiment using Panasonic video recorder on a pre-selected palm frond.	62
Plate 3.3.2.3b.	Field experiment on the predation activity of *O. smaragdina* on the larvae and pupae of *P. pendula.* The ant's barrack nest (red arrows) is taken from a difference host tree, *Syzygium aqueum*	64
Plate 3.3.3.	*Pteroma pendula* infestation and foliar injury level 1 to 4 in oil palm fronds at Teluk Intan MPOB station.	65
Plate 3.3.5.	Harvested Fresh fruit bunches (A) and young fruit bunches (B) still on oil palm tree	68

Plate 3.4.2.2a.	Stage 1- Foraging and detection of preys showing an Aggressive stance of *O. smaragdina* with a typical 90˚ abdomen vertical angle extension (green arrows).	76
Plate 3.4.2.2b.	Close-up view of Stage 2. The red arrow shows an individual weaver ant biting the base of the head of the bagworm larvae (Instar III). Another individual is biting the posterior part of the larva body.	77
Plate 3.4.2.2c.	Stage 2-Detection of *P.pe*ndula pupae resulting in a massive cooperation among *O. smaragdina* ants by antenna communication and body movements to secure prey (red arrows).	78
Plate 3.4.2.2d.	Stage 3-Piercing and releasing formic acid into prey causing paralysis with a characteristic downward gaster position functioning as a "water pipe" (red arrow).	79
Plate 3.4.2.2e.	Stage 4a-Lifting of the prey once secured on the oil palm frond rachis.	80
Plate 3.4.2.2f.	Stage 4b-Transporting back the prey to the nest for storage.	81
Plate 3.4.4	Healthy palms of *Elaeis guineensis* Jacq well benefiting from the presence of *Oecophylla smaragdina*. Photographer/Camera: Photo taken by Exélis Moïse Pierre using a Sony T20 digital camera. April 2011.	85
Plate 3.4.6 (A-C).	*Elaeidobius kamerunicus* weevil (A, blue arrows) observed on taller palms without any *O. smaragdina* ants activity around the male (B, blue arrows) or female flowers (C).	86

LIST OF TABLES

		Page
Table 1.1a.	Estimation in hectarage of Oil Palm in Malaysia from 1871 to 2000 (Source: Porla, palm oil statistics)	2
Table 1.1b.	Monthly export of palm oil & oil palm products from 2008 to 2012 (April)	5
Table 2.3.1a.	Species of defoliators present in the study area during the survey period (Nov 10- Aug 11)	24
Table 2.3.1b.	Mean monthly density of lepidopteran defoliators during the study period.	27
Table 3.1.3a.	Reports of *Oecophylla* spp. as beneficial predators.	50
Table 3.1.3b.	Summary of insect pest species controlled by green ants. Data are extracted from Appendix 3.1.3.	52
Table 3.4.1.	Distribution of Nests per Tree in Occupied Palms	71

LIST OF ABBREVIATIONS

BSLRC	Broad Spectrum Long Range Contact
CPO	Crude Palm Oil
CRSB	Chemara Research Sendirian Berhad
CAGR	Compound Annual Growth Rate
DFB	Developing Fruit Bunches
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
FFB	Fresh Fruits Bunches
GAP	Good Agriculture Practice
GMP	Good Manufacturing Practice
GNI	Gross National Income
IPM	Integrated Pest Management
IPMP	Integrated Pest Management Policy
IRHO	Institute de Recherche pour les Huiles et Oléagineux, France
LULUCF	Land use, Land-use change and Forestry
MMT	Million Metric Tons
MPOB	Malaysian Palm Oil Board
NGO	Non Government Organisation
PKM	Palm Kernel Meal
PKO	Palm Kernel Oil
POME	Palm Oil Mill Effluent
PORIM	Palm Oil Research Institute Malaysia
PORLA	Palm Oil Licencing Authority
RH	Relative Humidity (%)

RSPO	Roundtable on Sustainable Palm Oil
SPP	Southern Perak Plantation

CHAPTER 1

1.0 GENERAL INTRODUCTION

1.1 The Oil Palm Industry in Malaysia

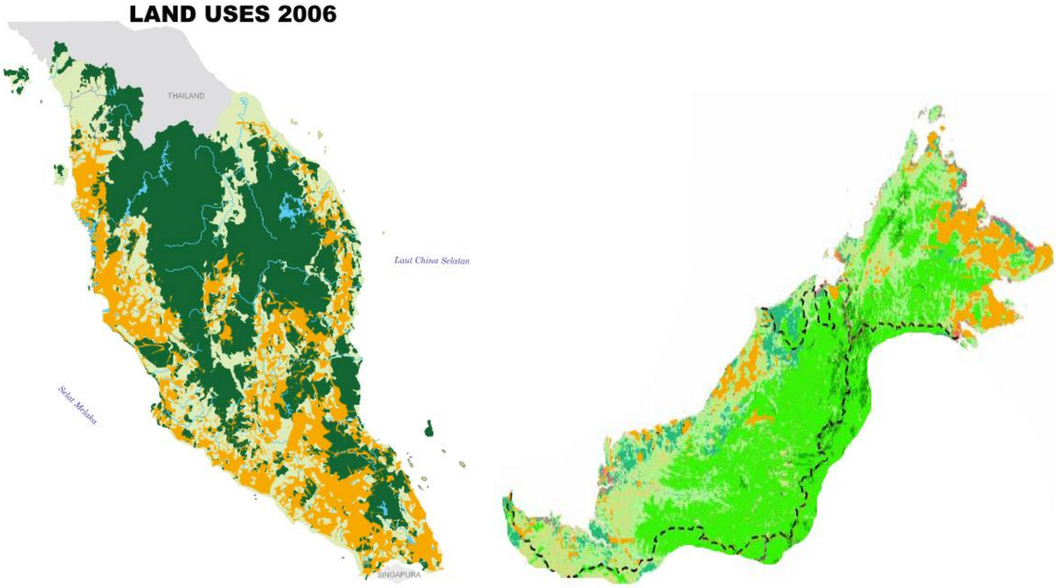
The oil palm trees (*Elaeis guineensis* Jacq) can be found naturally in the lowland rainforest of west and central Africa. Zeven (1967) and Hartley (1988) provide a summary of its native distribution in Africa. It was domesticated through harvesting of wild fruits and the trees were partially removed during clearance of forest for shifting cultivation resulting in semi-wild groves (Gerritsma & Wessel, 1997). Its cultivation dated as far back as the year 3000 B.C when the pharaohs of ancient Egypt civilization utilized them for production (Friedel, 1897).

Oil palm was introduced into Malaysia by the British as ornamental plants sometime in the 1870's. Later in 1917, it was planted on a commercial scale at the Tennamaran estate, Rantau Panjang, Selangor by Henri Fauconnier and Hallet (Singh *et al.*, 2010). Since then the oil palm industry expanded. By early 1960s the rate of growth was terrific under the government's agricultural diversification programme which was implemented to lessen the country's economic dependence on rubber and tin. In this regards, the Federal Land Development Authority (FELDA) was established and they introduced land settlement schemes for planting oil palm as a means to eradicate poverty for the landless farmers and smallholders. Table 1.1a shows the oil palm expansion in terms of hectarage from 1871 to 2000, provided by the Palm Oil Licensing Authority (PORLA). As of 2010, a total of 4.9 million ha of land is planted with oil palm comprising of 4.2 million ha of matured plantations and 0.65 million ha of young trees involving 150,000 small farmers and about 3,000 plantations. It clearly demonstrates that oil palm has drastically replaced the natural forest cover (MPOB website). Figure 1.1a shows the natural forest and oil palm land coverage in Malaysia. The palm oil production and exports from 1964-2006 is displayed in Figure 1.1b. It shows a steady increase over the years. Today Malaysia is the world largest producer of palm oil constituting 47% of the world production. Malaysia is also the world largest exporter whereby the commodity forms the central backbone of the national economy. As of 2010 the palm oil industry contributed about RM53 billion of the gross national income - the fourth largest component of the national economy. The industry covers the value chain from plantations to processing. Table 1.1b shows the monthly export revenue of palm oil from 2008 to 2012 (April). It indicates that there is a slow rise in the exportation of palm oil but not for other palm oil products.

Table 1.1a. Estimation in hectarage of Oil Palm in Malaysia from 1871 to 2000 (Source: Porla, palm oil statistics)

Hectares of Oil Palm in Malaysia		
Year	**Hectares**	**% Change**
1871 – 1910's	< 350	-
1920	400	-
1930	20 600	-
1940	31 400	-
1950	38 800	-
1960	54 638	0.0
1965	96 945	77.4
1970	261 199	169.4
1975	641 791	145.7
1980	1 023 306	59.4
1985	1 482 399	44.9
1990	1 984 167	33.8
1992	2 143 233	8.0
1993	2 281 010	6.4
1994	2 411 999	4.6
1995	2 515 842	4.3
1996	2 615 269	3.9
*2000	2 910 000	

Note *= Estimate.
Source: PORLA, Palm Oil Statistics



Legend:

Forest coverage in Peninsular Malaysia

Forest coverage in East Malaysia Sabah & Sarawak

Oil Palm Plantations

Figure 1.1a. Natural Forest and Oil Palm land Coverage in Malaysia. **Source:** Forestry Department Malaysia, MPOB and Department of Agriculture

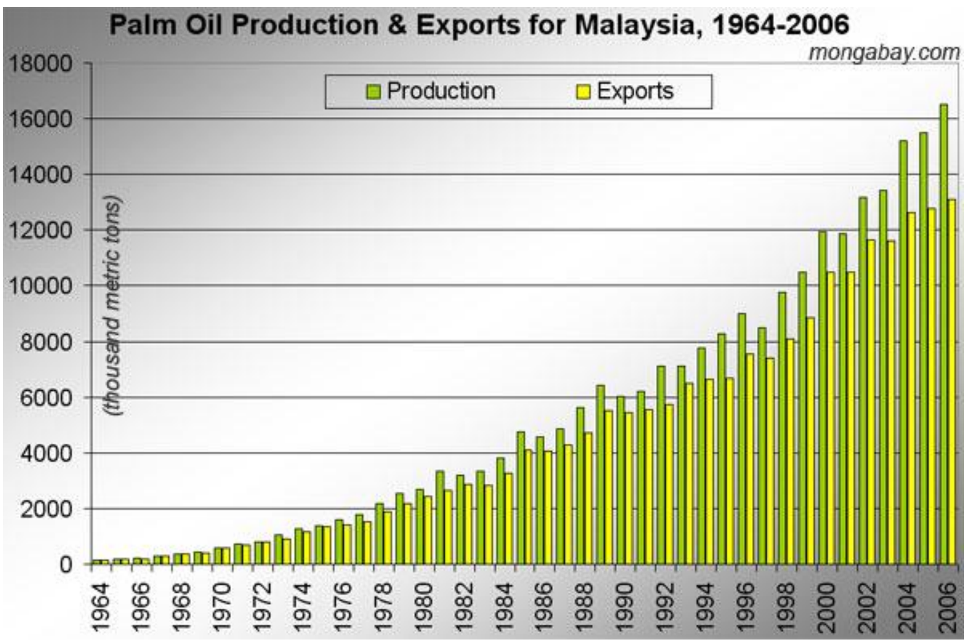


Figure 1.1b. Malaysian palm oil production and export from 1964-2006. Source: http://news.mongabay.com/2007/0515-palm_oil.html

Palm oil is used for many purposes – the crude palm oil (CPO) is used as cooking oil, ingredient in food products such as margarine, biscuits and ice-cream; vitamins, engine lubricant, softening agent in leather industry; base (binding agent) for cosmetics; constituent of paints and plasticisers and recently for the production of biofuel in the face of ever increasing price of petroleum. The Palm Kernel Oil (PKO) is widely used for the manufacturing of soaps, detergents, hydraulic brake fluids, as ingredient for insecticides and fungicides and as component in the electronics industry. The Palm Kernel Meal (PKM) is chiefly used as an animal feedstuff. Compare to other vegetable oils such as oil seed rape, soya bean, coconut and sunflower, oil palm gives a higher yield on a per hectare basis. This means lesser land is needed and thus is the most cost effective among the oil crops. Oil palm has other advantages – it is more stable, blend well with other oils and resistance to oxidisation. PKO has high content of lauric acid which gives it excellent melting properties.

Against these backgrounds the global demand for palm oil will continue to increase in the future. It is reported that the Compound Annual Growth Rate (CAGR) for global palm oil products has been 7.5 per cent over the last 20 years (Supaiya & Pereira, 2012). Palm oil held approximately 32% of the market share of all edible oils by production in the year 2006-2007 (Kongsager & Reenberg, 2012). In comparison, soybean oil share 29% of the world market, during the same period.

Table 1.1b. Monthly export of palm oil & oil palm products from 2008 to 2012 (April)

Product	Unit	Jan-Dec 08	Jan-Dec 09	Jan-Dec 10	Jan-Dec 11	Jan-Apr 12
Palm Oil	Tonnes	15,412,512	15,880,744	16,664,068	17,993,265	5,271,486
	RM Mil	**47,925.95**	**36,947.58**	**44,859.80**	**60,471.92**	**17,126.01**
Others palm oil products	Tonnes	6,351,417	6,546,106	6,375,969	6,278,407	2,267,285
	RM Mil	17,289.24	12,711.39	14,870.84	19,939.51	6,081.2
Total	Tonnes	21,763,929	22,426,850	23,040,037	24,271,672	7,538,771
	RM Mil	**65,215.19**	**49,658.97**	**59,730.64**	**80,411.43**	**23,207.21**

Source: Modified summary obtained by extracting data from Malaysian Palm Oil Board (MPOB), Economic & Industry Development Division (May 2012) records.

1.2 Agricultural Pests and Biological Control Management

In natural ecosystems, there are ecological forces that naturally regulate the occurrence and density of pests, thus providing a natural wall of protection to the environment and crop plants. Among others, the physico-chemical conditions, availability of food, predation and competitions are major important factors that regulate pest populations. However in monoculture cultivation such as in oil palm estates (Plate 1.2), the natural intricate ecological conditions does not prevail and thus become more vulnerable to pest attacks. The problem becomes more acute compounded by the fact that the crop plant itself may provide new food resources for the pests allowing a far higher population density at the detriment of the plantation (Flint & Bosch, 1981). Furthermore, the use of broad-spectrum pesticides would eliminate the natural predators responsible for the control of pests (Wood, 1968; Wood, 2002). Under these circumstances there is a dire need for agriculturists to shift from chemical-based to biological-based pest control.

Biological control is defined as “the process in which the population of one species lowers the numbers of another species by mechanisms such as predation, parasitism, pathogenicity, or competition” (Bale *et al*., 2008; Gurr *et al*., 2000; Evans, 2008, Van Drische *et al*., 2010). But this definition failed to mention clearly the specific nature of the target population (Boivin, 2001), which in the case of the present study is the defoliation of oil palm fronds. Boivin (2001) further explained the intricacies and confusion found in the definition of biological control of pests making the semantic of terms more complex and actually depending on certain specific official regulatory acts and laws. Nevertheless the contextual connotation of the definition is fitting for the purpose of the present study.

Improving pest control complements other methods, to significantly increase the yields. The best way to achieve this is through Integrated Pest Management (IPM). A valuable component of IPM is Biological control, i. e. the use of a living organism for pest management (Parrella & Lewis, 1997; Lacey *et al*., 2001).

Plate 1.2. Photograph showing young oil palm plantation in Teluk Intan, Perak.

The definition given by the University Of California State-wide IPM program stated that: “Integrated pest management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed and should be used according to prescribed protocols or guidelines. Only pesticides with selective application on target organism should be used.

1.3 Oil Palm Pest, Disease and the Bagworm Problem in Malaysia

Like any other agricultural crops, oil palm is not spared from the problem of pests. The Malaysian Palm Oil Board (Basri *et al*., 2003; Ramlah *et al*., 2007) published a comprehensive handbook related to pest and diseases aspects in oil palm and classified them into three categories: insect and mammalian pests; diseases; and weeds. There are 5 invertebrates and a single vertebrate species in the first category namely the bagworms, nettle caterpillars, rhinoceros beetles, bunch moths, termites and the rats. The second category comprises of three types of diseases namely the basal stem rot infecting trees under cultivation; the anthracnose and leaf spot disease infecting nurseries; and diseases of the seeds (*Schizophyllum* infection). Basal stem rot is caused by the fungus *Ganoderma bonisense* and is the most serious and problematic disease that can result in very high losses (Idris, 2012). The weeds made up the third category comprising of the grasses, creepers, woody broadleaves, sedges, ferns and brackens.

Bagworm is one of the most predominant insect pests of oil palm in Malaysia. Wood (1968) provided a systematic review of these lepidopterans (Family - Psychidae) base on previous studies done by entomologists from the Government Agricultural Department in Kuala Lumpur. The earlier research was on the pests of coconut palms but it provides great insights and information on the pest's status on oil palm. There are several species of bagworms found on oil palm but three species have shown to be dominant in Malaysia and Indonesia *i.e. Metisa plana Walker, Pteroma pendula* Joannis, and *Mahasena corbetti Tams*, (Wood 1968, Sankaran 1970, Basri *et al*., 1988, Normal *et al*., 1994, Corley & Tinker, 2003). However their occurrence may differ in different locality. As for example the first two species are predominant in Peninsular Malaysia whilst the latter are more prevalent in Sabah (Sankaran & Syed 1972, Cheong *et al*., 2010).

Among the three species, which one is the most damaging to oil palm? There are conflicting reports to this – a recent study in Hutan Melintang, Perak by Cheong *et al* (2010) demonstrated that *P. pendula* is the most aggressive and more dominant. However an earlier study by Norman *et al* (1994) and Norman & Basri (2007) had shown otherwise and provided evidences of *M. plana* being the most dominant species and is among the most economically damaging species. On the other hand, *P. pendula* is considered as second most abundant pest attacking the oil palm in West Malaysia (Basri *et al*., 1988). This inconsistency is answered by Wood (2002) who observed that *P. pendula* is in fact the most important pest prior to 1955 but after that *M. plana* became more widespread. The extensive usage of broad spectrum long range contact pesticides and agro-chemicals is reported as being the main factor for this change. *M. corbetti* is not considered as a virulent pest in oil palm in peninsular Malaysia since its occurrence is reported as not being significant. Nevertheless there are incidences of its outbreak in the state of Johor (Basri *et al*., 1988) and Perak (Norman & Basri, 2007). *M. corbetti* has long been known to be the pests of coconut palm in Peninsular Malaysia (Sankaran & Syed, 1972). Another species, *Brachycyttarus griseus* Joannis is found to induce infestations on oil palm seedlings under glasshouse confinement at the Palm Oil Research Institute Malaysia (PORIM), (Norman *et al*., 1994).

The bagworms found in Malaysia are polyphagous insects, apart from oil palm they feed on several other crops such as bananas (*Musa spp.*), cacao (*Theobroma cacao*), peach palm (*Bactris gasipaes*), coconut (*Cocos nucifera*), citrus (*Citrus spp.),* teak (*Tectona grandis*), eucalyptus (*Eucalyptus spp*.), *Eryobothria japónica*, *Terminalia catappa* (Norman *et al*., 1994).

Bagworms causes moderate to heavy defoliation of the oil palm fronds resulting in significant loss of productivity (Wood & Nesbit, 1969; Young, 1971) to the extent of incurring loss as high as 44% (Wood, 1973; Basri, 1993). During the period from 1981 to 1985, more than 10 000 ha of oil palm were seriously attacked by bagworms (Basri *et al*., 1988). MPOB data in 2005 recorded that bagworms were quite a serious problem in the oil palm industry as 35 657 ha were attacked by these pests (Norman & Basri, 2007) and indication are that it is becoming more widespread if no proper control is in place. So far the population of *M. plana* has been significantly checked through the establishment of beneficial plants *like Euphorbia heterophylla* and *Cassia cobanensis* in oil palm plantations. The former demonstrated a significant removal of *M. plana* as high as 93% and the latter to about 68%, through the mechanism of an increase in parasitoid population such as *Dolichogenidae metesae* (Ho *et al.*, 2003). The ability of natural enemies to effectively regulate pest population below economic threshold has been amply proven (Zhang & Swinton, 2006).

1.4 *Oecophylla Smaragdina* as a Potential Biological Control Agent in Oil Palms

The weaver ant or variously known as the green ant, green tree ant and sometimes as the orange gaster is scientifically known as *Oecophylla smaragdina* (Fabricius) under the ant family, Formicidae. Its common colloquial name in Malaysia, where this study was conducted is “kerengga” but in certain locality, it is inappropriately called as “semut api” or literally translated as “fire ants” which they are not. There are only two species of the genus *Oecophylla*: *O. longinoda* (Latreille) found in tropical Africa and *O. smaragdina* dwelling across Southeast Asia until westward to India, to the north until Taiwan and China and southward until the tropical region of Australia (Stapley, 1980; Chen, 1991; Van Mele & Cuc, 2000; Azuma *et al*., 2006). In Malaysia, it is common to find them inhabiting all kind of fruit trees such as mangoes, rambutans, langsat, air jambu, and mangosteen (pers obs). Its prevalence in oil palm plantations nationwide is reported by Wood (1968). The weaver ants have been known to prey on many insect species albeit its preference for nectary's exudes from plants as well as sugary secretions produced by homopteran and caterpillars (Blüthgen & Fiedler, 2002; Tsuji *et al*., 2004). They are very ferocious foragers, attacking almost any organisms that cross their path or deliberately intruding into their territory. It is because of this predacious attribute that the species was use for biological control of pests by farmers. It is recorded that the Chinese have been using weaver ants to protect their citrus orchards since the early centuries of the last millennium (Huang & Yang, 1987), by including a nest and promoting colonies expansion with bamboo strips on the branches of trees to form bridges helping the faster development of colonies to others trees. Peng and Christian (2004) found that *O. smaragdina* effectively control the main insect pests of cashew plantations in the Northern Territory of Australia and Papua New Guinea, (Peng *et al*., 2004), and against the red-banded thrips, *Selenothrips rubrocinctus* 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". *O. smaragdina* is reported to control over 50 varieties of pests' insects from around 12 diverse crops in tropical areas (Way & Khoo 1992; Peng & Christian 2006).

The presence of *O. smaragdina* in oil palm plantations (personal observation) offers the opportunity to study its predatory behaviours in relation to the bagworm problems cited in the preceding section, which so far have not been studied and documented.

1.5 Objectives of the Study

Against the background cited in the previous sections of this thesis, the present study was conducted with the following principal objectives:

- To examine the comparative presence of lepidopterans defoliators and determine the monthly fluctuations of infestation density of *P. pendula* and its correlation with rainfall and relative humidity.
- To study the predatory activities of *O. smaragdina* with the following sub-objectives:
    - To elucidate their occupancy patterns
    - To observe and describe their predatory behaviours on *P. pendula*
    - To assess the degree of infestation by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*
    - To assess the degree of foliar injury caused by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*
    - To assess the productivity of palms that is occupied and not occupied with *O. smaragdina*
    - To verify the absence of interference of *O. smaragdina* on *Elaeidobius kamerunicus* weevil.

CHAPTER 2

SURVEY AND ASSESSMENT OF *P. pendula* INFESTATION IN THE STUDY AREA

2.0 Introduction

In the preceding chapter it is stated that the bagworm infestation is significance in some oil palm plantations in Malaysia. There are several species of bagworms responsible for the infestation: *Metisa plana Walker, Pteroma pendula* Joannis, *Mahasena corbetti Tams, Manata albipes and Clania sp.* Among them, the first three species are dominant (Wood 1968, Basri *et al*., 1988, Norman *et al*., 1994, Corley & Tinker, 2003; Norman & Basri, 2007). The infestation from *P. pendula* is currently the most serious (Wood, 2002; Cheong *et al*., 2010). Not all species are present in the same area. Some species might be dominant in a particular area, and not prevailing in another area, with different species noticeably taking the lead. Thus it is crucial to determine the type of bagworm species present in the study area. It is observed and reported that the intensity of *P. pendula* infestation fluctuates over the periods of the year. In certain months the intensity of infestation is heavy and in other months it is lesser. Thus this study also aims to investigate and record these fluctuations in the study area. There must be certain reasons and factors that contribute to the observed fluctuations. In this regards this study shall relate or correlate the fluctuations to certain selected weather parameters in the study area.

2.1 Objectives

The objectives of this chapter are as follows:

1) To examine the comparative presence of lepidopteran defoliators.
2) To determine the monthly fluctuation of infestation density of *P. pendula* and its correlation with rainfall and relative humidity.

2.2 Methodology

2.2.1 Study Area

The study was conducted at the MPOB Research Plantation at Teluk Intan in the Hilir Perak District of Perak, Malaysia (4° 2' 0" N, 101° 1' 0" E). Access to the area from Kuala Lumpur is either by the state road 5 via Kuala Selangor or by using the North South Expressway (PLUS/E1) exit at Bidor and taking state road 58 to Teluk Intan (Figure 2.2.1a). The study area lies within the western coastal belt of Peninsular Malaysia. The terrain is generally flat with deep peat soil structure.

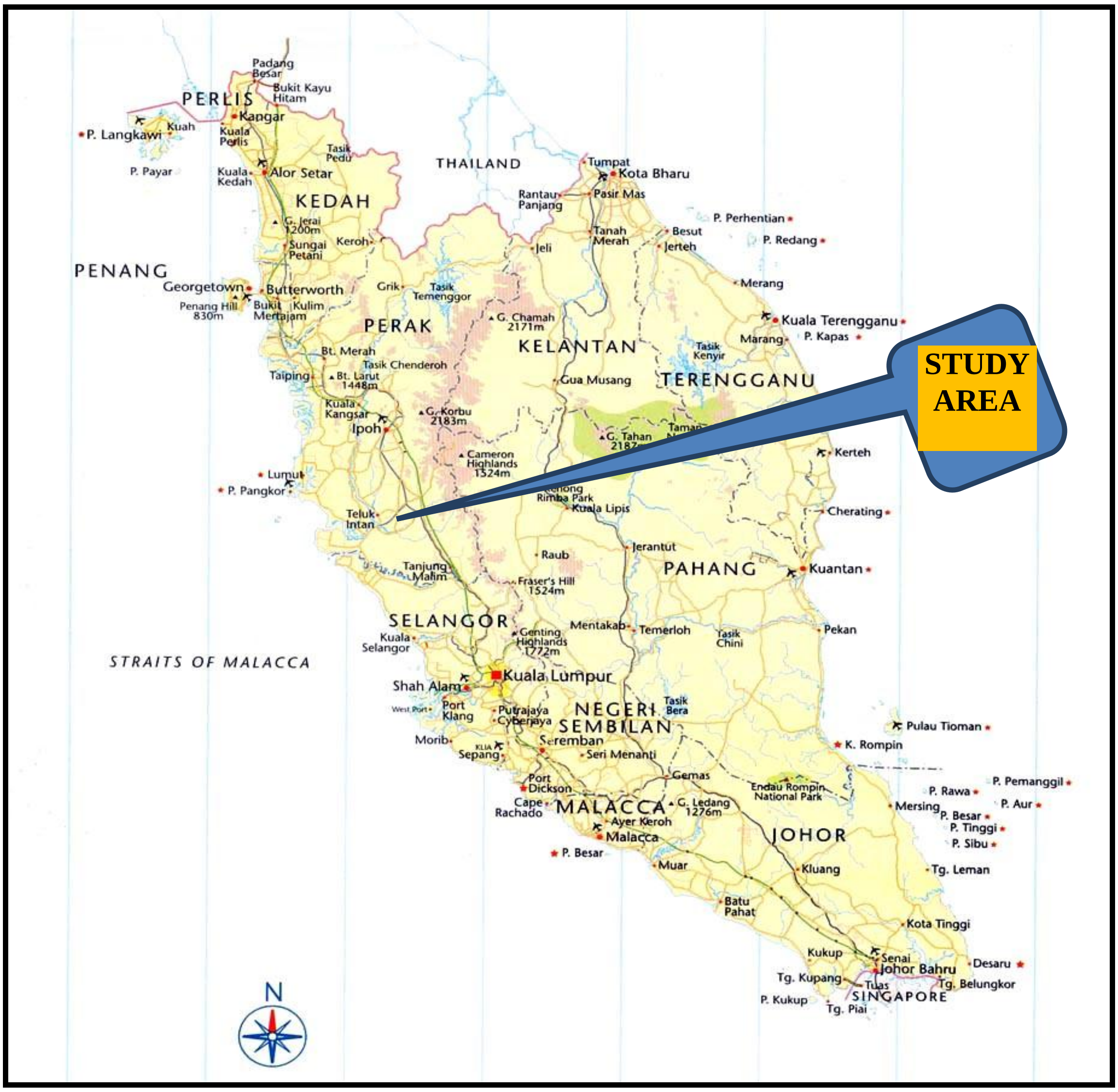


Figure 2.2.1a. Map of Peninsular Malaysia showing the location of the study area at Teluk Intan, Perak.

The area experiences the typical climate of Malaysia with characteristic year round uniform temperature (average temperature of 27.5^{0}C with daily ranges from 21˚C - 35˚C), high humidity (54%-94%), abundant rainfall (annual average of about 2600 mm) and generally light winds. There are some uniform periodic changes in the wind flow patterns resulting into four seasons distinguish as the southwest monsoon (May-September), northeast monsoon (November-March) and two shorter periods of inter-monsoon seasons. The seasonal variation of rainfall in Peninsular Malaysia is of three main types: firstly are the months with maximum rainfall from November-January in the east coast states, while June and July are the driest months in most districts; secondly over the rest of the Peninsula with the exception of the southwest coastal area, the monthly rainfall pattern shows two periods of maximum rainfall separated by two periods of minimum rainfall; and thirdly the rainfall pattern over the southwest coastal area (where the study area is marginally located) is much affected by early morning " Sumatras" from May until August with the result that the double maxima and minima pattern is no longer distinguishable. October and November are the months with maximum rainfalls and February the month with the minimum rainfall. The March-May maximum and the June-July minimum rainfalls are absent or indistinct.

Plate 2.2.1. Photograph of young **o**il palm plantation (3-4 years old) in the study area. The terrain is generally flat with underlying deep peat soil.

Figure 2.2.1b shows the ground plan of the MPOB plantation in Teluk Intan where the study is conducted. The total size of the plantation is 1000 ha comprising of different age blocks. The plantation is divided into 36 administrative blocks of various sizes and ages. There are five age-groups in the plantation: 25 years old (planted in 1986), 13 years old (planted in 1998), 9 years old (planted in 2002), 7-8 years old (planted in 2003-2004) and 3-4 years old (planted in 2007-2008). The taller ones comprised of the older palms (7-25 years old) and the shorter one are the younger palms (3-4 years old) (Plate 2.2.1). For the purpose of this study 5 blocks of young palm trees and 5 blocks of old palm trees was sampled at random.

Figure 2.2.1b. Ground Plan of MPOB Oil Palm plantation in Teluk Intan. (Source: MPOB station Teluk Intan, Perak).

2.2.2 The Systematic Census on *P. pendula* Infestation

This section provides the methodology used for the survey and assessment on the infestation made by *P. pendula*. Infestation made by other bagworm species and the nettle caterpillars are only noted and photographed for the purposes of comparison.

A monthly census covering a period of 24 months or two annual cycles were made beginning the month of June 2010 and ending in the month of May 2012 (Appendix 2.2.1 providing data for June 2010 & May 2012). In each month, two consecutive days towards the end of the fourth week were selected for the census. Thus, there is a total of 48 census days during the entire sampling period of 24 months. The monthly census was conducted systematically by the MPOB monitoring team comprising of four staffs. It was headed by an entomologist. The researcher was present during the census from November 2010 until August 2011. Monitoring was carried out until October 2012.

The census was made to determine the density of *P. pendula* during the census period. The density takes into account all the stages of the life cycle (i.e. the larva, pupae and adults, including dead larvae and pupae) and the dead specimens as well (larvae and pupae). It is worthy to note that the female adults are apterous and are confined to their bag.

There are 36 administrative blocks of oil palms in the study area (Figure 2.2.2a). Not all blocks are infested with *P. pendula*. Only 6 blocks, significantly infested with the species were selected for the census. This is based on field observation whereby a block is classified as not infested when no more than 30% of the palms are not infested. The significance of pest presence is determined according to established threshold level of injury (20-30 larvae/frond), (IRHO, 1991; Exélis Pierre & Azarae, 2013). The appendix

3.3.3 provides the economic threshold of important pests of oil palms, in particular *P. pendula*. Figure 2.2.2a is a diagrammatic representation of how the census is conducted. In each block, three plots of oil palm trees, representing three replicates, were selected by stratified randomness. In each plot, five trees were selected for the census based on a predetermined selection process. Each sampling plot is separated by two rows of palm trees.

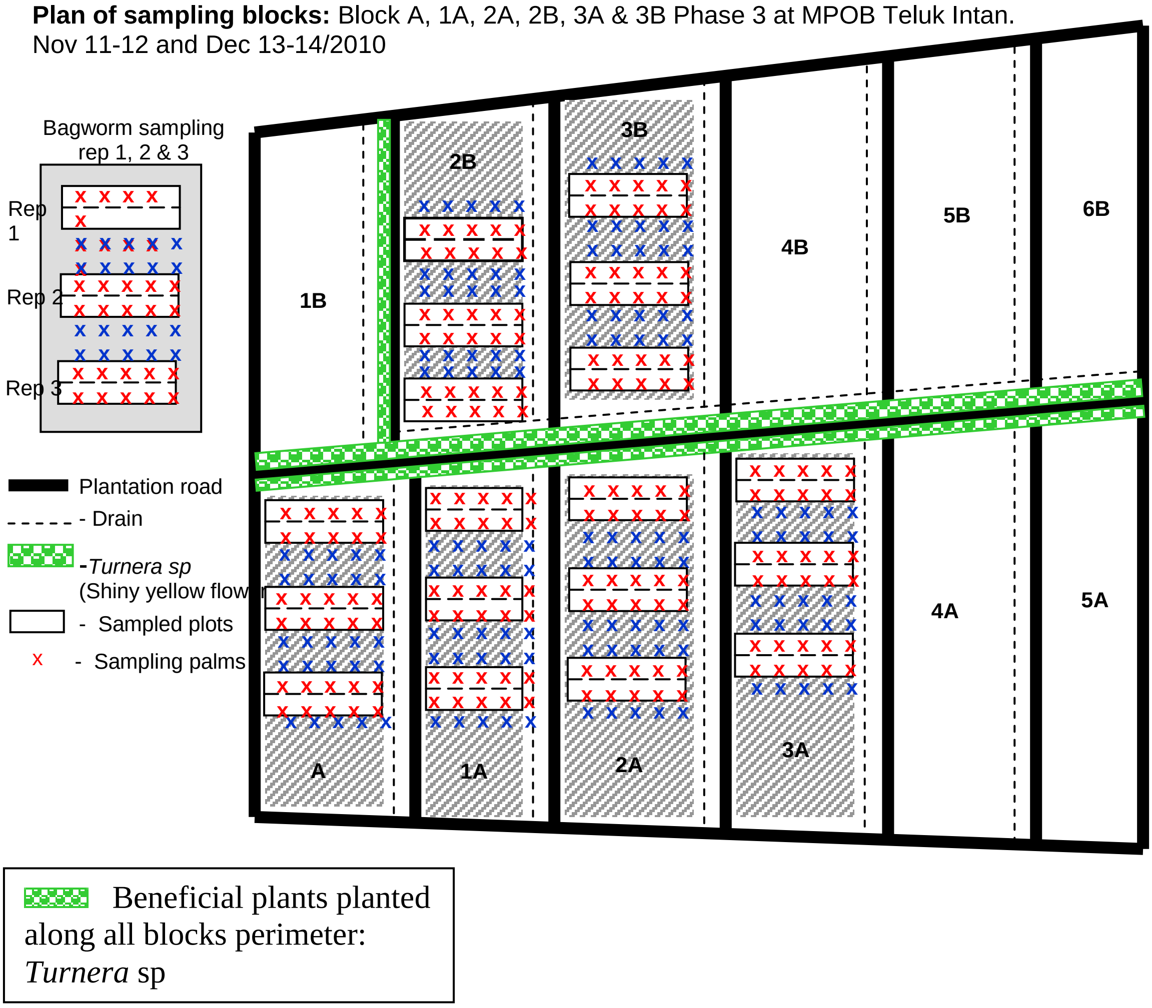
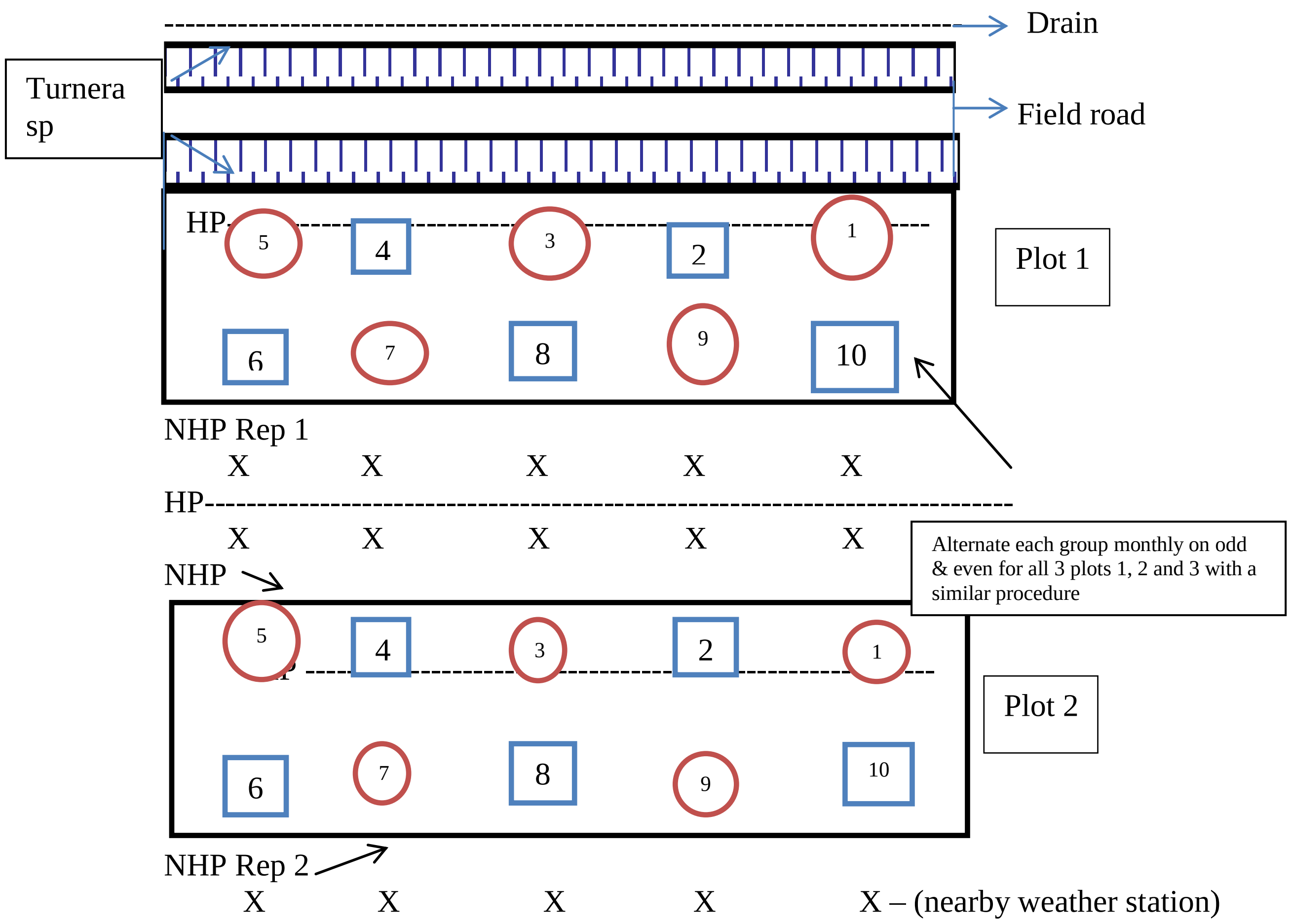


Figure 2.2.2a. Diagrammatic representation of how the census on *P. pendula* infestation was carried out in the study area.

The first tree is predetermined as one fronting the roadside were the researcher is standing. Alternate trees in the same row were then selected for subsequent census.

Sampled palms in the first month were numbered by odd numbers such as P_1, P_2, P_3, P_4 and P_5. The following month, sampled palms were selected by even numbers such as P_2, P_4, P_6, P_8, and P_{10}. A total of 5 trees were selected in two adjacent rows within each plot. This procedure was repeated for all successive month during two years.



Legend: HP – Harvesting path - - - - - with X representing palm trees not included in the sampling

NHP – Non harvesting path ______________

1 & 2 - Odd and even numbered palms.

Figure 2.2.2b. Layout of sampling plots.

A total of 15 trees for each block were selected, thus a total of 90 trees were sampled in 6 blocks for each sampling month (Figure 2.2.2.b). Replicates 1, 2 & 3 had weather records carried out in Blocks B, 1A, 2A, 2B, 3A & 3B for destructive sampling in tall palms. Similar censuses by non-destructive sampling were carried out in blocks $6B_1$, $5B_1$, $2B_1$, $2B_2$ and $4B_2$ for short palms.

In each tree a frond was selected using the method devise by Hartley, (1977) and also as modified by Corley & Tinker (2003).

In this technique an inclined middle canopy frond was cut base on the phyllotaxy of the oil palm (Figure 2.2.2c), using an adjustable harvesting pole Model 4.5 F (45 pin), with a length totalling 31.5 feet (Plate 2.2.2). The cut frond was then laid on the ground and all forms i.e. live and dead larvae, pupae and adults were enumerated. However, in this study only the data on the larval forms is use for the categorization of infestation levels. This is because only the larval stages are feeding and hence destructive to the frond. The density is taken as the number of larvae per frond. A correlation between pest density for live, dead larvae and rainfall precipitation records, relative humidity was done by using statistical software Sigma Plot 11 and 12.

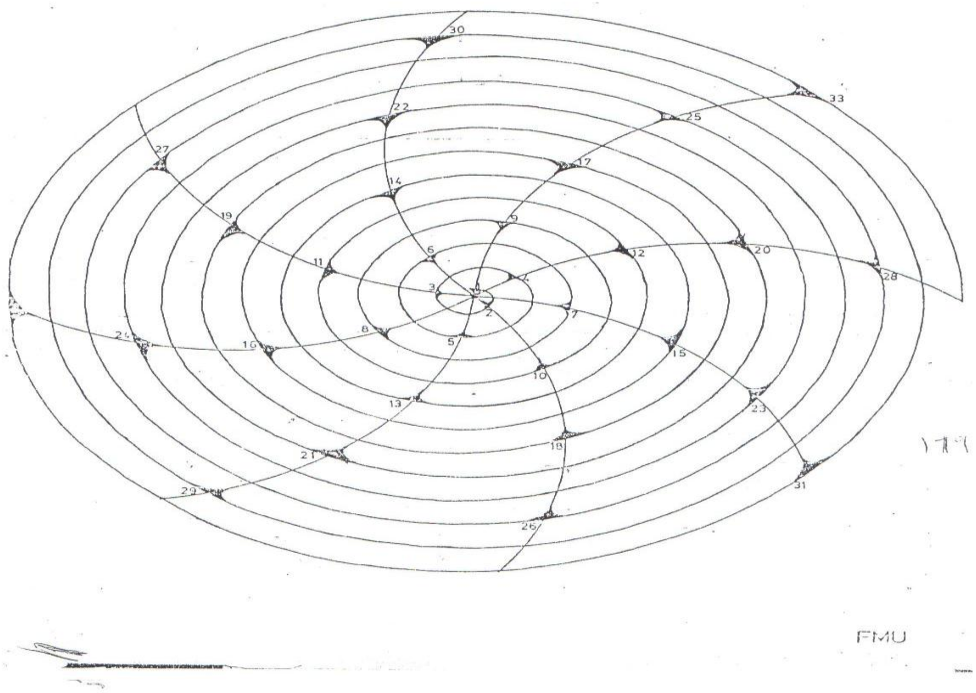


Figure 2.2.2c. Phyllotaxy of Oil Palms (Hartley, 1977).

Plate 2.2.2. Adjustable harvesting pole Model 4.5 F (45 pin) used for the destructive sampling of bagworms in the study area. Photo taken with digital camera Sony DSC-WX3.

Pearson Correlation Coefficient (r) was used to examine for any relationship between pest density with rainfall and relative humidity. The data is subjected to Pearson Correlation Coefficient and Linear Regression Analysis. Correlation is used to quantify the degree of relationship between the number of live larvae or dead larvae to rainfall and relative humidity respectively. A value of + 1 indicates a perfect positive correlation. A value of – 1 indicates a perfect inverse (negative) correlation. A value of 0 means there is no relationship. The value ranges between "0" and "+1" or "0" and "-1" indicates the strength of the relationship in the respective direction, whereby values close to "+1" or "-1" are of greater relationship.

The values of the Pearson Product-Moment Correlation is interpreted and defined as follows:

- 0 means no correlation
- ±(0.10 – 0.40) weak correlation
- ±(0.50 – 0.60) moderate correlation
- ±(0.70 – 0.90) is strong correlation
- ±1.0 is perfect correlation

The plus and minus sign indicates the direction of the relationship whereby, “plus” denotes a positive relationship and minus denotes a negative relationship.

On the other hand linear regression was use to finds the best line that predicts the dependent variable Y (number of live or dead larvae) from the independent variable X (rainfall or relative humidity) or in other word to quantify goodness of fit with $R^{2,}$ also known as Coefficient of Determination. The values of R^2 range from 0-1. An R^2 of 1 indicates that the regression line perfectly fits the data. The analysis was made using Microsoft Excel software 2010.

2.2.3 Comparative study on the presence of all type of defoliators

The study for the overall pest density was conducted for 10 consecutive months from November 2010 until August 2011. The census method is similar to the systematic census done for the *P. pendula* infestation by the MPOB monitoring teams. Since the comparative study was conducted only on short palms, non-destructive sampling was carried. Blocks were randomly selected. Randomness was determined using random numbers. The total number of bagworms and other defoliators were recorded and tabulated. Analysis was done on the density between the bagworms versus other defoliators and between the different species of the bagworm.

The diversity and evenness (relative abundance) index for the bagworm community in the study area is calculated using Simpson's Reciprocal Diversity Index (1/D).

$$D = \Sigma (n / N)^2$$

Where n = the total number of organisms of a particular bagworm species N = the total number of organisms of all bagworm species.

The value of this index starts with 1 as the lowest possible figure. The higher the value, the greater the diversity. The maximum value is the number of species in the sample.

Simpson Evenness Index (E), is calculated by dividing the value of D by $D_{maximum}$ (which is the maximum possible value for D or the total number of species present). The index ranges from $1/D_{max}$ to 1 (equal distribution of all species).

2.2.4 Recording of Meteorological Parameters

The daily weather parameters were automatically recorded by the weather station located at the centre of the study area managed by the MPOB staffs (Figure 2.2.2b) and combined on monthly basis. In this study, only the data on the total monthly rainfall precipitation and relative humidity were used for the correlation analysis using Sigma Plot statistical package. These data are provided by the Tropical Peat Research Institute unit (TROPI) under the Biology Division at MPOB headquarters.

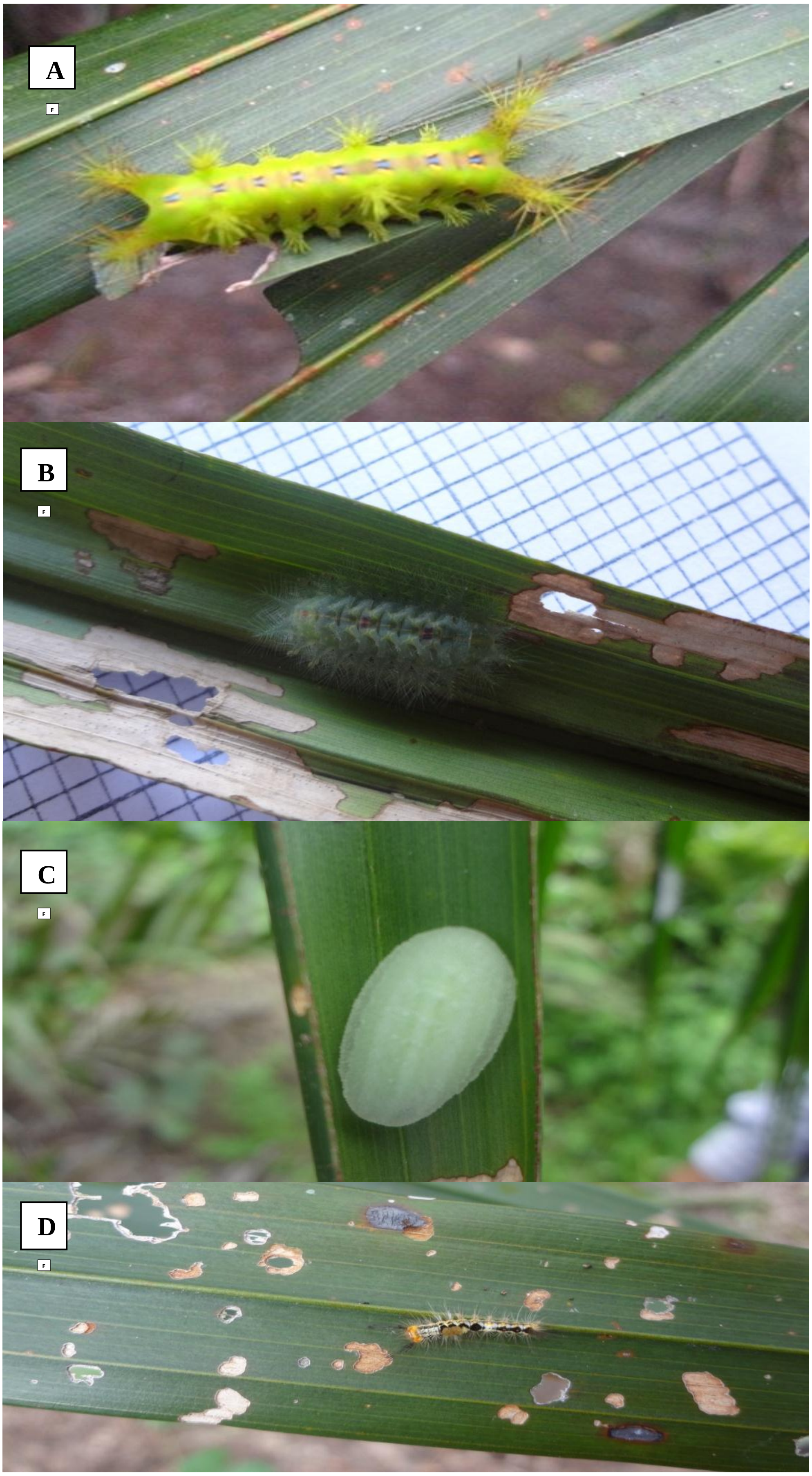
2.3 Results

2.3.1 Comparative presence of lepidopterans defoliators

A total of 9 species of lepidopterans defoliators were found to be present in the study area during the survey period comprising of 4 species of nettle caterpillars (Limacodidae) and 5 species of bagworms (Psychidae), (Table 2.3.1a; Plate 2.3.1 A-I). The existence of the various nettle caterpillar species, among them *Setosa nitens* (Walker) (A), *Darna trima* (Moore) (B), two unidentified species (C) and (D) were the most common in Teluk Intan MPOB, but never found reaching injury level. The count on mean monthly density of defoliators shows that the presence of the nettle caterpillar is insignificant (0.4 %) compared to the bagworms (99.6%). There are no other defoliators detected.

Table 2.3.1a. Species of defoliators present in the study area during the survey period (Nov 10- Aug 11)

Type of Defoliators	No	Species	Plate
Nettle Caterpillars	1	*Setosa nitens* (Walker)	2.2 (A)
	2	*Darna trima* (Moore)	2.2 (B)
	3	Unidentified species	2.2 (C)
	4	Unidentified species	2.2 (D)
Bagworms	1	*Pteroma pendula* (Joanis)	2.2 (E)
	2	*Metisa plana*	2.2 (F)
	3	*Manata albipes*	2.2 (G)
	4	*Clania* sp	2.2 (H)
	5	*Mahasena corbetti*	2.2 (I)


A
B
C
D

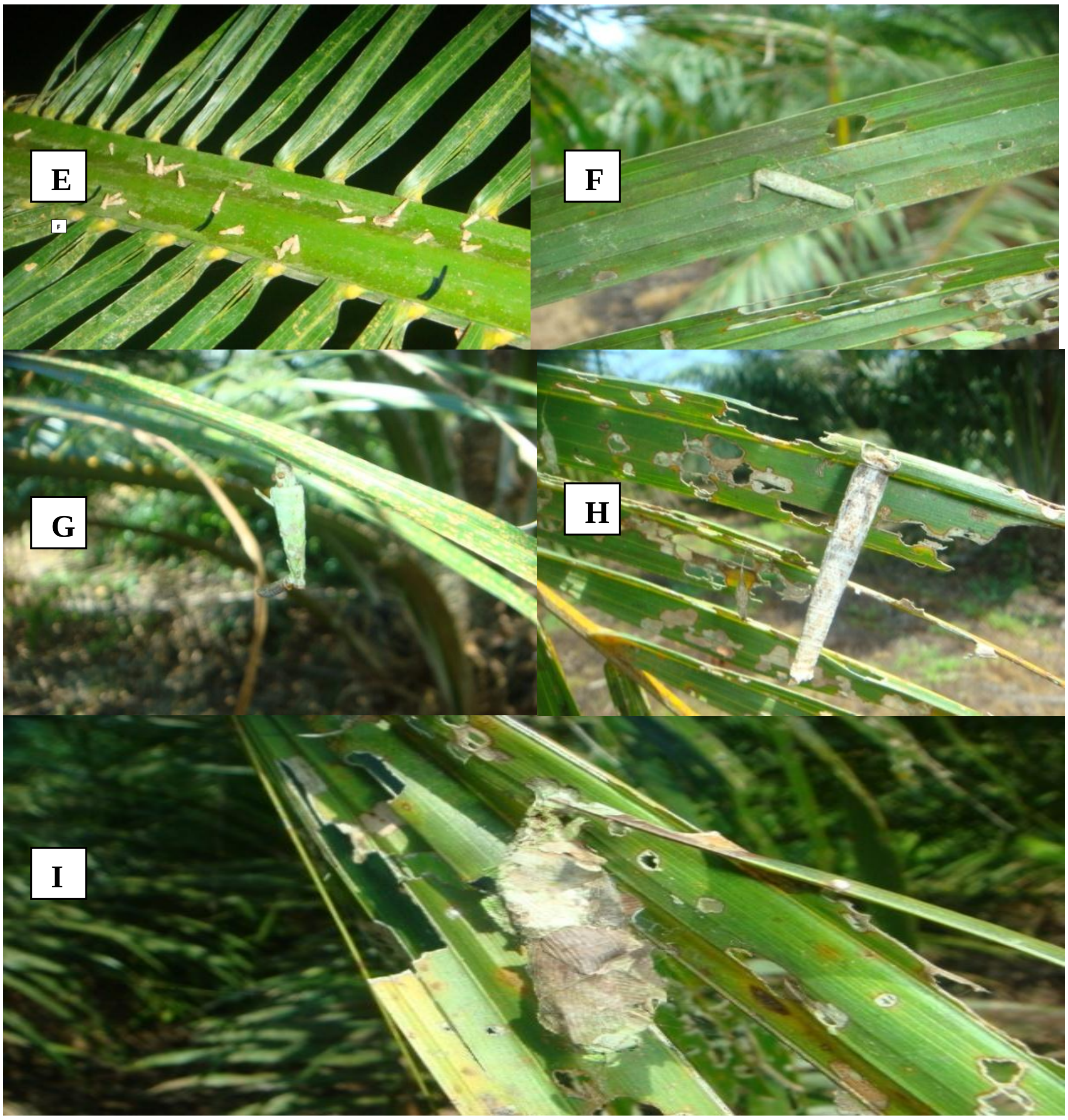


Plate 2.3.1 (A-I) Photographs of nettle caterpillars and bagworms found in study area at MPOB oil palm plantations, Teluk Intan, Perak.

As mentioned earlier, 5 species of bagworms were recorded in the study area: *P. pendula*, *M. plana*, *M. albipes*, *Clania sp* and *M. corbetti.* These represent about 71.4 % of the total number of bagworm species found in Malaysia. The diversity index as determined by using Simpson Reciprocal Index is 1.087. They are found in various stages of their life cycle i.e. adults, larva and pupae.

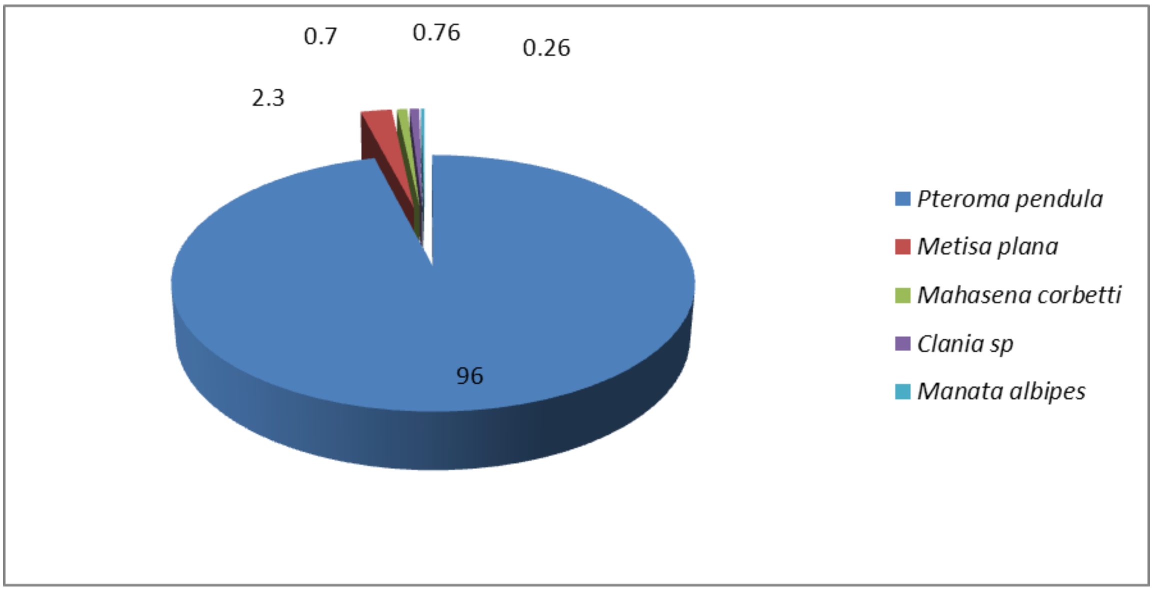


Figure 2.3.1. Frequency percentages of 5 bagworm species sampled in the study area. As depicted by the pie-chart, *P. pendula* is most abundant species.

Table 2.3.1b. Mean monthly density of lepidopteran defoliators during the study period

Defoliators	Psychidae	Limacodidae	Total Lepidopterans
Total count	28,331 (99.6%)	117 (0.4%)	28,448
Monthly mean	2,179.3	9	2,188.3

Figure 2.3.1 shows the relative abundance among the bagworm species. The relative abundance or evenness of the species distribution is very low (Simpson Evenness Index (E) = 0.217. The value is closed to the minimum possible thus indicating a low evenness distribution. In this regard, undoubtedly, *P. pendula* stands out as the most abunbant species accounting for 96% of the total count. *M. plana* is the second most abundant species contributing about 2.3%, but the figure is insignificant compared to the previous species. The number of the remainder three species, namely *M. corbetti*, *Clania* spp and *M. albipes* is respectively below 1% with the last species contributing only a significantly low presence of 0.26%.

Often, the bagworms can have a cryptic appearance in the field, making detection and monitoring more difficult (Plates 2.3.1 I & 2.3.1j).

Plate 2.3.1j. Abaxial view of a Cryptic apparatus of *Mahasena corbetti* on oil palm frond. Photographer/Camera: Photo taken by Exélis Moïse Pierre using a Sony T20 digital camera. February 2011.

2.3.2 Monthly fluctuation of infestation density of *P. pendula* and Correlation between Rainfall and Relative Humidity with Infestation Density

Figure 2.3.2a shows the monthly infestation density of *P. pendula* recorded in the six of the blocks studied between June 2010 until May 2012, a period covering 25 months or two annual cycles. Appendixes 2.3.2a and 2.3.2b show the actual mean recorded figures. All graphs show an almost similar pattern of monthly fluctuation in infestation.

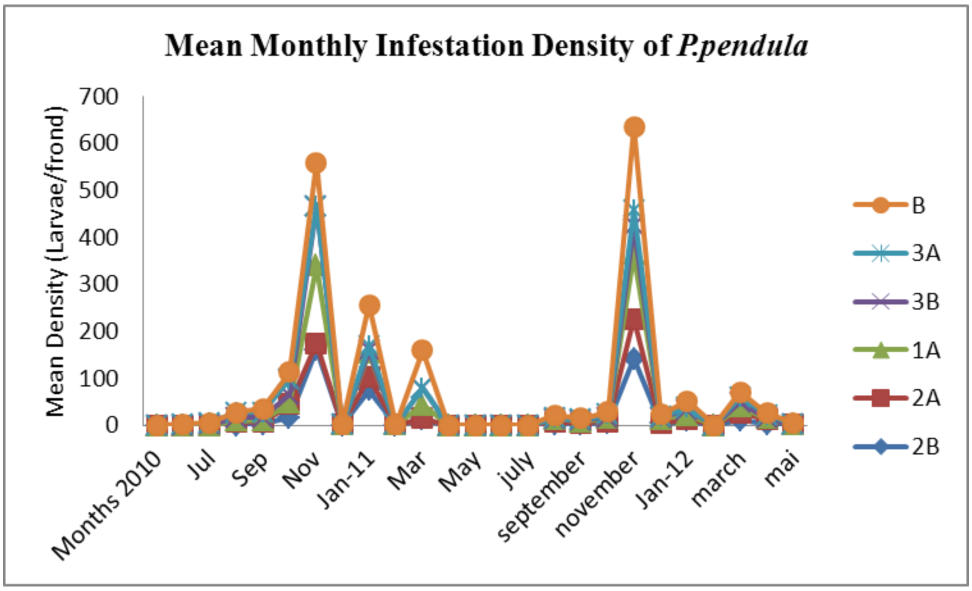


Figure 2.3.2a Mean monthly infestation density of *P. pendula* in Block 1A, 2A, 3A, 1B, 2B and 3B in the study area.

Figure 2.3.2b shows the shape of the graph for the combine data for all the 6 blocks. The shape of the graph did not depart significantly from the silhouette of the individual's blocks.

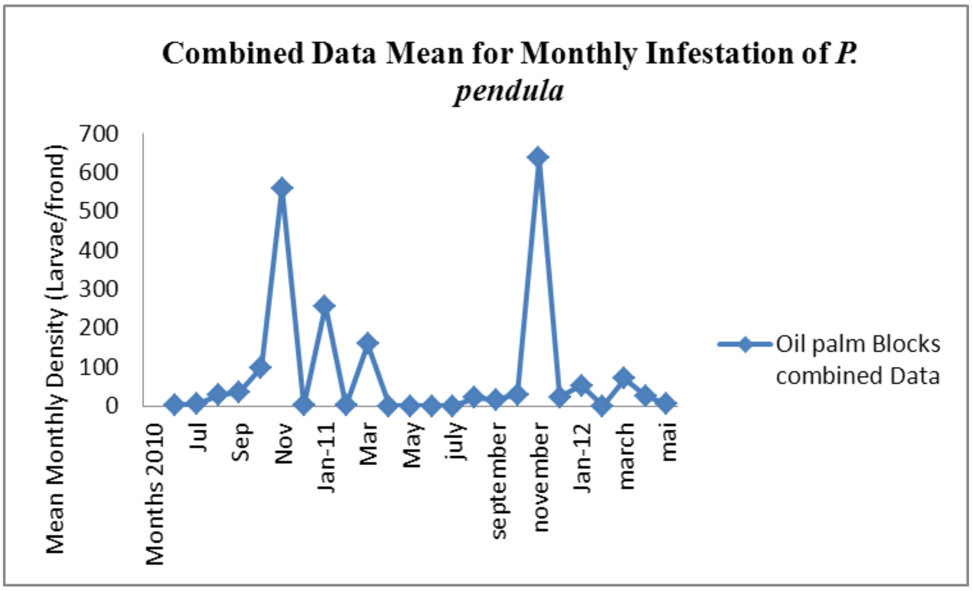


Figure 2.3.2b Mean monthly infestation density of *P. pendula* for combined data from Block 1A, 2A, 3A, B, 2B and 3B.

The graphs showing the monthly recorded fluctuations in pest density of *P. pendula* at larval stage reflect well the bagworms status in the oil palm plantations at MPOB Teluk Intan (Fig 2.3.2a & 2.3.2b). The month of November 2010, recorded the highest overall mean for two years of monitoring, with a mean of 160 live larvae in block 2B and an amount of 318 larvae in block 3B, plot 1. The period of August 2011 until May 2012 had recorded good average level of rainfall and similarly all monitored blocks in the study area did not have presence of the bagworms beyond the economic threshold norms, at the exception of November 2011 (Fig 2.3.2a & 2.3.2b). The highest average mean of live larvae was in block 3A with 177.7 and 2B with 141.2. All blocks recorded a mean above the threshold of economic injury.

Statistical Sigma Plot 11 software analysis conducted for both live and dead larvae suggested a positive correlation between the decreases or increases in pest density in relation to rainfall precipitation fluctuations levels for 25 months monitoring period as shown by Figure 2.3.2c in all six census blocks by using combined data.

There is a positive correlation between the increases in live larvae of all instar stage with the decrease of rainfall.

Figure 2.3.2c shows the correlation analysis between the mean monthly infestation density of *P. pendula* against the mean monthly rainfall for the combined data for block 1A, 2A, 3A, B, 2B and 3B.

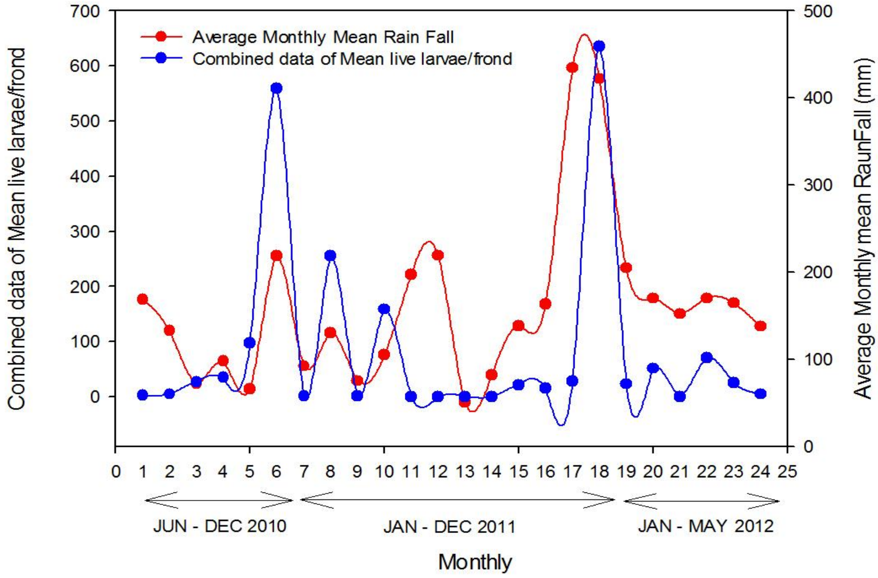


Figure 2.3.2c. Correlation analysis between mean monthly infestations (live larvae/frond) for *P. pendula* against mean monthly rainfall for the combined data of 6 Blocks.

A Pearson product-moment correlation coefficient was computed to assess the relationship between the larvae intensity/number and mean monthly rainfall. There was a weak positive correlation between the two variables, ($r = 0.474$, $n = 144$ $p = 0.0193$). Graphs in Figures 2.3.2c summarize the results. Overall, there was weak, positive correlation between larvae intensity and mean monthly rainfall. An evaluation of the graphs shows that the bagworm density level increases about a month later after the end of the rainy period.

The mean pest density refers here to the average total number of live or dead larvae for each block recorded in each census carried out in the monitored oil palm blocks during 24 months of the study. The analysis for combined data is presented in the graphs of figures 2.3.2c and 2.3.2d.

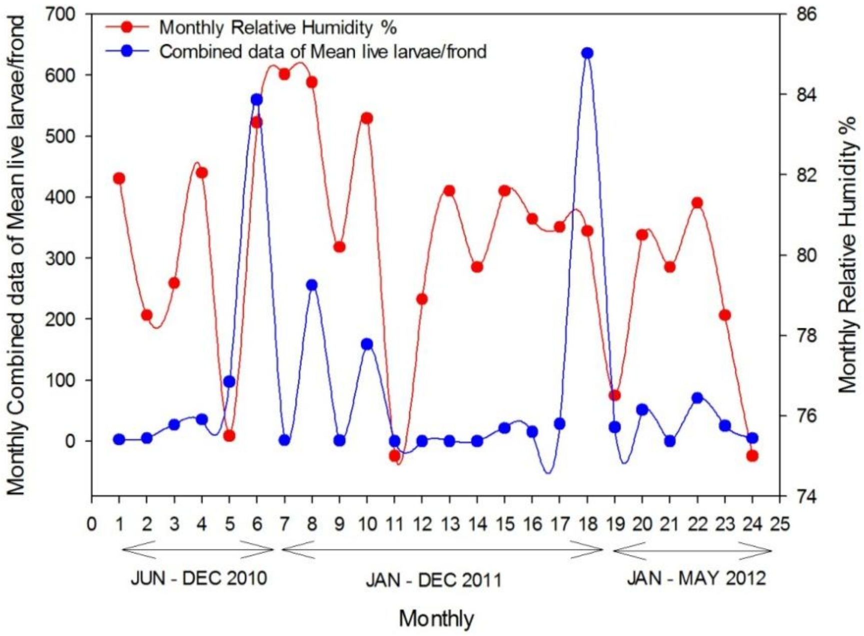


Figure 2.3.2d. Correlation analysis between mean monthly infestations (live larvae/frond) for *P. pendula* against mean monthly relative humidity for the combined data of 6 Blocks.

Overall, the Pearson product moment correlation analysis shows that there is weak relationship between any pair of variables in the correlation table (r=0.309, n=144 for 24 samples, P=0.142, thus P>0.050) for combined data RH versus the mean live larvae as shown in figure 2.3.2g below. The appendix 2.3.2c resumes the Pearson moment correlation coefficient values.

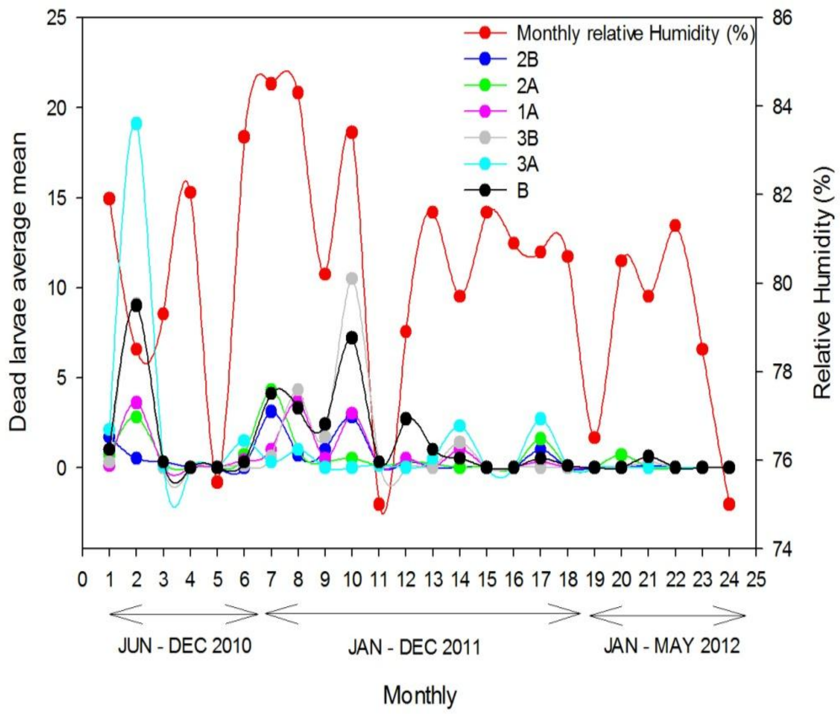


Figure 2.3.2e. Correlation analysis between mean monthly dead larvae density for *P. pendula* against mean monthly relative humidity for data of 6 Blocks.

The Pearson product-moment correlation coefficient shows a moderate positive correlation between relative humidity RH and the mean dead larvae per frond, for block 2B (r=0.501, n=24, P=0.0127). There was a weak positive correlation for block 2A (r=0.372, n=24, P=0.0734) and a small positive correlation in block 1A (r=0.334, n=24, P=0.110). For blocks 3B (r=0.220, n=24, P=0.302), and B (r=0.266, n=24, P=0.209), the correlation is low, there was no correlation in block 3A (r=-0.0700, n=24, P=0.745). Figure 2.3.2f and Figure 2.3.2g show the correlation analysis between the mean monthly dead larvae density of *P. pendula* against the mean monthly rainfall and relative humidity RH for the combined data for block 1A, 2A, 3A, B, 2B and 3B. There are no significant relationships between any pair of variables in the correlation table (P > 0.050), for both rainfall (r=0.0302, p=0.889, N=144) and relative humidity (r=0.268, p=0.206, N=144).

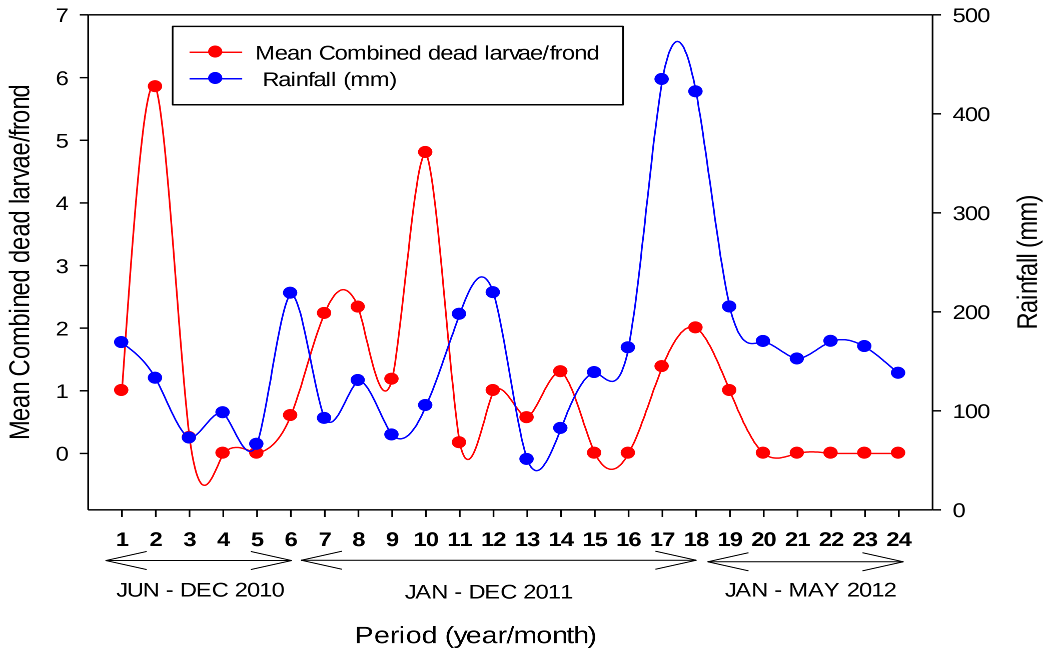


Figure 2.3.2f. Correlation analysis between mean monthly combined data (dead larvae/frond) of 6 blocks against rainfall.

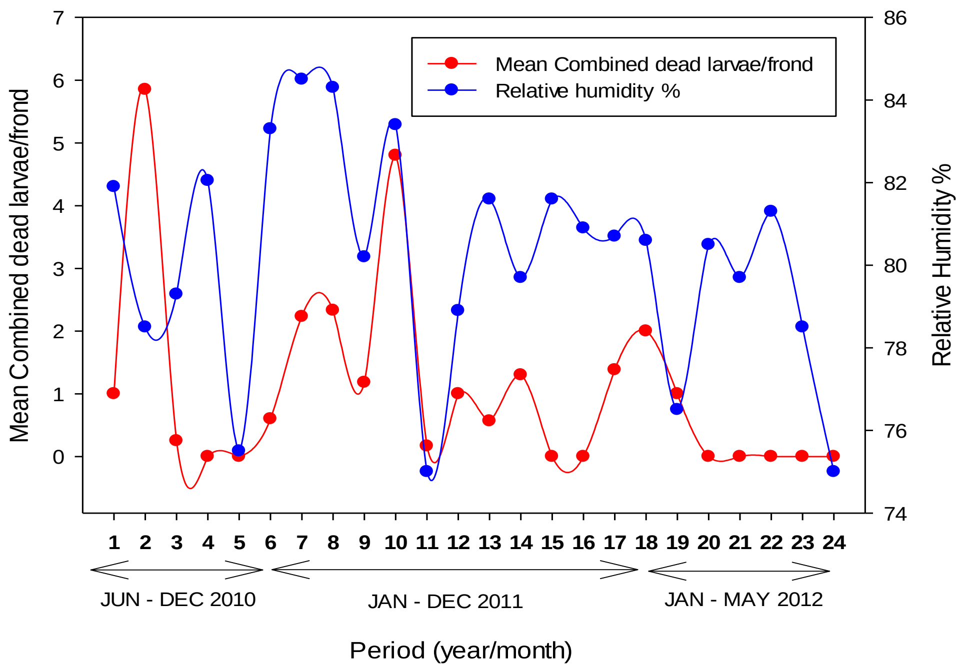


Figure 2.3.2g. Correlation analysis between mean monthly combined data (dead larvae/frond) of 6 blocks against relative humidity.

Regression analyses on the number of live and dead larvae against rainfall data yield R^2 values of 0.2246 (Fig. 2.3.2h) and 0.1415 (Fig.2.3.2i) respectively. This result infers that it is not possible to predict the number of live larvae based on the amount of rainfall.

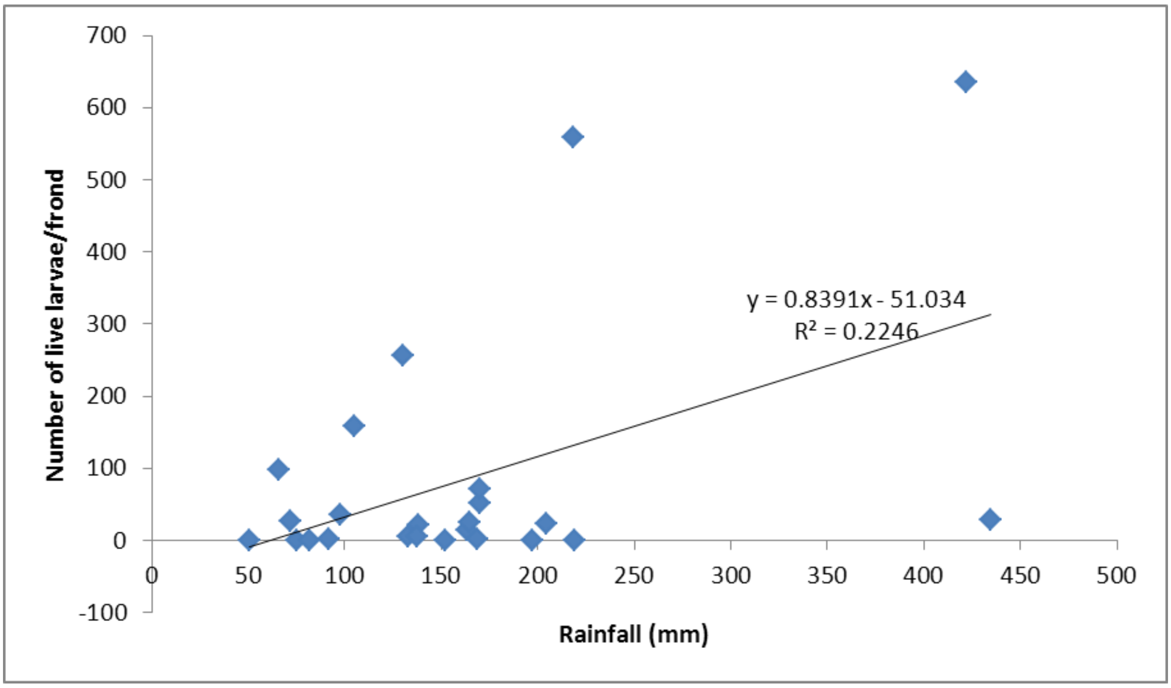


Figure 2.3.2h. Regression scatter plot ofaverage number of live larvae/frond against rainfall.

The two fundamental differences between the correlation analysis by Pearson moment coefficient shown in Figures 2.3.2c-g with the scattered regression analysis diagrams 2.3.2h-k are as follows:

1. A correlation analysis only establish the relationship available between the variables of the study as for instance *P. pendula* population density in live and dead larvae with air temperature and relative humidity. That is absolutely not causal. It does not allow any

prediction of the outcomes on decrease/increase of pest larvae population in relation to the two weather parameters.

2. The regression analysis on the contrary is a causal forecasting of these variables interaction between them. A determined relationship between those variables allows an estimation of how close these two climatic variables are to the main one (fluctuations of pest density). The closer the dots on the scatter diagram, the more of a relationship there is between those variables by establishing an estimated causal effect.

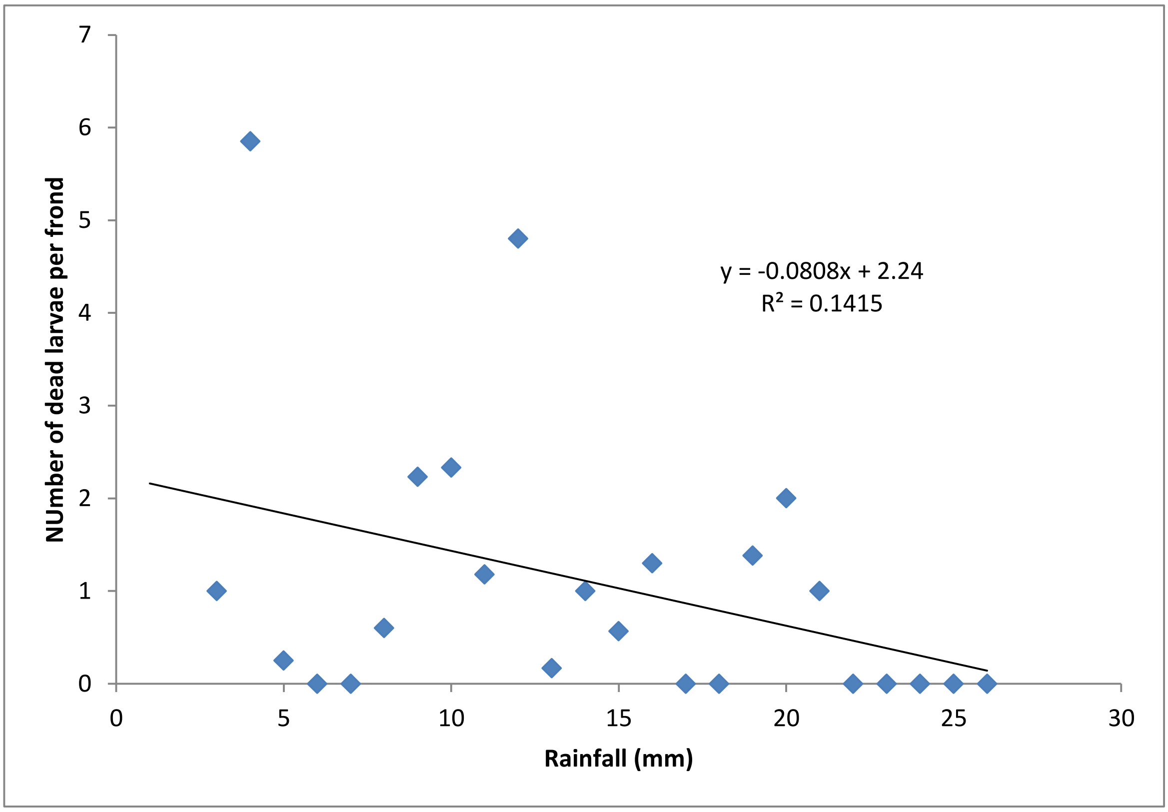


Figure 2.3.2i. Regression scatter plot of average number of dead larvae/frond against rainfall

Regression analyses on the number of live and dead larvae against relative humidity data yield R^2 values of 0.0956 (Fig. 2.3.2j) and 0.0716 (Fig. 2.3.2k) respectively.

The main differences between the analysis in the Figures 2.3.2c-g and Figures 2.3.2h-k are as follows:

1. The Sigma plot represented the fluctuations of *P. pendula* over the time period of the year.
2. The regression scatter plot represented the fluctuations of *P. pendula* over the rainfall and relative humidity directly.

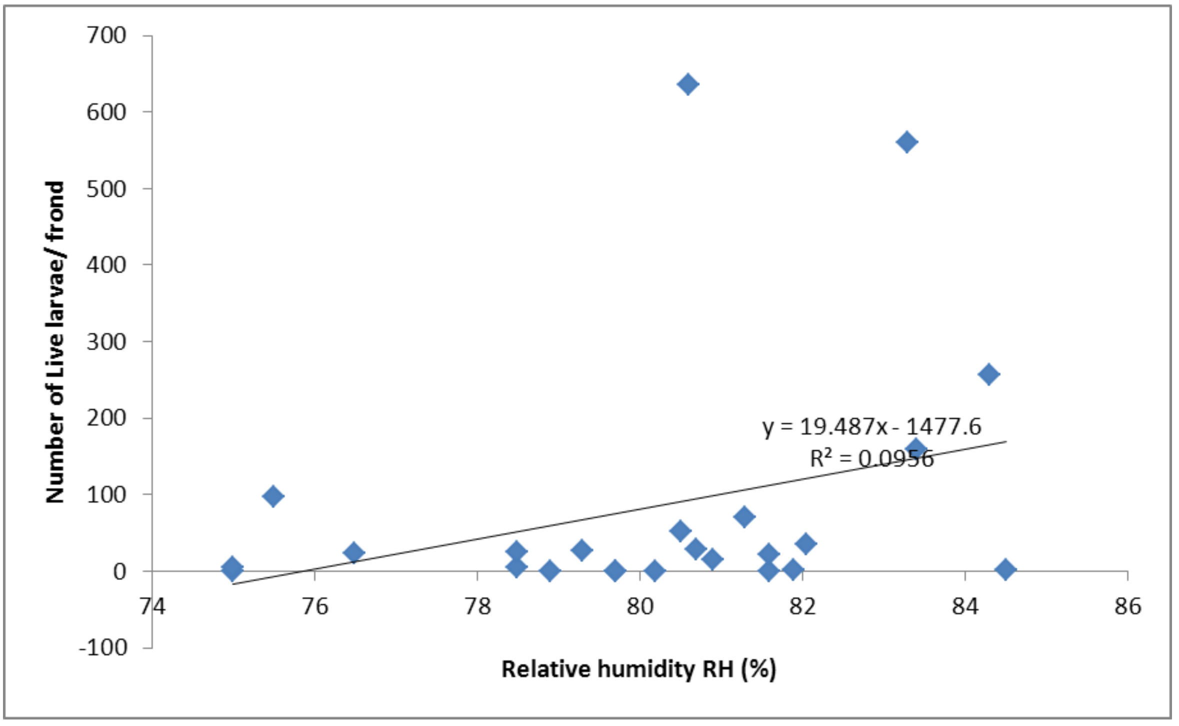


Figure 2.3.2j. Regression scatter plot of average number of live larvae/frond against relative humidity

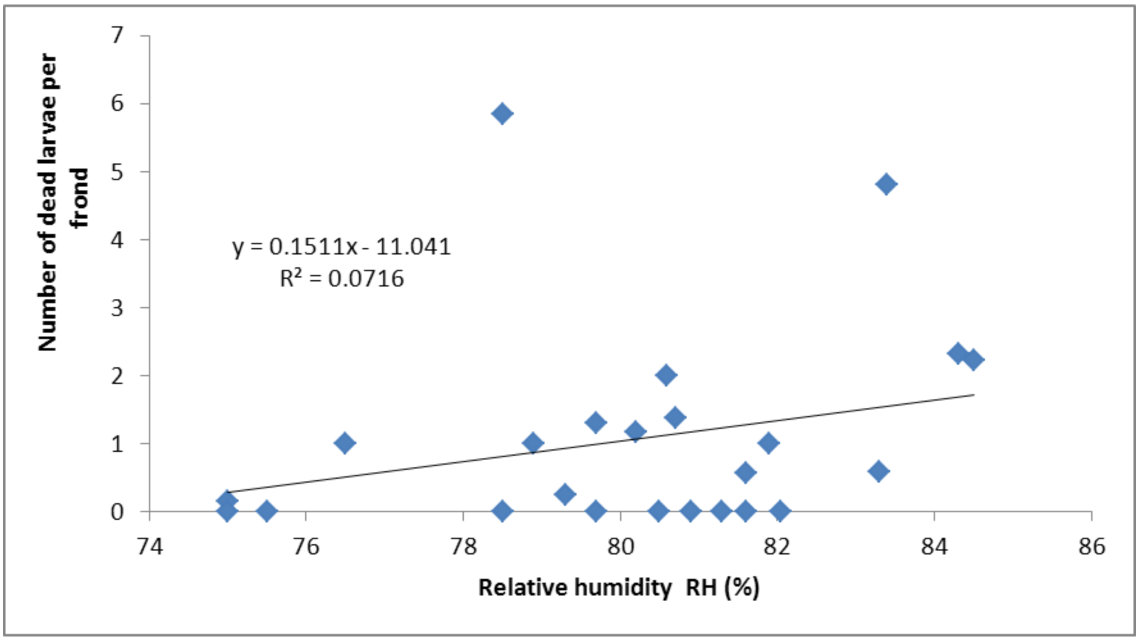


Figure 2.3.2k. Regression scatter plot of average number of dead larvae/frond against relative humidity

2.4 Discussion

2.4.1 Comparative presence of lepidopteran defoliators

Oil palm pests found in Malaysia are those native species that has established and adapted to the monoculture system (Sankaran & Syed, 1972). Pest taxa have a comprehensive range able to significantly affect economically any scale commercial plantations. They are noticeable, from early investiture of the local industry, with the most manifest being lepidopteran defoliators, majority from bagworms (Psychidae) and nettle caterpillars (Limacodidae) as shown by this study (Sankaran, 1970; Wood, 2002; Cheong *et al*., 2010). The most common mentioned in other report (Norman & Basri, 1992) were also found in few oil palm blocks at Teluk Intan.

Early study conducted in Malaysia has been done on *Metisa plana*, *Mahasena corbetti* with less interest given to *Pteroma pendula*. These three species are the most common of all bagworms species ever reported in Peninsular Malaysia (Wood, 1968; Sankaran, 1970).

M. corbetti has been reported in Johor (Basri *et al*., 1988) and particularly in Perak (Norman & Basri, 2007), which is similar to the present location in Teluk Intan (Perak), is still rarer in West Malaysia. Exhibiting a prominent activity in Sabah in the late 60s (Wood & Nesbit, 1969) and early 70s (Young, 1971), the present investigation permit to notice a presence that should not be underestimated since the economic threshold is only 5 larvae per frond.

A comprehensive ecological study had been conducted on *P. pendula* by Ho (2002). Ho was the first to unveil and complete the life cycle study of the bagworm. He also directed his investigations to other important aspects pertaining to integrated pest management of oil palm plantations in Malaysia. This study, establishing *P. pendula* as the most dominant species of bagworms in peninsular Malaysia, corroborates with others recent findings in the same area of "Hutan Melintang, Perak" (Cheong *et al*., 2010). A wider national survey conducted earlier by MPOB (Norman & Basri, 2007) had shown otherwise putting *M. plana* as dominant defoliator. Nevertheless, only *P. pendula* attained the threshold level of injury throughout 25 months of monitoring and assessment in the field.

2.4.2 Correlation between pest density fluctuations and rainfall, relative humidity

The figures 2.3.2.a and 2.3.2.b provided a clear insight on the monthly update of larval infestation, showing regular fluctuations from high to low. Many planters and MPOB field staffs, researchers alike claimed that there is a relation between pest density variations with the rainfall distribution which is similar to results obtained here. This finding contrasts with another study done recently in the same geographical vicinity stating that correlation was not significant (Cheong *et al*., 2010). The availability of bagworms in oil palm plantations were shown to be maintained irrespective of dry or rainy season, corroborating with another study (Chung & Sim, 1991). However one recent result obtained in Perak by the former author, still demonstrate that outbreaks is related to the monthly rainfall regime (Cheong *et al*., 2010). In that report, heavier precipitation was followed by an absence of infestations. Precipitation for November 2002 amounted to 400 mm in 20 days, resulted in no outbreak records until April 2003 (5 months). In June 2003, for rainfall amounted to a total volume of 280 mm in 14 days, there was no account of infestations until January 2004 (7 months). Moreover, there were nine months of very low record on rainfall monthly volume, and seven month of more sustained rains in the two subsequent years (Cheong *et al*., 2010). A detailed analysis on average monthly mortality of larvae in the sampled blocks is important to relate any real link. Our observation in the present study suggests that higher frequency of daily rainfall coupled with sustained volume may significantly impair the life cycle of the bagworm by causing disruption. This is the case particularly in the month of November 2010 with the highest frequency and total volume, correspondingly showing a dramatic plunge of pest density in the subsequent month (Fig 2.3.2a & 2.3.2b) of the same year. Further, the statistical analysis using Pearson Correlation Coefficient suggested a relative weak relation between the rainfall and the pest density of live and dead larvae for certain blocks (Fig. 2.3.3a, Fig. 2.3.3b & 2.3.3c). This probably suggests that microclimate factors are important as well (Mahadi *et al*., 2012), and more accurate monitoring by census need to be conducted periodically for outbreaks prevention (Chung & Sim 1991; Caudwell, 2000), systematically during outbreaks (current census provided approximated data).

However, regression analysis between infestation with rainfall and relative humidity gave a very low index values. This infers that both factors cannot be used as a tool for predicting an outbreak.

Larval mortality is not associated only to rain, but other factors may influence such outcome in oil palm plantations. Our preliminary observations are similar to Cheong *et al* study (2010), reporting the important combination of natural enemies predators such as *Callimerus arcufer* (Coleoptera: Cleridae), *Sycanus dichotomus* (Hymenoptera: Reduviidae), hyper parasitoids *Pediobius elasmi* (Hymenoptera: Eulophidae) and entomopathogenic fungi like *Metarhizium anisopliae* and *Paecilomyces fumosoroseus*. There are several other factors that are responsible for pest outbreaks. One of these factors is the duration of the species' life cycle. *P. pendula* has been demonstrated to have the shortest life cycle history among others bagworms species by an average of 45 days (Ho, 2002). By having a short life cycle, the generation turn over is several folds compared to other bagworm species.

Another factor which may be advantageous to *P. pendula* in causing outbreak is the fact that the species is highly polyphagous. It is reported that *P. pendula* exhibits an extensive range of host plants amounting to more than 30 species (Ahmad & Ho, 1980; Norman *et al*., 1994).

The use of chemicals for the control of *P. pendula* is crucial to be discussed in the context of outbreak causal factors. During pest control using chemicals, it can move to nearby untreated areas because it can survive on other host plants. As for example, there are brush cherry trees (*Syzygium aqueum*) growing at the peripheral of the treated oil palm blocks (Exélis Pierre & Azarae, 2013). It was observed to harbor *P. pendula* when adjacent oil palm trees were treated for pest control. The same condition prevailed in neighours plantations like Southern Perak Plantations (SPP) and Federal Land Consolidation and Rehabilitation Authority (FELCRA). It will return when condition is back to normal but now without competitor and thus the population can explode to an outbreak level.

2.5 Conclusion

Based on the result of this study, the following conclusions are made:

- Census found 9 species of lepidopterans defoliators comprising of 4 species of nettle caterpillars and 5 species of bagworms. The bagworms are the most dominant defoliators contributing 99.6% of the frequency percentages.

- Among the bagworms, *P. pendula* is the most dominant species contributing 96% of the total count.

- Survey on mean monthly infestation density of *P. pendula* shows singular annual peak around November. Two lower peaks occurs around January and March for the first year of survey but less obvious in the second year.

- Correlation analysis on the number of live larvae against rainfall shows a weak positive correlation (r=-0.070 to r= 0.474). The number of live larvae increases or decreases with rainfall but with a lagging period of about one month. However it has weak positive correlation with relative humidity (r= 0.309).

- Correlation analysis on the number of dead larvae against rainfall shows almost no correlation (r= 0.0302) while for relative humidity (RH), there exist a moderate positive correlation in block 2B only (r= 0.501). The influence of rainfall and relative humidity should not be underestimated and nullified on *P. pendula* occurrences.

- However from this study, regression analyses suggest that it is not possible to use the two weather parameters as a tool for predicting the outcome of an outbreak of *P. pendula* at the oil palm plantations of Teluk Intan convincingly enough.

CHAPTER 3

3.0 STUDIES ON THE PREDATORY ACTIVITIES OF *Oecophylla smaragdina* ON *Pteroma pendula*

3.1 Introduction

3.1.1 The Asian Weaver Ants

The Asian weaver ant is a eusocial insect due to the existence of their reproductive queen's sterile workers and soldiers. This concept was well describe as being articulated around three main characteristics: overlapping generation between parents and offspring's, a particular exceptional cooperation for brood care, and finally the present of sterile individuals highly organized in specialized castes (Wilson, 1971).

Weaver ants exhibit arboreal habits but sometimes they can be found foraging on the ground. Their large polydomous nests are normally always found on tree canopies (Dejean *et al*., 2007). Weaver ants demonstrate a characteristic ability of binding leaves and twigs with silk produced from her larvae, enabling them to establish colonies on tight nests along the trees (Hölldobler & Wilson, 1977a). Nest building began with the detection of a suitable site, enabling workers to initiate nest construction by pulling two leaves edges together while other workers assisted the task by lining up in a strong chain - holding and pulling each other's leaf blade resulting in a tent like formation with the weaved leaves. Only major workers would then carry and manipulate spinning larvae of late instar stage to bind and glue weaved leaves in order to finally obtain a real finished "camping like water proof shelter" (Hölldobler & Wilson, 1990).

Oecophylla smaragdina can be found on many species of host plant, either wild or domesticated. Many local wasteland plant species such as *Macaranga spp*, *Vitex vestita*, *Trema oreintalis*, *Mallotus paniculatus* and *Dillenia suffroticosa* harbours them. Locally, they are common in orchards thriving on fruit trees like *Nephelium lappaceum* (rambutan), *Lansium domesticum* (langsat*)*, *Syzygium aqueum (jambu mawar)*, *Garcinia mangostana* (manggis), *Citrus maxima* (limau), *Mangifera indica* (mangga) and *Theobroma cacao* (koko) (Dejean *et al,*. 1997; Kenne *et al,*. 2003). It was aslo reported to inhabit mangroves ecosystem (Offenberg, 2004; Azarae –pers comm). The distribution of *Oecophylla smaragdina* in Australia was reported to be associated to temperatures and humidity (Lokkers, 1986; Lokkers, 1990) with a formula enabling prediction and identification of suitable territory.

They are also prevalence in oil palm plantations nationwide as reported by Exélis Pierre & Azarae (2013).

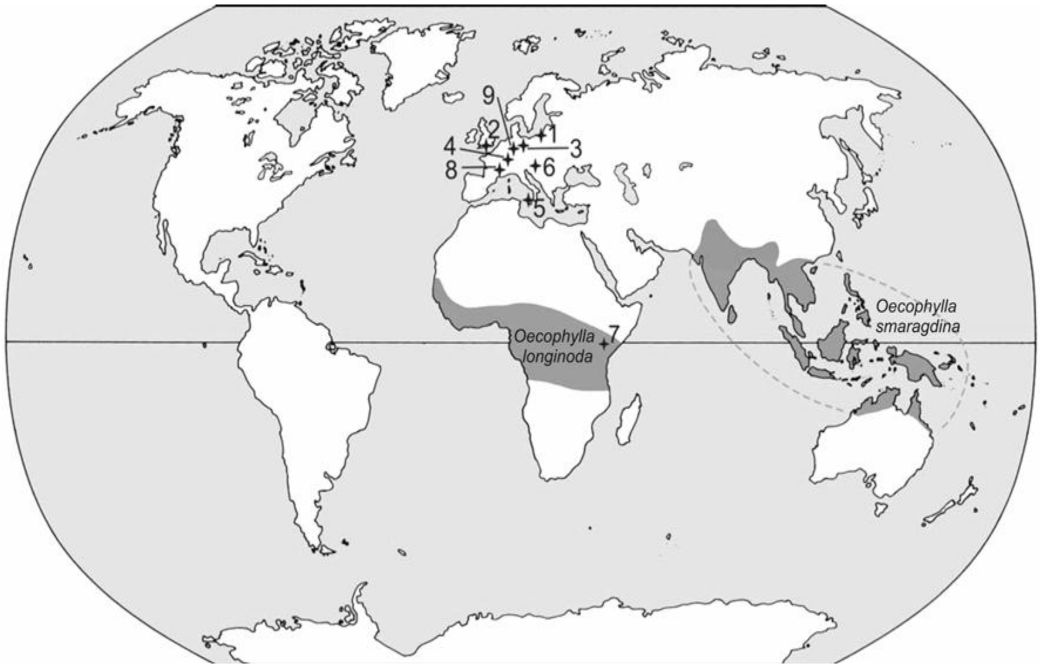


Figure 3.1.1. Distribution of the two extant species of *Oecophylla*, and fossil sites (numbered 1-7) (Lokkers, 1986, Dlussky *et al*., (2008). Extracted from Crozier *et al*., 2010.

Figure 3.1.1 shows the distributions of the two currently-recognized species of *Oecophylla*, and fossil sites (numbered, some numbers cover two nearby sites), from Dlussky *et al*., (2008), after Lokkers (1986), by permission. Sympatric pairs of fossil species have been found twice – *O. brischkei* and *O. crassinoda* in the Eocene (Baltic amber, site 1) and *O. atavina* and *O. megarche* in the Oligocene (Isle of Wight, site 2), whereas the extant species are allopatric. Site 7 is where the fossil nest of *O. leakeyi* was found. The information was extracted from a masterpiece of evolution – *Oecophylla* weaver ants (Hymenoptera: Formicidae), (Crozier *et al*., 2010)

3.1.2 Taxonomical Note

Oecophylla smaragdina is taxonomically placed under the Family Formicidae of the Order Hymenoptera which among other comprises the bees, wasps and sawflies. The Family is subdivided into 11 subfamilies, 297 genera with approximately 8,804 known ant species (Hölldobler and Wilson, 1990). *O. smaragdina* belong to the Formicinae subfamily which are species without a functional sting. It is further classified into 6 subspecies: *O. s. fuscoides* - *O. s. gracilior* - *O. s. gracillima* - *O. s. selebensis* - *O. s. smaragdina* - *O. s.* subnitida. In this chapter, the species investigated is *O. smaragdina*.

3.1.3. Biological control

Since the negative side effect of broad spectrum pesticides in chemical control system of pests induced a significant elimination of natural enemies by resulting into extensive secondary heavier pest's infestations, their necessary ecological balancing became more relevant. This was the case of outbreaks like the brown plant hopper in Asia's rice plantations in the 1980s (Kenmore, 1981; Wilson & O'Brien, 1986). Since then, many ecological studies have been conducted on indigenous natural enemies of pest to be used as an ecologically friendly pest control management regime (Barbosa, 1998; Altieri & Nicholls, 1999 & 2004; Bianchi *et al*., 2006).

The overwhelming abundance and omnipresence of ants and their many beneficial ecological roles as predators in tropical agro systems (Philpott & Armbrecht, 2006; Philpott *et al*., 2008) did not attract enough attention from entomologists as it should be expected in terms of biological control. It is reflected in the scarcity of publications on the role of ants as biological control agents which accounts to a mere 1%. The problem is more critical for Africa than for Asia since the integration of *Oecophylla* in IPM has increased steadily in Southeast Asia, Vietnam (Van Mele & Cuc, 2000) and Australia.

The weaver ants have been known to prey on many insect species albeit its preference for nectary's exudes from plants as well as sugary secretions produced by Hemipteran and caterpillars (Blüthgen & Fiedler, 2002; Tsuji *et al*., 2004). They are very ferocious foragers, attacking almost any organisms that cross their path or deliberately intruding into their territory. It is because of this predacious attribute that the species was use for biological control of pests by farmers.

It is recorded that the Chinese have been using weaver ants to protect their citrus orchards since the early centuries of the last millennium. In this respect, it is interesting to distinguish three main chronological records: the first records dated 304 A.D to 877 A.D giving proper accounts and basic description of the so called "yellow ants", manipulated as a biological agent against pest insects of oranges. The second record is from 985 A.D to 1401 A.D, whereby the ants have been baited by the usage of fat on cut bladders of hog or sheep. This was the Chinese habitual method of initiating the weaver ant colonies. The last dated back from 1600 by the introduction of long bamboos strips interconnecting tree to facilitate the dispersal of colonies (Huang & Yang, 1987). On a similar note, Greenslade (1971) working in Solomon Island demonstrated that the proximity of non-crop vegetation to crop plants had a significant influential effect on the dispersal of *O. smaragdina* in coconut plantations through bridging the gap.

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". In the middle of the 20th century, a British entomologist, Michael Way investigated *Oecophylla* for its biological control efficiency in coconut palm tree pests in Zanzibar by demonstrating how weaver ants could effectively control the Coreid bugs *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) which was responsible for the "coconut gumming disease" by sucking the nuts (Way, 1953). Albeit that his work is more focused on the biology, behavior and ecology of *O. longinoda*, he provides methods for a potent usage of the weaver ant's natural skills in reducing or suppressing of pests (Way, 1953). A recent survey conducted on the island of Unguja, Zanzibar reported the continuing beneficial impact of *O. longinoda* on coconut palm nuts by increasing the yield (Sporleder & Rapp, 1998). Peng and Christian (2004) found that *O. smaragdina* effectively control the main insect pests of cashew plantations in the Northern Territory of Australia and Papua New Guinea, (Peng *et al*., 2004), and against the red-banded thrips, *Selenothrips rubrocinctus* on mango crops in the former territory.

Oecophylla smaragdina is reported to control over 50 varieties of insect pests' from around 12 diverse crops in tropical areas (Way & Khoo, 1992; Peng & Christian, 2006), such as in mango orchards in Australia (Peng & Christian, 2005). Offenberg (2004) reported that the presence of weaver ants on the mangrove species, *Rhizophora mucronata* in Thailand helps to significantly reduce the presence of two herbivores damaging pests – the chrysomelid beetles and sesarmid crabs which was responsible for 62% and 25% defoliation damages respectively. Table 3.1.3a provides the list of crop plants and their pest species where the weaver ants is used as control agents while Table 3.1.3b provides the summary of insect pest species controlled by green ants.

In Malaysia, large area has been planted with oil palm since half a century ago. It is known that the infestation of the leave fronds by the bagworms, *Pteroma pendula* is serious in certain areas (Norman & Basri, 2007; Cheong *et al*., 2010). It contributes to the declining of productivity due to damage leaves caused by the pest especially during the larval stage which is actively feeding. In heavily infested area, the defoliation injury may cause substantial economic loss (Wood, 1973), as high as 44% (Basri, 1993). The presence of *O. smaragdina* in oil palm plantations (Exélis Pierre & Azarae, 2013) offers the opportunity to study its predatory behaviours in relation to the bagworm problems, which so far have not been studied and documented.

Table 3.1.3a. Reports of *Oecophylla* spp. as beneficial predators

Ant species Pest	**Region**	**References**
Coconut	*Pseudotheraptus wayi*	East Africa Vanderplank F.L (1960)
O. longinoda		
		Way M.J (1953)
	Pseudotheraptus devastans	Ivory Coast Jones, C.G *et al*., (1979)
O. smaragdina	*Amblypelta cocophaga*	Solomon Islands Brown, E.S (1959)
		Phillips, J.S (1940)
	Axiagastus cambelli	Solomon Islands Lever, R.J.A.W (1933)
		New Britain Baloch, G.M (1973)
		Papua New Guinea O' Sullivan, D.F (1973)
	Brontispa longissima	Solomon Islands Stapley, J.H (1980)
	Promecotheca spp.	Papua New Guinea Murray, G.H (1937)
Cocoa	*Distantiella theobroma*	West Africa Leston, D (1973)
		Markin, G.P *et al*., (1973)
O. longinoda		
	Crematogaster spp.	West Africa Strickland, A.H (1951)
O. smaragdina	*Helopeltis theobromae*	Malaysia Way, M.J & Khoo, K.C (1989)
	Amblypelta theobromae	Papua New Guinea Szent-Ivany, J.H (1961)
	Peudodoniella laensis	Papua New Guinea Szent-Ivany, J.H (1961)
	Pantorhytes spp.	Papua New Guinea Szent-Ivany, J.H (1961)
		Room, P.M & Smith E.S.C (1975)
	Pantorhytes biplagiatus Rodents	Solomon Islands Stapley, J.H (1973)
		Malaysia M.J Way
Coffee	*Antestiopsis intricata*	
O. longinoda		Ghana Leston, D (1973)
Citrus		
O. smaragdina	*Tessaratoma papillosa* and other	China Huang, H.T & Yang P (1987)
		Needham, J (1986)
	Heteroptera	China Yang, P (1982)

	Rhynchocoris humeralis	
	Rhynchocoris serratus	Philippines Garcia, C.E (1935)
Eucalyptus *O. smaragdina*	*A. cocophaga*	Solomon Islands Macfarlane *et al*., (1976)
Mango *O. smaragdina*	*Cryptorrhynchus gravis*	Indonesia Voûte, A.D (1935)
Timber trees O. longinoda	Scolytidae Platypodidae	Ghana Leston, D (1973)
Oil palm *O. smaragdina*	*Cremastopsyche pendula* and others	Malaysia G.F Chung*

* Personal communication. (Source: Way & Khoo, 1992). Modified references by the present author
^ Personal observation.

Table 3.1.3b. Summary of insect pest species controlled by green ants. Data are extracted from Appendix 3.1.3

Order	Family	Number of species
Coleoptera	Chrysomelidae	2
(Beetles)	Curculionidae	5
	Scarabaeidae	2
	Cerambycidae	5
	Agriidae	1
Hemiptera	Coreidae	5
(Bugs)	Miridae	6
	Pentatomidae	7
Lepidoptera	Noctuidae	2
(Caterpillars)	Gracillariidae	1
	Papilionidae	1
	Psychidae/*Cremastopsyche pendula* (Joannis)	1
	(Crop: Oil palm in Malaysia. Reference: Way & Khoo, 1992)	1
	Geomitridae	1
Other caterpillars		1
Thysanoptera	Thripidae	1
(Red banded thrips)		
Total	**14**	**40**

In this study, the Asian weaver ant colonies are observed to be represented by four different types of individuals which are:

1. The mother laying eggs wingless queens, red brownish in colour, with a much larger body compare to others members (Plate 3.1.3a). Among them, virgin queens are green in colour with a pair of wings (Plate 3.1.3b A-B).

Plate 3.1.3a. Captured laying eggs wingless maternal queen surrounded and protected by major workers.

Plate 3.1.3b. Multiple winged virgin queens (A) with a single one (B) exhibiting green colour type from brood nest type (green arrows).

2. The winged males, of black colour, smaller than the queen
3. The minor workers (nursing ant broods and scouts), shortest in size
4. The major workers with strong ferocious mandibles used for predation on various oil palm pests (Plate 3.1.3a) and protection of the mother queen in particular.

3.2 Objectives

Against the above given background, this chapter is to the study the Asian weaver ants in oil palms with the following objectives:

- To study the occupancy patterns of the weaver ants on the palm trees;
- To elucidate the predatory behaviours of *O. smaragdina* towards *P. pendula* with respect to active feeding bouts, attacking tactic and prey (larvae versus pupae) preference.

- To assess the degree of infestation by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*.
- To assess the degree of foliar injury caused by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*.
- To assess the productivity of palm that is occupied and unoccupied with *O. smaragdina;*
- To evaluate the impact of *O. smaragdina* on *Elaeidobius kamerunicus* weevil.

3.3 Methodology

3.3.1 Occupancy patterns of *O. smaragdina* on palm trees

For the purpose of this study 5 blocks of young palm trees and 5 blocks of old palm trees were sampled at random. There are five age-groups in the plantation – 25 old (planted in 1986), 13 years old (planted in 1998), 9 years old (planted in 2002), 7-8 years old (planted in 2003-2004) and 3-4 years old (planted in 2007-2008). The taller ones comprised of the older palms (7-25 years old) and the shorter one are the younger palms (3-4 years old). Each block contains an average of 1000 palms. In each block 50 trees were randomly sampled, with adjacent trees excluded whenever they fell into the random sample. Random selection for blocks was made by assigning each block an identification number. These numbers are individually written on papers and put inside paper bag. Ten numbers (5 for short and 5 for tall palms) are taken out at random and those selected are sampled. In each selected block, 50 palm trees were randomly sampled for occupancy of *O. smaragdina*. Similarly, random selection for individual palm trees was made by assigning each tree an identification number base on coordinates of rows and columns.

A total of 500 palm trees were sampled: 250 from each category. These were distinctively different in physiognomic appearance whereby younger palm trees are short and shrubby in appearance and without any interconnecting fronds (1.5-2.5 m), while the older (4-8 m and above) have an obvious bole and crown and overlapping canopies. For this study, it is important that no chemical pesticide was used by the estate several months prior to the start of the study as well as during the duration of the study. Checking with the estate management confirmed that there is no record of chemical insecticide spraying operations for the last two years in the study area.

For each selected palm tree direct observation using naked eye or with the aid of binoculars was made for the presence of all kinds of nests and individual ants of all castes. There are three types of nests:

1. Queen right nests – nests containing a single or multiple queens with eggs and/ or larvae but no pupae (Plate 3.3.1a A).

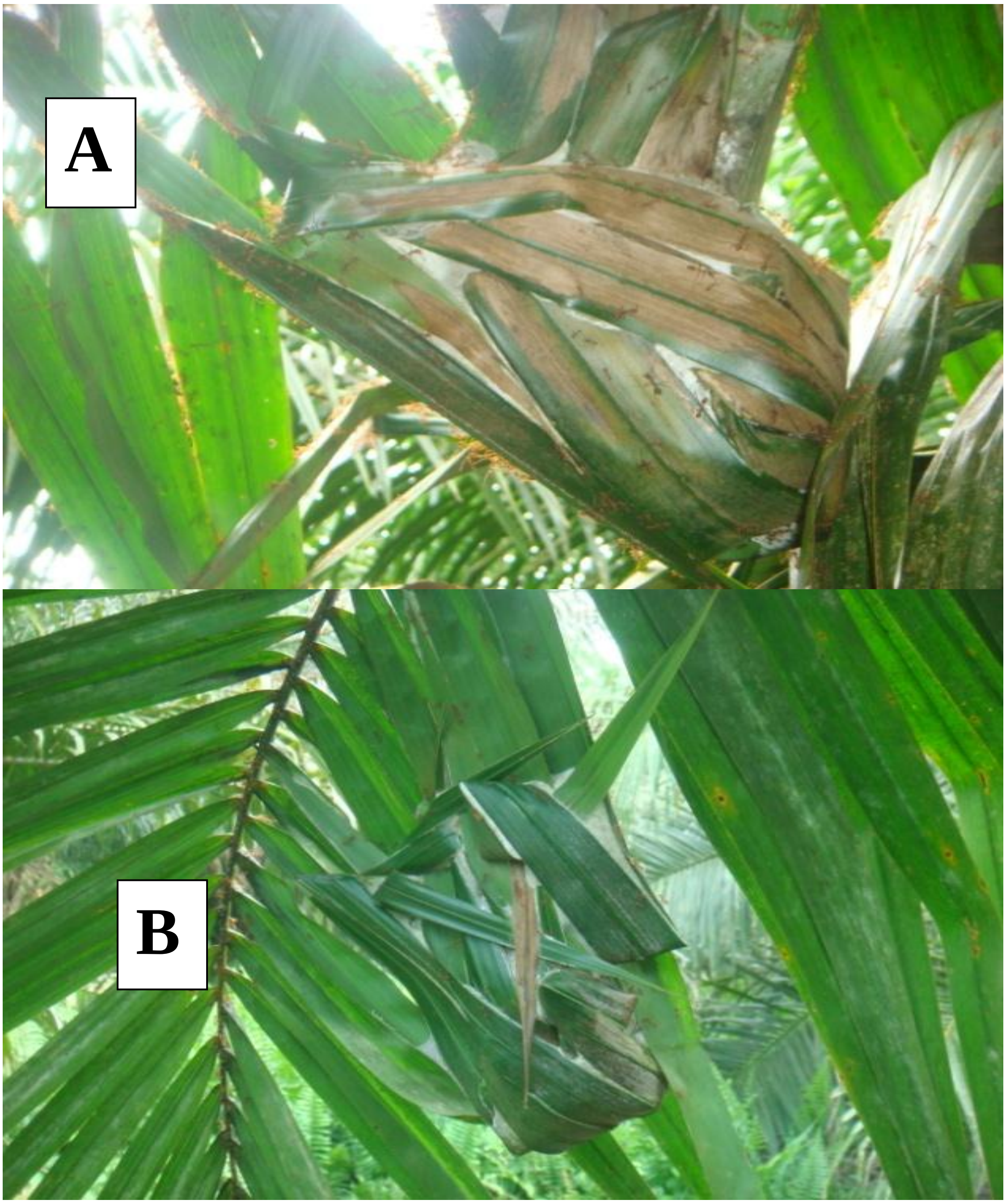


Plate 3.3.1a. (A-B). Queen right nest A heavily guarded by major workers and brood nest B showing much modest presence of guards.

2. "Brood" nests – nests with the presence of eggs, larvae and pupae but without any queens (Plate 3.3.1a B).

3. "Pavilions" (Lim, 2007) or "barracks nests" (Hölldobler, 1983) – nests with no queen or eggs or pupae but could have late instars larvae necessary for binding leaflets of oil palms fronds' (Plate 3.3.1b).

Plate 3.3.1b. Pavilions or barrack type of nest, smaller in size at lower palm frond.

A palm tree was considered occupied by *O. smaragdina* if during the field survey there was a presence of one or more nests (of any type) or one or more individuals or both. An index of preference for occupancy P_i was used to indicate the degree of preference for occupancy for each of the category. $P_i = U_i/A_i$, is calculated based on the degree of utilisation (U_i) over the degree of availability (A_i) where U_i is the percentage of occupied palm trees (as opposed to unoccupied palm) for each category (short vs. tall category) and A_i the percentage of available resources (palm trees) for each category. The index range from 0 to 2 where $0 \leq 1$ indicates avoidance, 1 = no occupancy and ≥ 1 is the degree of occupancy.

The total number of all nests per palm tree was recorded for 100 palm trees. Nests were dissected and examined for the presence of queens. Photographs were taken for records.

3.3.2 Predatory Behaviour of *O. smaragdina* towards *P. pendula*.

In this section three aspects related to the predatory behavior of the weaver were studied: active foraging bouts, attacking strategy and prey (larvae versus pupae of bagworms) items preference.

3.3.2.1 Active Foraging Bouts

Active foraging bouts are defined in this study as the situation when the ants were outside their nests and in foraging activity i.e. continuously moving albeit with some brief halts in-between. An intensive 24-hour scanning sampling was conducted in five occupied blocks. In each block 3 rows were selected for observations. A total of 72 hours (3 replicates) of observations was made. The number of ants foraging on the observed frond was counted and recorded on an hourly basis for 15 minutes from 06:00 h to 05:00 h the next day. The results were plotted on a graph to reveal the hourly numbers and peaks if any.

It is quite common in the animal world that foraging or feeding bouts are related to abiotic parameters. In this study the relation of the active foraging bouts were investigated against air temperature and relative humidity. The weather recording was obtained from a weather station (managed by MPOB) located about 50 m from the observation site. A statistical correlation software Sigma Plot 11 analysis was performed between the average ants foraging circadian cycle with both weather parameter.

3.3.2.2 Attacking Tactic

The tactic used by *O. smaragdina* when attacking the larvae and pupae of the *P. pendula* is studied by direct observation under field and field experimental conditions. Observations are supplemented by video camera recording using Panasonic SDR-S71 video camera with 78X advanced optical zoom and night vision system and subsequently play-backed in the laboratory to scrutinize the tactical actions in details. Base on this careful observational analysis, the holistic approach to attack as used by the weaver ants is broken-down into several phases. A particular tactical act is established base on at least 10, repeated or replicates observations and analysis (as shown in figure 3.3.2.2). Results are presented as descriptive narrations and supported by photographs.

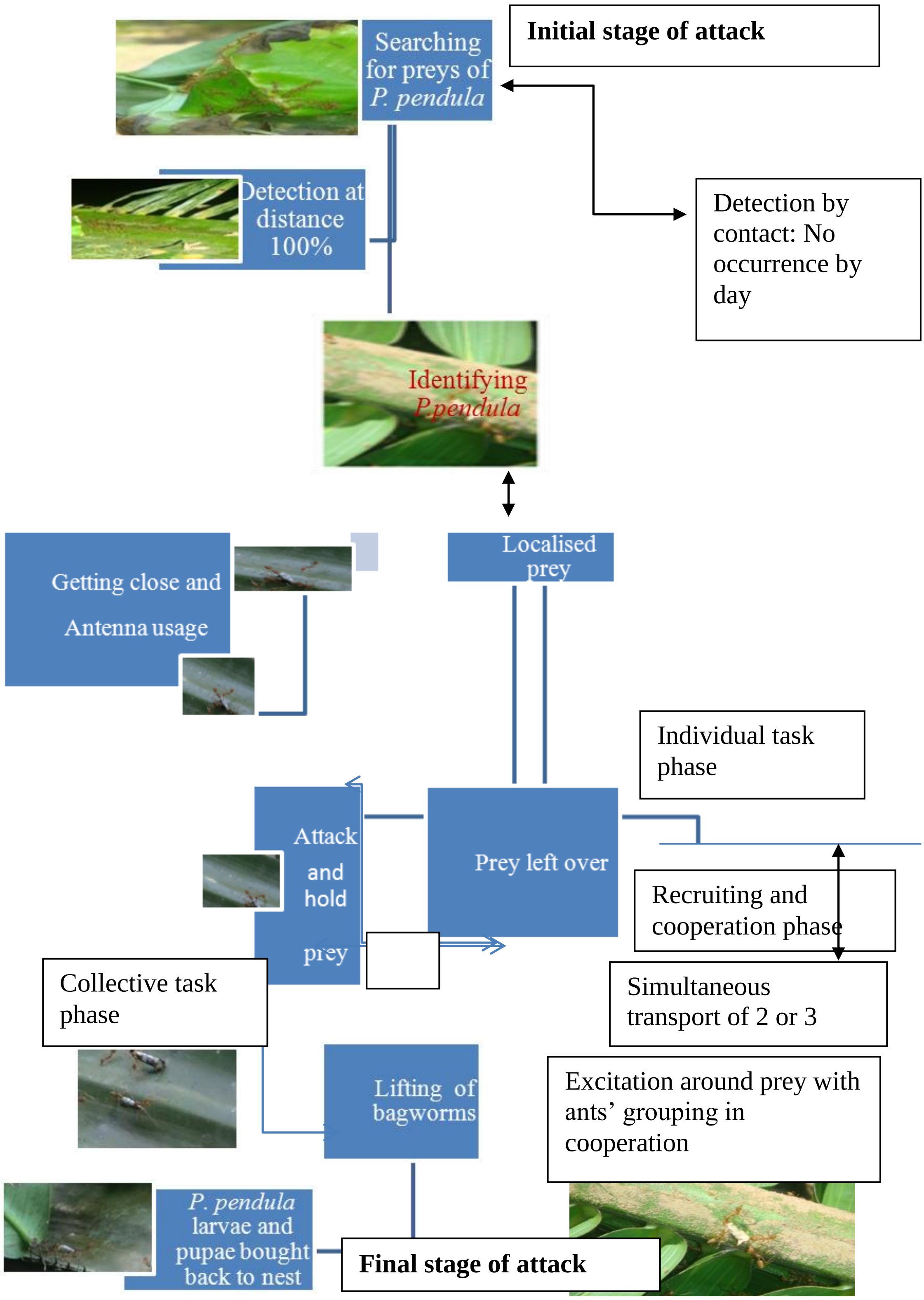


Figure 3.3.2.2. Flow chart of *O. smaragdina* predatory behaviours individually and collectively on various instars larvae and pupae demonstrating major stages of the pest elimination.

3.3.2.3 Prey Preference Experiment

There are four different morphological phases of the bagworm life cycle i.e. the egg, larva, pupa and adult. The Section investigates on the preference of ants with respect to the larvae and pupae as their target only.

The numbers of bagworms on occupied palms is usually low because it is continuously preyed upon by the ants. Thus it is quite difficult to conduct this study in the field. Consequently, an experimental condition was set up in the field by 'artificially' creating encounters between the ants and the bagworms during day and night (Plate 3.3.2.3b). This is done by placing a small nest (of the barrack type) of *O. smaragdina* (Plate 3.3.2.3a) and *P. pendula*.

Plate 3.3.2.3a. Experimental setting. Recording predation experiment using Panasonic video recorder on a pre-selected palm frond with small nest of "jambu air" tree (red arrow)

The number of ants in barrack nests is normally small (usually less than 50 ants) and this small number facilitate the observations. The ants were taken from another host tree, *Syzygium aqueum* (“Jambu air”), (Plates 3.3.2.3a and 3.3.2.3b). In other words, these experimental weaver ants have not been exposed to oil palm as host or to bagworms as prey. The experimental nest was placed on a pre-selected frond. Fifteen *P. pendula* larvae and 15 pupae were simultaneously placed 30 cm from the nest on the same pre-selected frond. A total of 20 replicates of field experiments were conducted.

The number of pupae or larvae preyed on by the ants was noted every 5 minutes for duration of 90 minutes. In this experiment there is a need to determine the cut-off time when most of the pupae or larvae have been taken. The cut-off period of 90 minutes was used based on preliminary experiments whereby it was shown in 6 replicates that after 90 minutes more than 90% of the pupae were taken. Thus the preference analysis is confined to the time period from the moment the experiment starts until the cut-off time (Plate 3.3.2.3b). Video recording was made using Panasonic SDR-S71 video camera with 78X advanced optical zoom and night vision system.

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 (bagworm larvae or pupae) for each category. The index ranged from 0 to 2, where a value of < 1 indicates avoidance, 1 = no preference and > 1 is the degree of preference. The difference in survival rate between pupae and larvae was statistically calculated using the log-rank and Wilcoxon test, by determining its chi-square value obtained from the predation trial done for the 20 replicates in the field.

Plate 3.3.2.3b. Field experiment on the predation activity of *O. smaragdina* on the larvae and pupae of *P. pendula.* The ant’s barrack nest (red arrows) is taken from a difference host tree, *Syzygium aqueum*

3.3.3 Assessment of Infestation by *P. pendula* on Occupied and Unoccupied Palms with *O. smaragdina*

Field surveys were conducted to assess the pest (*P. pendula*) density as well as the degree of frond damage/injury on each selected palm tree. One frond from each palm with 45° angle to the trunk, corresponding to the middle of the palm canopy was assessed for the degree of infestation. For tall trees the fronds were cut by destructive sampling method (Phyllotaxy - Hartley, 1977) and the short palms by non-destructive sampling. The degree of infestation of *P. pendula* is categorized into 5 levels of intensity of infestation (Plate 3.3.3): Level 0 – total absence of infestation; 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.

Plate 3.3.3. *Pteroma pendula* infestation and foliar injury level 1 to 4 in oil palm fronds at Teluk Intan MPOB station.

These categories were formulated based on preliminary sampling of *P. pendula* infestation in the study area whereby the lowest and highest recorded number (lumping all phases of life-cycle) were apportioned on a pro-rata basis into 5 categories based on the economic threshold for *P. pendula* value of 20-30 larvae per frond (appendix 3.3.3), (Wood, 1971; Krishnan, 1977; IRHO, 1991; Basri, 1993). 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 the 250 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* (at the time of the survey conducted), comparison of infestation between an occupied and unoccupied on short palm category could not be made.

3.3.4 Assessment of Foliar Injury by *P. pendula* on Occupied and Unoccupied Palms with *O. smaragdina*

Assessment on the degree of foliar injury was also made on the same palm trees selected for the infestation and occupancy studies. The assessment of foliar injury was made on per palm basis. The total number of palm trees of each level of damage was counted. The degree of damage is categorized into 5 Levels. Level "0": All fronds are green and healthy with no noticeable injury from a distance. Level "1": Fronds with small cut holes (eaten by *P. pendula* larvae), showing sign 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 fronds injury with 34-66% defoliation and desiccation exhibiting numerous and obvious holes. Level "4": Almost all fronds are severely injured with characteristic dried and burning look, resulting in a severe tree dieback (Plate 3.3.3 no.4). Chi-square tests

(Fowler & Cohen, 1986) were conducted to see if there is any significant difference between the occupied and unoccupied palm with respect to *P. pendula* infestation and foliar injury.

$$X^2 = \frac{(O-E)^2}{E}$$

where O is the observed frequency in each category
E is the expected frequency in the corresponding category
X^2 is the calculated 'chi square' value

Correlation analysis using Spearman coefficient r_s was performed between the levels of pest infestation and foliar injury.

3.3.5 Assessment of Productivity of palm that is occupied and unoccupied by *O. smaragdina*

Productivity in this study is defined as the combined number of developing fruit bunches (DFBs) and fresh fruit bunches (FFBs) per palm tree (Plate 3.3.5). The higher the number, the higher was the productivity. Palm trees were selected at random during the field survey conducted for the census/occupancy. For each palm tree sampled, either occupied or unoccupied by *O. smaragdina*, the sum of the number of DFBs and that of FFBs was counted and recorded. The size and weight of the FFB were not taken into consideration in this aspect of the study.

For the purpose of this study productivity was categorized into four Levels: Level 1 (not productive) with <5 DFB/FFBs 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. Ideally the weight of the FFB should be measured and taken into account to determine productivity. However, since this will involve destructive sampling (the FFB need to be harvested) and not allowed by the estate management, the weight element is not used in the definition of productivity. The number of DFB/FFBs produced for each level of productivity between occupied or unoccupied palm trees were compared statistically using the non-parametric Mann-Whitney U-Test.

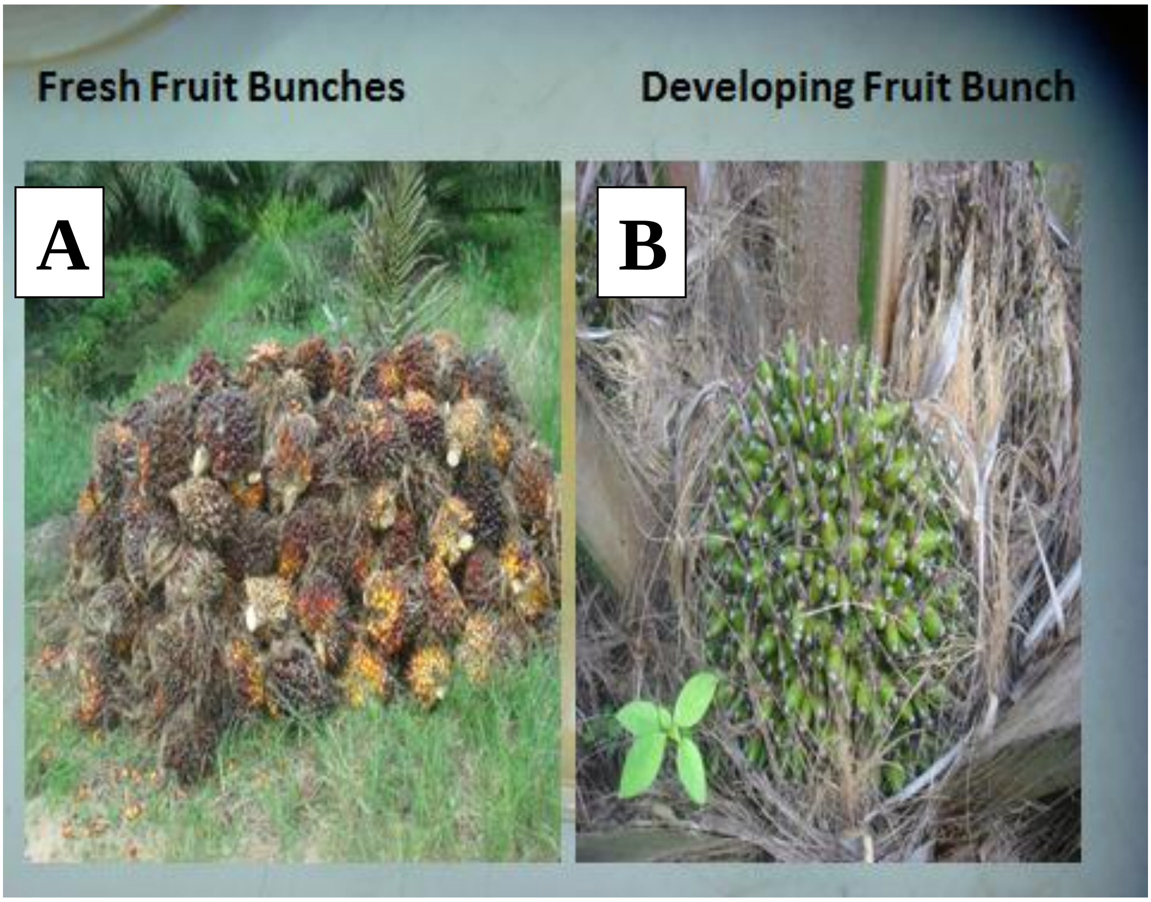


Plate 3.3.5. Harvested Fresh fruit bunches (A) and young fruit bunches (B) still on oil palm tree

3.3.6 Verification on interference of *O. smaragdina* activities on pollinator weevil *Elaeidobius kamerunicus*

The weevil, *Elaeidobius kamerunicus* is a very indispensable pollinating agent for the oil palm (Syed *et al*., 1982; Adaigbe *et al*., 2011). Thus, it is very crucial to determine whether *O. smaragdina* also prey or is harmful to the weevil because if this is the case it may outweigh the benefits obtained from exterminating *P. pendula*. To determine the impact of *O. smaragdina* on the weevil *E. kamerunicus*, observation was made on the spikelet's, when both the weevil and the weaver ant were present. Each spikelet was continuously observed for up to 1 hour during the peak time of ants' activities in the day (12:00-15:00 h and 18:00-19:00 h). Three types of behavior related to attack were monitored and recorded: 1) Attack approach 2) Attack posture 3) Physical attacks. If any of these behaviors is recorded, then it would be considered that *O. smaragdina* does prey on or disturb the weevil. A total of 25 samples were made. Spikelet's exhibiting intense pollinator activity in the flowers was selected for the experiment. Video and photographic recordings (x3000 magnification was applied to capture photos on computer software using software Panasonic VideoCam Suite 3.5, SDR. S71) were made and analysed (Plate 3.4.6 A-C) further in the laboratory to double check the observation made in the field. This is necessary to verify and confirmed the field observation.

3.4 RESULTS

3.4.1 Occupancy patterns of *O. smaragdina* on palm trees

Since the ultimate aim of the thesis is the utilization of the *O. smaragdina* as potential biological control agents in palm oil plantations, thus it is essential to determine its occupancy on the palm trees. The results may lend some insights in its prevalent and occupancy habits.

The results shows that all short palm trees were not occupied by the weaver ants (Occupancy = 0% of 250). Among the tall palms, 230 palm trees (92%) were occupied by *O. smaragdina* with 20 trees (8%) unoccupied (Fig.3.4.1). The ant shows a high preference for tall trees with a Preference Index (P_i) of 1.84 and avoidance of short trees (P_i =0). As expected, the presence of *P. pendula* was significant on shorter palms. However, tall palms with *O. smaragdina* colonies were not affected by the bagworms.

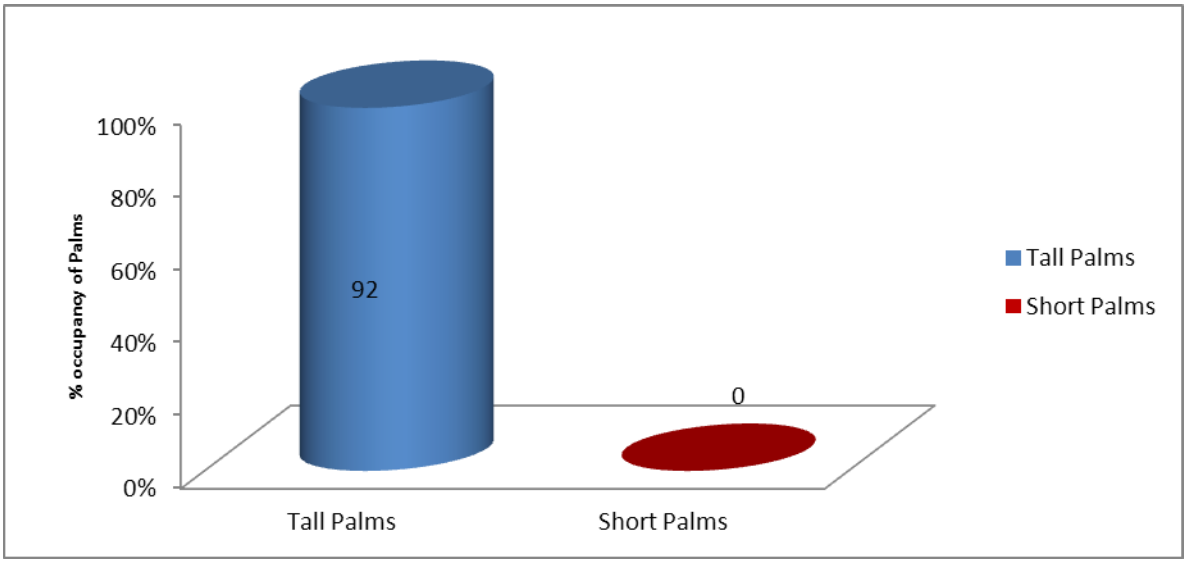


Figure 3.4.1. Frequency percentage of occupancy of *O. smaragdina* on sampled short and tall palm trees**.**

Of the 230 occupied palm trees, 100 (40%) were observed to contain nests of various types (Plate 3.4.1b). These contained an average of 3.98 ±1.74 (mean ± SD, range 1-13) nests per tree (Table 3.4.1). The number of nest per palm tree ranges from 1-13 with an average figure of 5 nests per palm. The present study shows, that the number of nest per palm trees is always odd. This is a peculiar phenomenon that needs to be studied further and affirmatively verified.

The ants also exhibited polydomous nesting behaviour, as reported by another author (Debout *et al*., 2007), whereby a single palm tree may contain more than one nest with multiple queens (pers.obs) observed in main nests, (Table 3.4.1) suggesting pleometrosis and polygyny. However, further study by using microarray satellite DNA profiling technique is necessary to confirm the phenomenon.

Table 3.4.1. Distribution of Nests per Tree in Occupied Palms

No of Nest/ Tree	No of Trees	Total Nest
1	15	15
3	25	75
5	59	295
13	1	13
Grand Total	**100**	**398**

3.4.2 Observation on the Predatory Behaviors of *O. smaragdina* on *P. pendula*

Preliminary observations and countless literature reported the predatory habits of *O. smaragdina*. This section of the study will attempt to elucidate certain parameters relevant to the predatory of the ants towards the bagworm as outlined under the respective methodology (Section 3.3).

3.4.2.1 Active Foraging Bouts

The predatory activities of the ants occur when they forage outside the nests. Hence, examining the temporal patterns of their movements lend a possible clues of peak predatory activities. Active peaks are defined here as the median taken from three replicated observations for three times of a 24-hour cycles. It was observed that the weaver ants had two active peaks during a 24 hour cycle. In other words, they exhibited a bimodal pattern with two peaks during a circadian cycle (Fig.3.4.2.1a). The first peak occurs around midday (12:00 h -15:00 h) and the second peak around dusk (18:00 h-19:00 h). The lowest number occurs around after 24:00 h until about 6:00 h in the early morning. The weaver ants were seen patrolling any time of the day during 24 hours with a noticeable peak activity during the heat time (12:00 h to 15:00 h around), while a drastic decline occurred by night fall and with heavy rains. The average number during the peak is about 10 folds compared during the ebb (peak average =45 ants ±2; ebb average =1 ant, N = 30 observations).

It was observed that the active periods or peak coincides with the increase in air temperature. In order to verify this, a 24-hour observation was conducted for 70 replicates over a period of 90 days. Fig 3.4.2.1a shows that both the first and second active period coincides with the peak of the daily air temperature (Appendix 3.4.2.1a-d providing average foraging, air temperature and relative humidity graphs records). Apart from air temperature, this study also relates the active peak bouts to the condition of the relative humidity prevailing at that point of time. A figure 3.4.2.1b shows that both the first and second active periods are ‘negatively’ coincides with the ebb of the daily relative humidity (Appendix 3.4.2.1d).

O. smaragdina activity has a strong negative correlation with the increase of relative humidity (r = -0.921; p =1.67*E^{-10}; N=24) and a strong positive correlation with temperature increase (temperature: r = 0,874; p =51*E^{-8}, N=24). The pair of variables with positive correlation coefficients and P values below 0.050 tends to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables. Thus, in this case study the correlation is highly significant.

This suggests that temperature and humidity influence is mostly limited to predatory activity during dry period preferably intense in the day and negatively influenced during rainfalls (Fig. 3.4.2.1a).

The graphs clearly show that the first and highest peak period (blue graph) coincide with the peak of the daily air temperature (red graph), (Fig.3.4.2.1a).

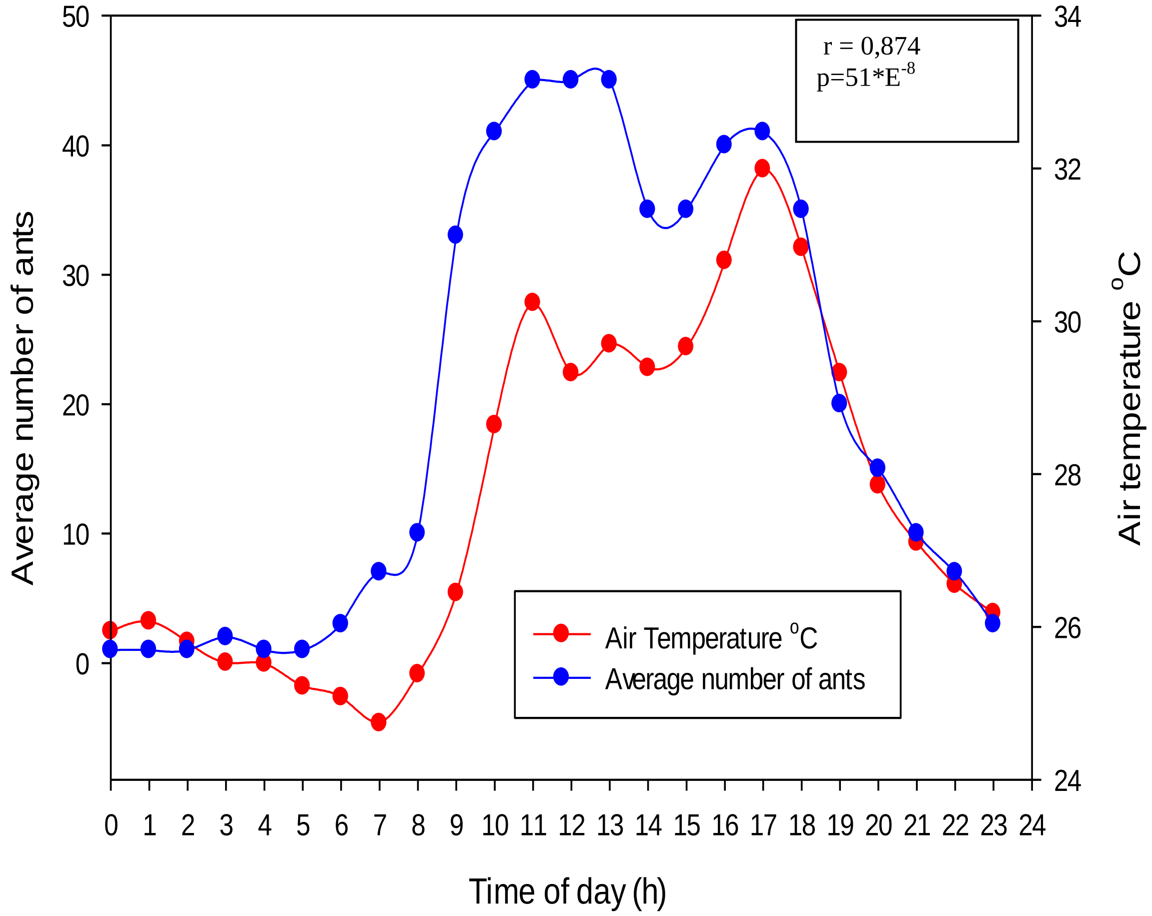


Figure 3.4.2.1a. Two medians of activity peaks in 24 hours circadian rhythms on fronds related to the two Daily temperature peaks lowest level at similar time in oil palm Teluk Intan.

This suggested that the second peak at 17:00 h - 18:00 h before sunset fall might be related to a storage time before the next day usual activity, therefore food supply is made available for the whole night, thus securing the needs of the colony. This behavior was noticed and repeated on following days of observations for successive weeks from 18/04/2011 – 20/04/2011 and 9/05/2011 until 17/05/2011; 24/05/2011 – 27/05/2011 (24 hours basis).

Night activity in foraging of the weaver ants was drastically reduced to show a recrudescence at the first morning light with a first peak beginning from 12:00 h to 14:00 h and 17:00 h to 19:00 h.

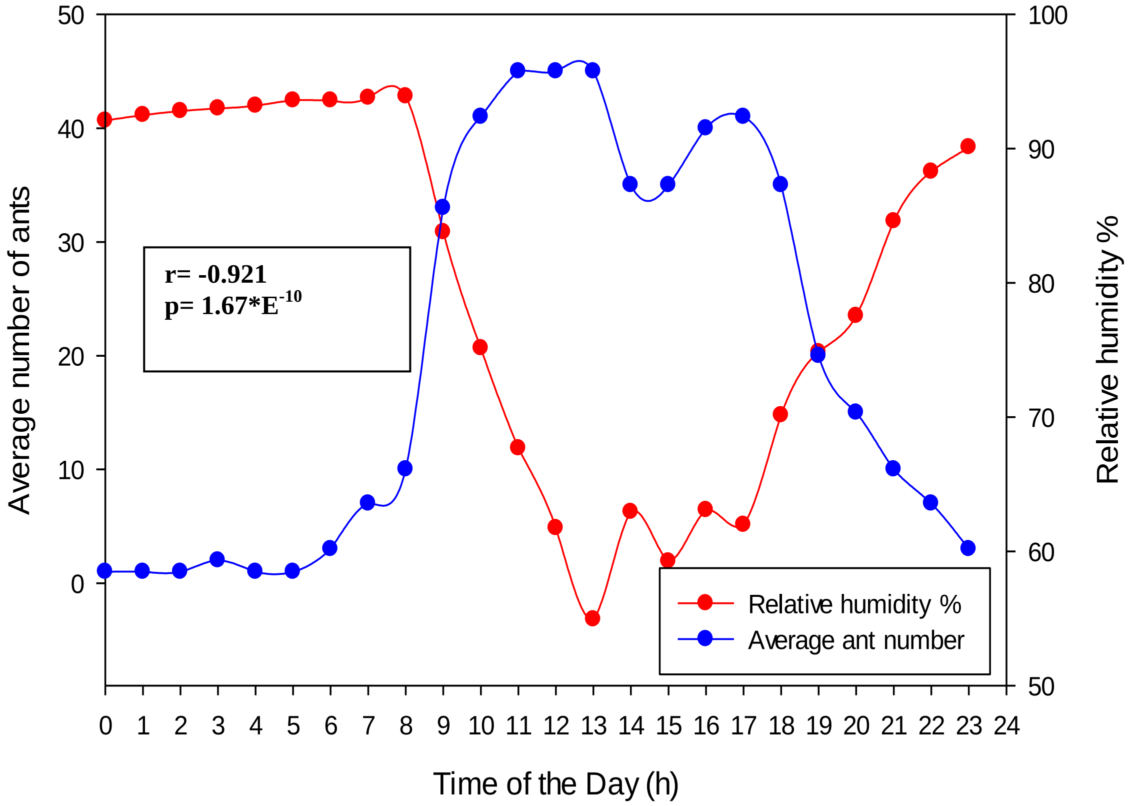


Figure 3.4.2.1b. Sigma plot 12 correlation between average foraging ant and relative humidity (%) against time of the day (h)

The graphs clearly show that the first and highest peak period (blue graph) negatively coincide with the ebb of the daily relative humidity (red graph), (Fig.3.4.2.1b).

3.4.2.2 Attacking Tactic – Analysis of Sequential Acts

The fact that *O. smaragdina* preys on *P. pendula* (larvae and pupae) are established beyond doubt. However, the actual tactical deployment has not been documented in the literature as yet. Results of this study show that the sequence or phases of attack can be simplified into four main phases (Plates 3.4.2.2a-f).

Stage 1 – Foraging and Detection of prey

Many workers, were seen foraging for prey (larvae and pupae of *P. pendula*) when they came out from the nest. It starts with few ants acting as scouts. Once prey is detected, the scout ants went back either to their nest (if members are still inside) or to the point they meet more members and communicated to them by physically touching their sensitive feelers (Plate 3.4.2.2c). Antennae touching is very brief, 1 second on the average (n = 450). More members are seen moving to the detected and targeted prey. Foraging is conducted during daylight. Detection is done visually at an average distance (the maximum tested distance was 30 cm on fronds; N = 30 times). Detection of prey is typically characterized by the gaster being raised at a 90° angle at distance (Plate 3.4.2.2a). There were no detection done by contact between prey and the ant predator.

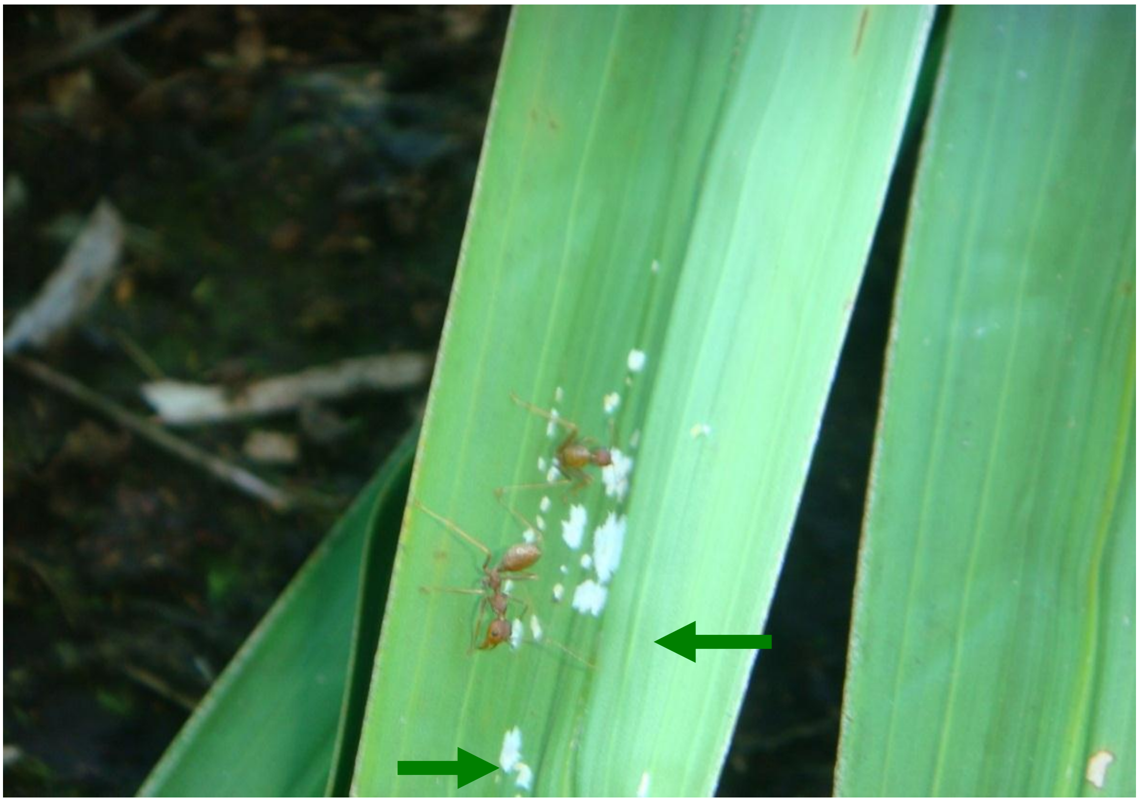


Plate 3.4.2.2a. Stage 1**-** Foraging and detection of preys showing an aggressive stance of *O. smaragdina* with a typical 90˚ abdomen vertical angle extension (green arrows).

Stage 2 – First physical attacking act and securing the prey

Stage 2 starts when an individual ant moves towards the prey and seized it ferociously and aggressively. They first attacked at the base of the head of the prey (if larvae) or the extremities of the pupa bag (if pupae) by inserting their mandibles to physically secure the prey (Plates 3.4.2.2b & c).

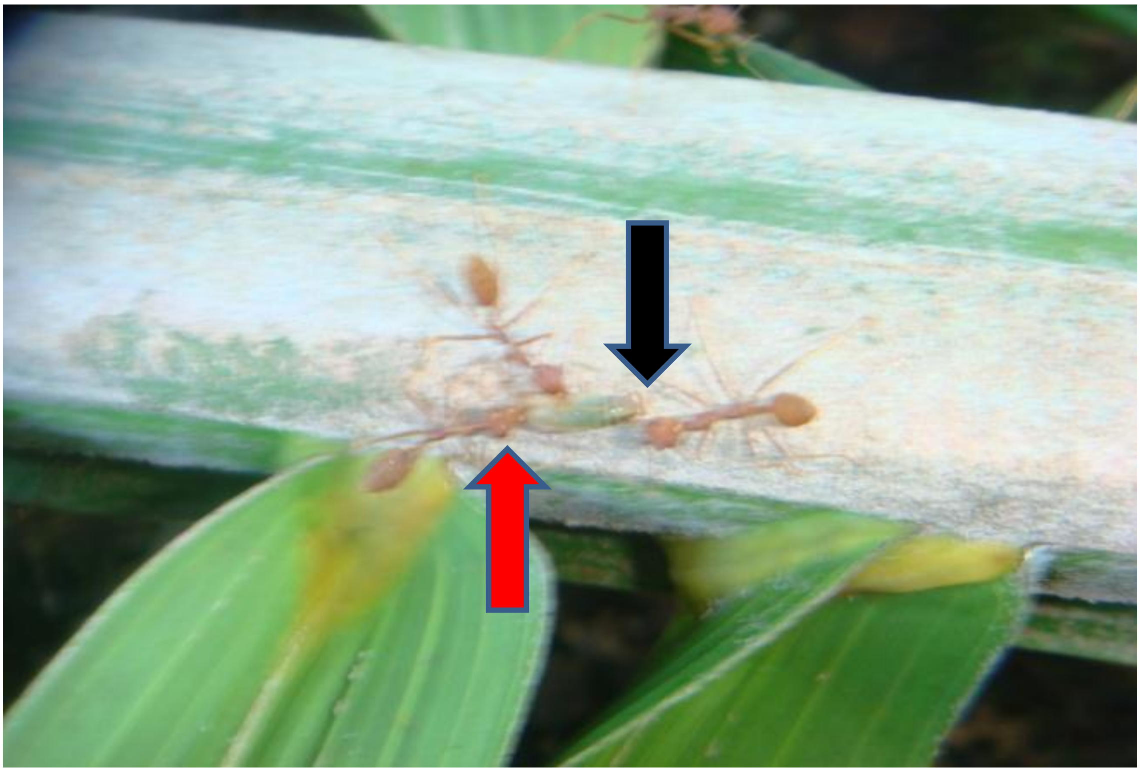


Plate 3.4.2.2b. Close-up view of Stage 2. The red arrow shows an individual weaver ant biting the base of the head of the bagworm larvae **(**Instar III). Another individual is biting the posterior part of the larva body (black arrow).

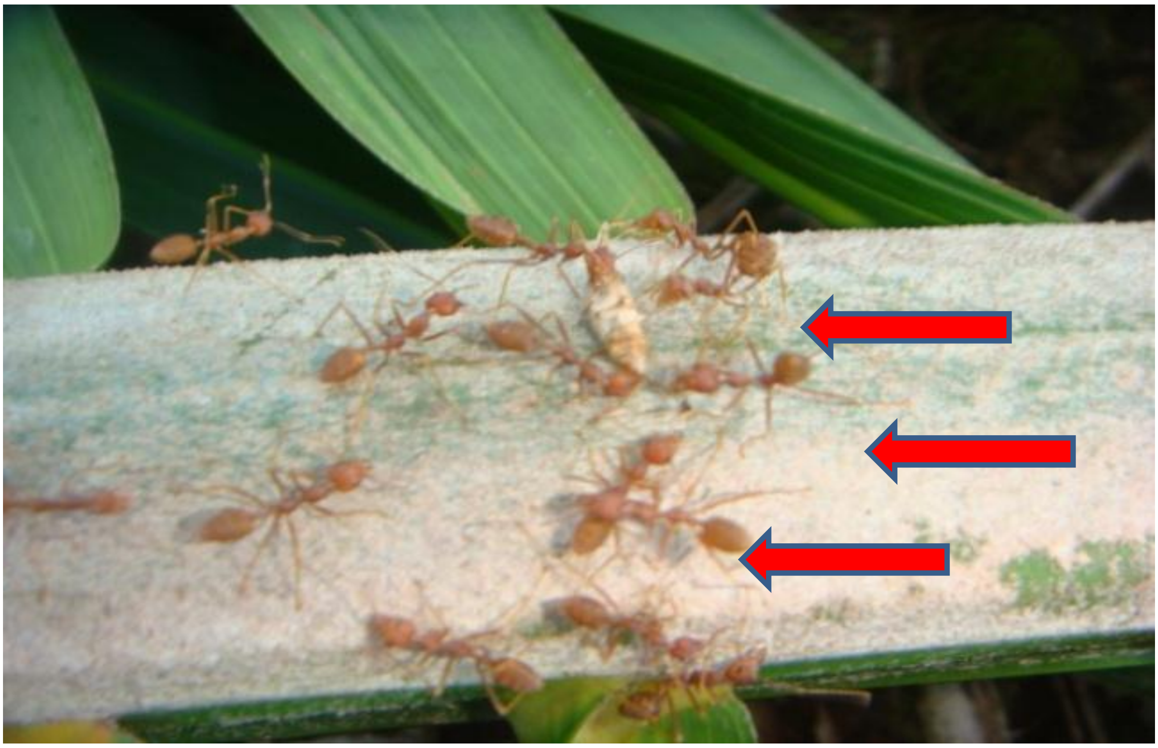


Plate 3.4.2.2c. Stage 2-Detection of *P. pe*ndula pupae resulting in a massive cooperation among *O. smaragdina* ants by antenna communication and body movements to secure prey (red arrows).

Stage 3 – Piercing and releasing of formic acid

Following Stage 2, more ants will now joint the attack by inserting their mandibles into the cuticle of the abdomen of the larva or body of the pupa. Analysis of video recording shows of a lot of biting/piercing taking place during this stage. It is at this stage the ants release formic acid into the body of the prey. This is distinctively recognizable with the elevated gaster arching forwards, just the opposite to the direction of Stage 1. Once enough formic acid enters the prey, it will be somewhat paralyzed (Plate 3.4.2.2d).

Plate 3.4.2.2d Stage 3-Piercing and releasing formic acid into prey causing paralysis with a characteristic downward gaster position functioning as a “water pipe” (red arrow).

Stage 4a – Lifting of the prey

Once the prey is neutralized, several ants will now lift up the paralyzed ‘body’ by ‘clipping’ their mandibles. If the prey is big sized or heavy, the number of ants involved is bigger (Plate 3.4.2.2d).


Plate 3.4.2.2e. Stage 4a-Lifting of the prey once secured on the oil palm frond rachis.

Stage 4b – Transporting the paralyzed prey to the nest

Once lifted, the paralyzed prey which is considered as food item is transported to the nest (Plate 3.4.2.2f). The numbers of ants involved depend on the size and weight of the food item. Along the route, many more ants may join the carrying party. Ninety-five percent of the observed preys/items were bought back to nest (n=1000).

Plate 3.4.2.2f. Stage 4b-Transporting back the prey to the nest for storage.

The chronology and sequence of attacks can be summarized as follows: foraging and detection for prey, initial physical attacks by biting & holding the prey, injection of acid formic into the body of the prey, lifting and finally transportation to the nest.

3.4.2.3 Prey Item Preference

Preliminary field observations show that *O. smaragdina* will attack the pupae of *P. pendula* first before attacking the larvae (various instars), although both are present in the vicinity. Fig. 3.4.2.3 shows 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. 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, the ants now prey on the larvae. They effectively used the rachis of the leaflets to move at high speed. When prey items are in abundance and widespread, the ants can quickly spread over a whole palms to forage.

The log-rank test demonstrated a statistically significant difference in survival ability between pupae and larvae (for equivalence death rates X^2 = 3.42, d.f =1; P = 0.06), (Appendix 3.4.4.3). The preference index P_i calculated for the 90 minutes cut-off period is 1.73 for the pupae and 0.13 for the pupae. This shows that *O. smaragdina* had a high preference for pupae compared to the larvae when the former was still in abundance (Appendix 3.4.2.2).

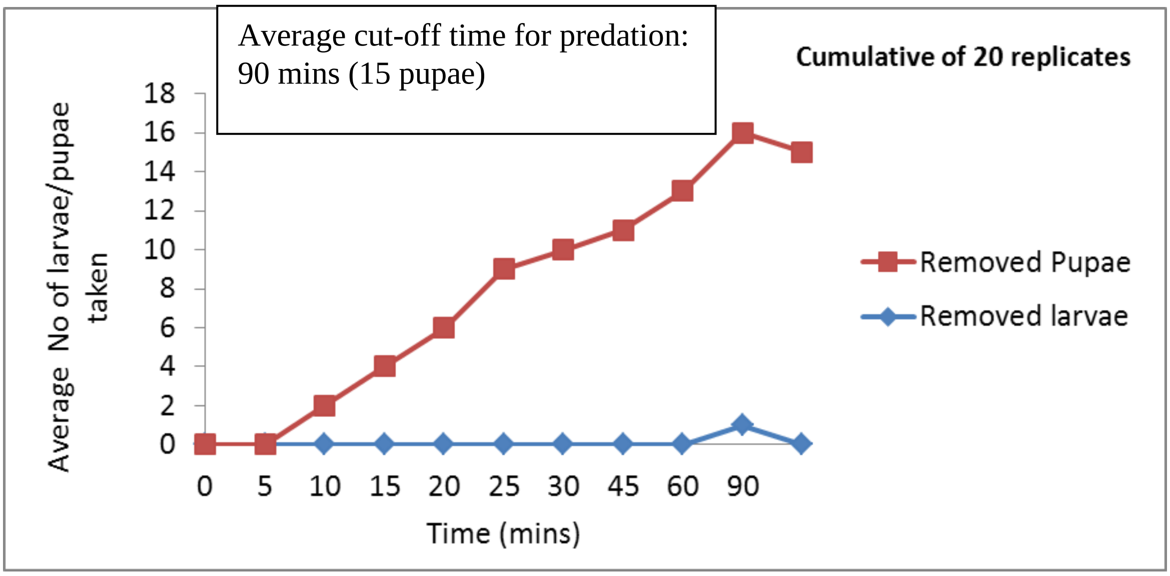


Figure 3.4.2.3: The average cumulative number of larval and pupal *P. pendula* prey taken by *O. smaragdina* in the prey preference experiment.

3.4.3 Assessment of the degree of infestation by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*.

Since it is confirmed that *O. smaragdina* prey upon *P. pendula* larvae and pupae, it is vital to determine the degree of infestation of the bagworm between the occupied and unoccupied palms.

Fig. 3.4.3 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 Level 3 and 4, with 210/250 palms (84%) not infested 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%) and Level "3" (28%). Tall unoccupied palms had a pest density of level 3 and 4 by 40% and 25% respectively.

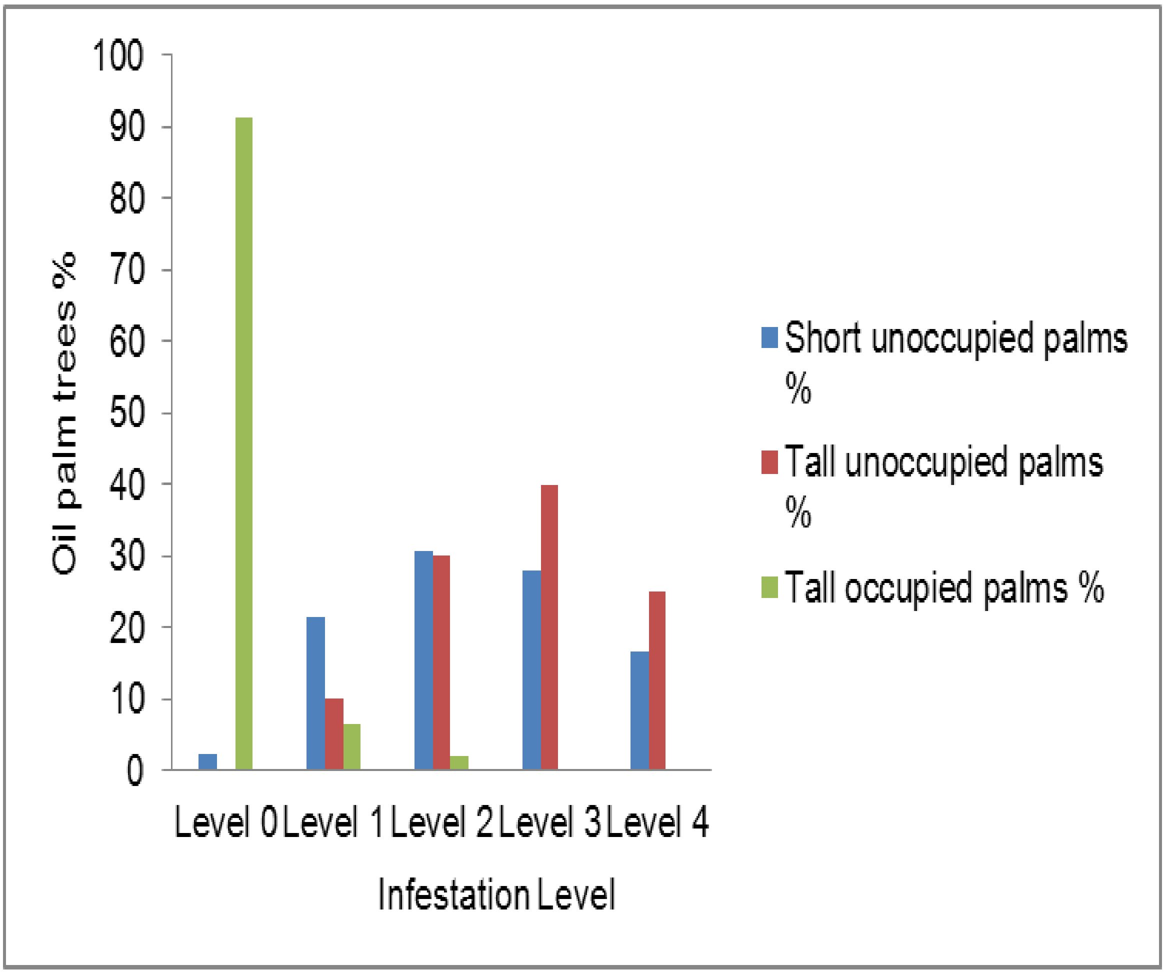


Figure 3.4.3: Degree of Infestation of *P. pendula* on occupied and unoccupied palms.

3.4.4 Assessment of the degree of foliar injury caused by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*

There was a significant difference in the degree of foliar injury between palms occupied by the weaver ants and those unoccupied (X^2= 439.2), d.f = 4, p < 0.001), (Fig.3.4.4). Of the 230 sampled occupied palm trees, 210 (91.3%) showed no sign of foliar injury. The fronds of these palm trees were in healthy state (Plate 3.4.4). 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).

Plate 3.4.4. Healthy palms of *Elaeis guineensis* Jacq well benefiting from the presence of *Oecophylla smaragdina*. Photographer/Camera: Photo taken by Exélis Moïse Pierre using a Sony T20 digital camera. April 2011.

A Spearman's one-tailed correlation analysis between the degree of *P. pendula* infestation and the degree of foliar injury shows 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). Thus we reject H_o concluding that infestation and foliar injury is significantly associated.

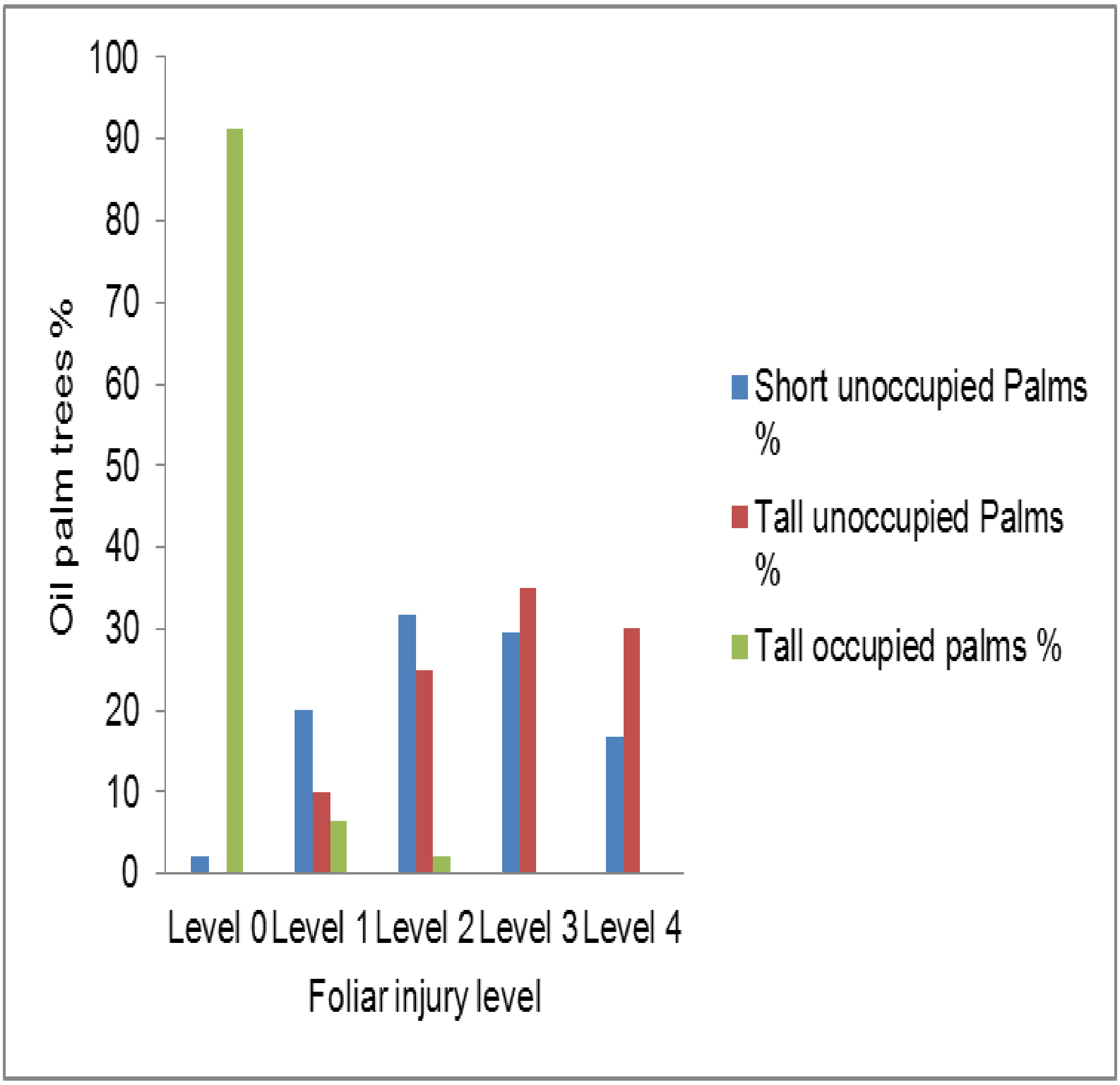


Figure 3.4.4. Degree of Foliar Injury caused by *P. pendula* on occupied and unoccupied palms with *O. smaragdina*

3.4.5 Assessment of the productivity of palm occupied and unoccupied with *O. smaragdina*

Base on the classification of 4 levels of productivity as outlined in Section 3.3.5 it was found that 35% of the tall-occupied palms were very productive and the remainder 65% as productive. For the tall-unoccupied palms 85% were moderately productive, 10% productive and 5% not productive. Among the short-unoccupied trees 7% were very productive, 38% productive, 41% moderately productive and 14% not productive (Fig. 3.4.5).

The results shows that the Mann Whitney U, Wilcoxon Rank Sum test for small sample is highly significant between tall occupied and tall unoccupied palms at $P < 0.02$ ($N1 = 7$, $N2= 7$, $U = 1$).

There is a significant difference between the productivity of tall-occupied against the short-unoccupied palms ($z \geq 4.16$, $p < 0.0003$; Mann Whitney U test for large samples). However, the difference in productive is not conclusive to the effect on the presence of the weaver ants. It might be due to the differences in age of the palm and this factor is not taken into consideration. Another aspect is the visual obvious difference in the quality of FFB from occupied and unoccupied palms, exhibiting a clear ripeness, while in blocks attacked by bagworms, a certain amount of fruit bunches looked immature.

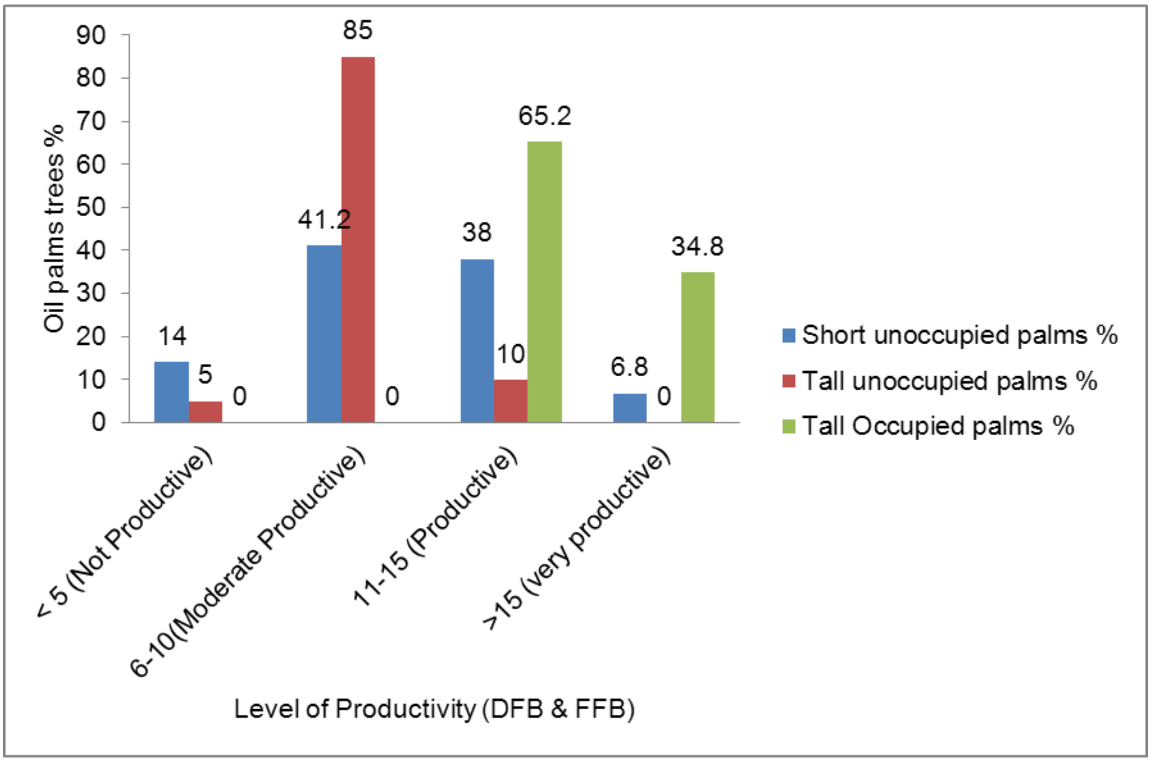


Figure 3.4.5: Productivity of palm occupied and unoccupied with *O. smaragdina*

3.4.6 Evaluation on Impact of *O. smaragdina* activities on the pollinator weevil *Elaeidobius kamerunicus*

During the observations on 25 palms where there was concurrent presence of *O. smaragdina* and *E. kamerunicus* but no *P. pendula*, none of the three aggressive or attacking behaviours (as outlined under Section 3.3.6: attack approach; attack posture; physical attack) were observed. *O. 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, (Plate 3.4.6 A-C).

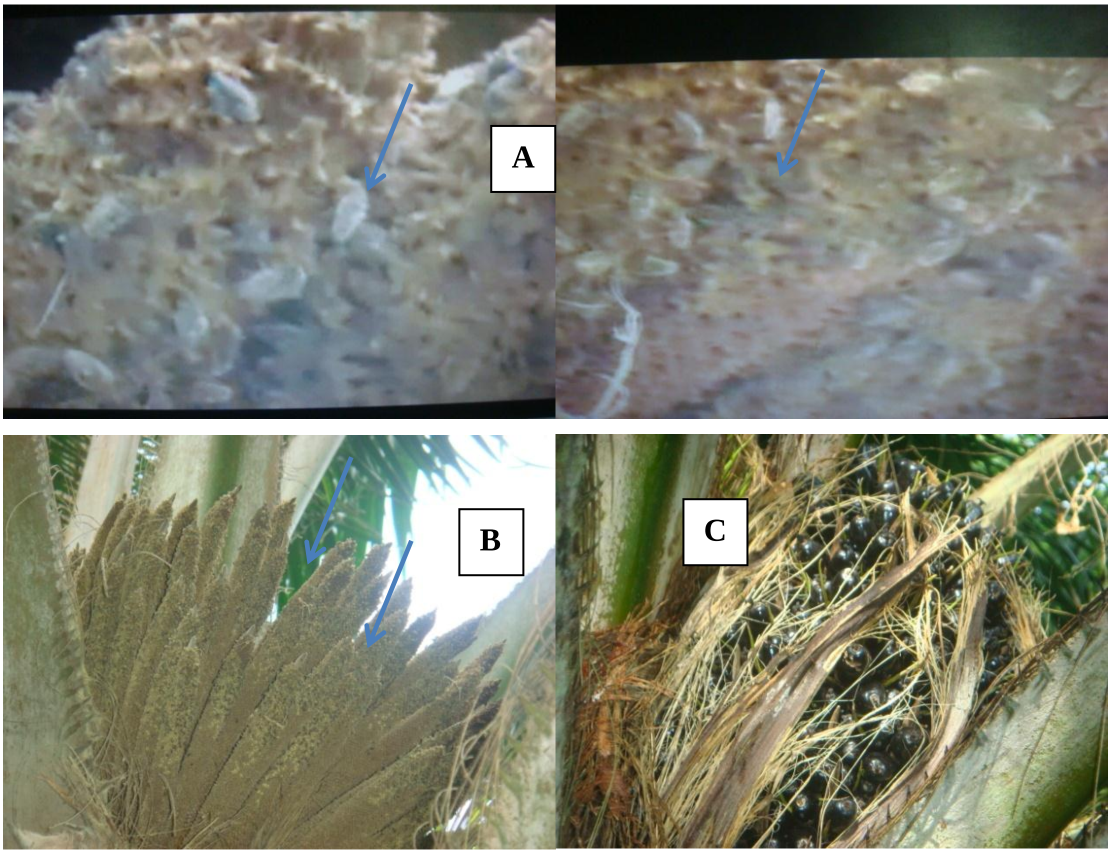


Plate 3.4.6(A-C): *Elaeidobius kamerunicus* weevil (A, blue arrows) observed on taller palms without any *O.smaragdina* ants activity around the male (B, blue arrows) or female flowers (C).

3.5 DISCUSSION

3.5.1 Occupancy patterns of *O. smaragdina* on palm trees

From the study it was shown that *O. smaragdina* dwells in older taller palms. In fact none was found in the younger shorter palm. Habitat selection preferences of arboreal ants were suggested in several earlier publications. *O. smaragdina* preference to position their nests at the top of the canopies under direct sun light, demonstrated a predilection to solar radiation exposure (Ribeiro *et al*., 2013). These findings concur with those found by Pfeiffer *et al* (2007, 2008). Similar occurrence was reported by Dejean *et al* (2007) for *O. longinoda*. Microclimatic conditions might possibly be one of the determining factor (Wielgoss *et al*., 2010). The findings of this study corroborate with those of Lokkers in Australia (1986, 1990) for showing a strong bound with key environmental factors like temperature and relative humidity influencing the outcome of *O. smaragdina* distribution and general activities. A recent report support these findings by suggesting the effects of temperature on ant abundance, diversity, and foraging activities (predation, scavenging, seed dispersal, nectivory, granivory) in two deciduous forest with *Crematogaster lineolata* as the dominant species (Pelini *et al*., 2011; Stuble *et al*., 2013).

There is much more shade in older taller palms compare to shorter younger ones. Possible trees heights effects on ant foraging behaviors (Doak *et al*., 2007) were highlighted. There might be a possible relation between the height impacts of palm trees preferential occupancy by *O. smaragdina* determined by the mutualistic relation with honey dew tended homopterans predilection for shaded larger canopy found in taller trees as reported for *O. longinoda* (Bigger, 1981).

The distribution of nests found was similar to other studies (Hölldobler & Wilson, 1990; Blūthgen & Fiedler, 2002). They are polydomous in nature (Hölldobler, 1983; Dejean *et al*., 2007) and a single tree may harbours as many as 13 nests as reported in this study (Exélis Pierre & Azarae, 2013). Nest distribution may be influence by the proximity of palm trees. Interconnected palm canopies provide bridges for colony expansion. Since not all palm trees in a particular block are occupied by the ants, this suggests that artificial bridges could be established to facilitate their quick expansion to other trees as what had been practiced by the Chinese (Huang & Yang, 1987), if this species is to be used as agents in the oil palm estates (Peng *et al*., 2004).

3.5.2 Observation on the Predatory Behaviors of *O. smaragdina* on *P. pendula*

3.5.2.1 Active Foraging Bouts

This study revealed that the ants have two peaks active periods when the numbers foraging is as high as 10 folds compared to the inactive period. Bimodal active periods especially during midday and around dusk is quite common among diurnal animal species. For the larger vertebrate species, the bimodal peaks are normally in the early morning (dawn) and late evening (dusk). The morning peak coincide with the first feeding bout after a long night of inactive feeding and the peak around dusk as the last feeding bout before the onset of darkness, with noticeable insects abundance increase during heat period of the day (Finlay, 1976). However for most invertebrates, particularly among the flying species, they are not yet active during early morning because the relative humidity is still high giving a sort of heavier and wetter air (Finlay, 1976). For crawling species, most of the ground surfaces are still wet with dews not yet evaporated. This microclimatic condition might be the factor for most insect's species not to have their peak active period during the early morning. But by midday and dusk, if it is not raining or cloudy, the air is drier and more conducive for active activities (Finlay, 1976).

This natural circadian cycle may be utilized to minimized attacks but again physical disturbance might induce assaults, which does confirm another evaluation done on cashew nuts (Peng *et al*., 1999) in Australia with the same ants' species.

3.5.2.2 Predation strategy of *O. smaragdina* on *P. pendula*: Attacking Tactic – Analysis of Sequential Acts

3.5.2.3 Prey Item Preference

The obvious reason for this strategy may be attributed to static behaviour of the pupae against the much more mobile larvae. In terms of energetic principle the ants use less energy per unit prey item of pupae than for the larvae. However, when no more pupae are available, the ants naturally will take on the larvae albeit more energy needs to be expended. In this argument it is assumed that both item per unit of pupae and larvae provide the same amount and quality of energy.

The Asian weaver ants' demonstrated a strategy of predation based on cooperation among colonies members task management as manifested in many insect group in what is now called swarm intelligence (Miller, 2010). This is directly related to the cost of energy, control and more effective transport of preys which is a key factor in organizing a proper hunt strategy (Hölldobler & Wilson, 1990). Polyphagous arboreal ants' like *Oecophylla* species are well known for characteristic group hunting (Hölldobler & Wilson, 1990; Wojtusiak *et al*., 1995).

3.5.3 Assessment of the degree of infestation, foliar injury caused by *P. pendula* and productivity on occupied and unoccupied palms with *O. smaragdina*.

It is very clear from this study that the level of infestation by *P. pendula*, the degree of foliar injury and productivity of DFB/FFBs between occupied and unoccupied palm trees, by *O. smaragdina*, is very significant. Since there are no other element involves, it is quite conclusive to infer that *O. smaragdina* is responsible for the above observed situation. Infestation of *P. pendula* was reduced because the ants preyed on them. Thus when infestation is low, naturally foliar injury due to the feeding of the larvae and pupae of *P. pendula* is reduced as well. It follows that when the leaves are not damaged, photosynthetic activities are not impaired and hence the tree can produce more yields in terms of DFB/FFBs. Similar results were obtained for other crop like cashew nuts in Australia (Peng *et al*., 2004). At Level 3 and 4 of the foliar injury, almost the whole frond is rendered useless for productivity causing substantial economic loss to the planters (Basri 1993; Basri & Kevan 1995; Basri *et al*., 1988, 2003). However, the age factor is not taken into consideration here, remain a confounding element in the study. Further, an interesting aspect could have been to determine the grade and the quality of the oil palm fruit bunches by using photogrammetric grading system (Roseleena *et al*., 2011) to conduct a field comparison between occupied and unoccupied palm plantations blocks with the ripeness index value. The colour of the fresh fruit bunches is maintained as a major factor determining grade and quality by human vision and manual process in Malaysian plantations (Malaysian Palm Oil Board DVD, 2012).

3.5.4 Evaluation on Impact of *O. smaragdina* activities on the pollinator weevil *Elaeidobius kamerunicus*

The positive absence of any interference on the weevil pollinator agent *E. kamerunicus* in oil palm plantations is reinforcing on the interest of having the Asian weaver ant as a potent deterrent on defoliators. This ensured a large neutralization of defoliator's activity, keeping foliar injury low in occupied trees. If there is a conflicting report in another crop from Indonesia (Tsuji *et al*., 2004), the author insisted that no significant impact on impairing the yield of fruits "mangosteen" was shown (Tsuji, personal communication).

3.6 Conclusion

This study provided a new perspective for integrated pest management by emphasizing on the following aspect in oil palm plantations in Peninsular Malaysia:

- The Asian weaver ant's *O. smaragdina* 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. The number of nests per tree ranged from 0 to 13 in average.

- 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*.

CHAPTER 4

4.0 GENERAL DISCUSSION AND CONCLUSION

4.1 General Discussion

Sustainability in oil palm industry, popularly called as 'sustainable oil palm' is gaining importance due to the concern of various international groups. In respond to this, the Roundtable on Sustainable Palm Oil (RSPO) was formed in 2004 with the objective of promoting the growth and use of sustainable oil palm products through credible global standards and engagement of stakeholders. RSPO is a non-profit association that represents seven groups of stakeholders - oil palm producers, palm oil processors or traders, consumer goods manufacturers, retailers, banks and investors, environmental or nature conservation NGOs and social or developmental NGOs (Lim *et al*., 2012). The pressure to be sustainable is tremendous because at the end of the day the buyer determine the deal in trading. Approximately 30% of the edible oils traded and consumed around the world currently are palm oil. It has been estimated that 40 million tonnes of palm oil was traded in 2008. By end of 2009, approximately 1.5 million tonnes of certified sustainable palm oil was traded (Hamburg-based Oil World Trade Journal). Multi-nationals and industry players have pledged to have most of their outputs certified sustainable by 2015.

There are several issues on 'sustainable palm oil' – which among the major ones are the conversions of natural forests & peat swamps into palm oil plantations; the habitat loss or degradation for endangered species such as the Orang Hutan and Sumatran tiger and the excessive use of chemicals (fertilizers, pesticides, fungicides) detrimental to the environment. The issues are wide-ranging but what concern this study is to find ways of how to minimise the use of chemicals or pesticides.

In the past, planters put large quantity of fertilizers to ensure good harvest. Currently less fertilizers are applied through good agricultural practice (GAP) such as natural nutrient recycling by returning mill residues like palm oil mill effluent (POME), empty fruit bunches and frond spreading. Similarly GAP of integrated pest management requires lesser quantity of pesticide through the usage of biological control such as barn owl to control rat, bio pesticides (*Metarhizzium* fungi and virus) to control Rhinocerous beetle grubs, *Bacillus thuringiensis* for control of bagworms and *Trichoderma* to control *Ganoderma* fungi. These are examples of land use, land-use change and forestry (LULUCF) activities in oil palm cultivation. It is the mission of the MPOB executed through the Plant Protection Unit of the Biology Research Division to promote sustainable practices in oil palm management via integrated control of pest and diseases. The goals is to intensify awareness and better integration of biological control agents in pest management, reducing reliance on pesticides and to promote greater use of integrated disease and weed management with bio agents to reduce chemical use.

The danger of repeating aerial insecticides treatment over generations in a bid to annihilate the entire pest population had been proven to promote the resurgence of secondary pest's outbreak with more severe density in distribution (Roy & Thomas, 1996). For this regard, it is known that their sphere of activity is usually limited to certain areas only (Corley & Tinker, 2003) without normally expanding to larger neighbouring plantations. Our findings in Teluk Intan do not follow Corley's evaluation for the bagworm species of *Pteroma pendula*. Many more factors seem to be involved in determining and influencing the occurrences of infestations.

Abiotic (e.g. solar radiation and rainfall means) and biotic, (e.g. predators and parasitoids) factors are playing a main and significant key role in determining the course of an outbreak (Norman & Basri, 2010). Wood (1976) again stress out about the life cycles "dislocation" consideration to be given to understand and explain the causal factors of endemic persistent infestations similar to the case faced now in Teluk Intan MPOB. The author demonstrated this principle by relating it to the example found in Fiji with the leaf mining hispid beetle *Promecotheca coeruleipennis*. Outbreak accidentally occurred by introduction of the parasite mite *Pyemotes ventricosus* leaving the pest into a single phase life cycle history reproduction, by reducing remarkably "indigenous enemies", making the industry of coconut palms in state of peril.

A recent study conducted on the same estate suggested that the usage of non-selective chemicals like trunk injection methamidophos and spraying by cypermethrin had the potential of causing revival of outbreak (Norman & Basri, 2010). The authors explained that natural enemies of *P. pendula* like predators and parasitoids are left without target insects, thus diminishing in density. When this happens, the bagworm can revives quickly and sometimes into an outbreak scale.

The non-integrated usage of pesticides on oil palm plantation for controlling infestations incidences had actually the reverse unwanted result of destroying the natural enemies (Ramlah *et al*., 2007; Wood, 1968). The usage of herbicides or pesticides by blanket sprays to contain or as a mean of prevention against outbreaks, has been strongly discouraged after discovering the adverse effect done on the sustainability of natural enemy populations of main oil palm pests (Wood, 2002). Because of a direct physiological sensitivity to the pesticides, broad spectrum usage means that the range of insects killed is diverse. After the application of the treatments has been completed, insect's population continue to be killed for an extended period which means that there is a long residual effect. Broad spectrum long range contact pesticides (bslrc), such as cypermethrin, are commonly used in Teluk Intan oil palm plantations (Norman & Basri, 2010). The natural balance between these organisms is already well established and maintained; whereby intricate inter-dependent factors play a role for the survival of the community.

Studies on the pest, diseases and the methodologies of proper management affecting the yield of oil palm in Malaysia have been generally well documented since the early stage of the development of the industry (Basri *et. al*, 2003; Norman *et. al*, 1994; Norman & Basri 1992, 1995, 2007; Norman & Othman, 2006; Yunus, 1966; Young 1971, Wood, 1968, 1976, 2002). More recently, several reports were given on the conditions of pests and diseases in plantation planted on peat soils (Lim *et al*., 2012). Nevertheless in the light of the ever escalating international demand for sustainable palm oil, it is prudent for the industry to look at integrating more environmentally element into its existing integrated pest management programme.

Base on the preliminary findings of this study, integrated pest management involving the use of *O. smaragdina* as bio control agents looks promising. However more biological and ecological information on the species is needed before it can be used as bio control on a large scale integrated pest management programme.

For a species to be a good candidate for bio control its population must be self-sustaining subsequent to the initial ‘artificial’ establishment of the colony. If the population decrease and requires continuous large-scale anthropogenic interference to stabilise the population number then it may be economically not feasible. Hence, the most basic ecological understanding that is needed is on population dynamic of the species. Population dynamics is the segment of ecology that deals with the variation in time and space of population size and density for one or more species (Begon *et al*., 1990). It is comprised of two basic components: quantitative accounts of the fluctuations in population number and form of population growth or decline and secondly investigations on the forces (biological and physical processes) responsible for those variations. This knowledge of causal processes affecting population dynamics is important to forecasts population trends of the agent.

To date, no population dynamic studies have been done on any ant species directly in the field. Thus on this scientific pursuit alone, the study on population dynamic of any ant species is most desirable. The reason for the lack of this very basic but essential study is due to the fact that most ant colonies are subterranean. A population dynamic study requires the counting of the population numbers. However with the current state of technology it is almost impossible to count individual ants in their underground nesting burrows especially with large colonies. Excavation of nests is however not practical because it will be destructive to the survival of the colony. Because of this factor some workers used mathematical model to elucidate the population dynamics of ants (Britton *et al.*, 1996).

Oecophylla smaragdina offers an excellent opportunity to conduct population dynamic studies. This is for two practical reasons: firstly the species exhibits arboreal habits where most nests are found on tree canopies and secondly their colony sizes are not that large to allow physical counting possible. *O. smaragdina* is never subterranean and at the most some nests are found on ground surface under heaps of debris or piles of vegetation. Thus the first obstacle of destructive sampling is not necessary. In addition, preliminary direct counting of the colony size of *O. smaragdina* in oil palm plantations (Exélis Pierre & Tsuji, unpublished data) in Peninsular Malaysia gave satisfactory results without complications. It may range from hundreds of thousands if not in the millions (Hölldobler & Wilson, 1990). This would tremendously provide valuable data to implement strategies for a future adoption of the Asian weaver ant's species in oil palms. Based on these two factors and the fact that *O. smaragdina* is a good candidate for biological control of oil palm bagworms pest, it its strongly recommended that the population dynamic studies to be carried out for future works of the species in oil palm plantations.

A key feature of any population is whether its size and growth rate are regulated by density dependent processes and if so, what those processes are and at what stage of the life they act (Murdoch, 1994). This aspect is vital because density-dependent regulation is a basic parameter to be known for any bio control agent. However, some other density independence factors such as some biotic and abiotic processes may also operate to influence mortality and fecundity rates. Abiotic factors such as extremes of weather condition are typical density independent causes of mortality. Biotic factors including human interference which is common under oil palm plantations can act in density independent ways. This can be really significant and might have disastrous impacts on populations and may affect its standing as bio control agent. Some reports defined clearly the interdependence between abiotic and biotic factors with coexisting species based on the natural principles of competition by predation (Martin, 2001) which was the case of bird's nests. The effect on habitat selection and geographical distribution of these species by those various interconnected biotic and abiotic parameters, can be a determinant factor in deciding the outcome of this coexistence. That would eventually decide on the future stability of species, which is an important concept to implement efficiently the usage of any biological control agent like *O. smaragdina* in oil palm plantations. Tropical and subtropical habitats were suggested to be positively enhancing predation and parasitoids effects on phytophagous insect pests mortality, while parasitism was higher in temperate regions (Hawkins *et al*., 1997). Finally, environmental factors like temperatures were found to significantly influence the lethal potency of pathogens/parasites on host with existing optimal conditions increasing mortality (Thomas & Blanford, 2003). It is extremely recommended that such aspects are given more attention for further study and need to be highlighted more for field study in oil palm plantations.

Biological agent behaviors are also a determinant factor in the field that would influence greatly mortality and survival of the used agent's. In this respect, *O. smaragdina* is known to be ferocious ants and strictly territorial even within the same individuals species from different colonies (Hölldobler & Wilson, 1977b, Hölldobler, 1983, Dejean *et al*., 2007) in the same oil palm plantations (Personal observations, Exélis Pierre, Azarae, Tsuji & Yamane). It will attack all intruders into its territory including human. However the very nature of oil palm plantation is the requirement of harvesting and pruning manually by man. In the process of harvesting it is inevitable not to disturb the ants' nest. It is currently observed that workers resort to burning down the weaver ant's nest to eliminate their nuisance during harvesting and pruning activities. If the species is to be used as a bio control agent in oil palm, then there exists a conflict between keeping the ant's colony intact or to destroy it to safeguard the workers so that revenue is forthcoming. Thus this applied aspect cannot be taken lightly and need to be addressed if the species is to be used as bio control agent. It is difficult to reduce the nuisance of *Oecophylla* bites (Van Mele, 2009). Nevertheless, protective garments worn by harvesters might be an option but the extra cost involve may be financially preventive. The use of chemical deterrent may be counter-productive to the whole spirit of sustainable farming but natural insect repellent may be rewarding to discourage the ants from making offensive manoeuvre. This study revealed that the ants have two peak active periods when the numbers foraging is as high as 10 folds compared to the passive period. This natural circadian cycle may be utilised to minimised attacks but again physical disturbance might induce assaults. A balance between all relevant factors needs to be strike somewhere and this requires a further study dedicated to this aspect. At least the problem can be reduced to an accepted level.

The potential use of *O. smaragdina* in an integrated pest management program is taking a different pathway than the existing techniques. Current biological control of bagworm in Malaysia includes the use beneficial plants, pheromone mass trapping of male moths, bacteria and entomopathogenic fungus. Beneficial plants act as host of parasitoids which are the natural enemies of the bagworms by providing them with nectars. Basri & Norman (2000) have found that *Cassia cobanensis, Crotalaria usaramoensis* and *Euphorbia heterophylla* are the most effective beneficial plants in that order. The use of pheromone traps for monitoring and controlling *M. plana* gave satisfactory results (Norman & Othman, 2006; Norman *et al*., 2009) in tall and shorter palms for *P. pendula* (Norman, Unpublished data; Exélis Pierre, personal field trial with MPOB). *M. plana* and *P. pendula* receptive adult females being placed in the center of glued traps will trigger massive male moth's flight, leaving them imprisoned. Another method involves the use of the gram-positive, soil-dwelling bacterium *Bacillus thuringiensis* (Marçon *et al*., 2000; Ramlah *et al*., 2012). During sporulation, many Bt strains produce crystal proteins (proteinaceous inclusions), called δ-endotoxins, that have insecticidal action, thus killing the bagworms (Ramlah *et al*., 2012). The fourth method currently in practice is the use of biopesticides fungus such as *Beauveria bassiana* (Darus & Basri, 2000; Darus *et al*., 2000). When the microscopic spores of the fungus come into contact with the body of an insect host, they germinate, penetrate the cuticle, and grow inside, killing the insect within few days. Afterwards, a white mold emerges from the cadaver and produces new spores and ready for another round of invasion. The synergistic combination of *B. bassiana, Metarhizium anisopliae, Paecilomyces spp, Nomuraea* *rileyi, Lecanicillium lecanii and Hirsutella thompsonii* with various pesticides gave encouraging results (Ambethgar, 2009). There is yet another biological control technique by using virus particularly the baculoviruses but its potential has not been totally exploited (Ramlah *et al*., 1996). An integrated pest management also includes the use of chemical. In Malaysia, the spraying of pesticides (Wahid *et al*., 1988; Wood, 1976; Chung, 1989) such as Pybuthrin, environmentally benign (Chung *et al*., 2000) and trunk injection of insecticides (Chung, 1989; Darus & Basri, 2000; Wood, 2002) is widely practiced. Kok *et al* (2012) tested the selective Chlorantraniliprole insecticide on *M. plana* with promising results.

As can be seen from the above discussion, it is evident that *O. smaragdina* works against the bagworm in completely different pathway. The ants physically consumed the bagworms directly. Hence, it offers an excellent opportunity of diversifying the existing inventory of biological control. In other words *O. smaragdina* can be used as a supplementary method within the framework of the current integrated pest management regime. It has the added advantage of preying on several other pest species (Way & Khoo, 1992; Peng & Christian, 2006).

It is noteworthy that the use of *O. smaragdina* is simple without the need of any sophisticated or complicated scientific technique. It is also cheap and if implemented on a small scale a colony can be artificially established almost for free. The colony expansion can be facilitated by using artificial bridges as mentioned earlier in the text. This technique is as old as antiquity. Its cost-effective advantage over other technique makes it suitable for use by smallholders. When an outbreak occurs, smallholders are most badly hit because they do not have the financial and technical capacity to deal with it. Thus by simply rearing or even ‘allowing’ *Oecophylla* colonies to thrives in their plantation, they have taken preventive measures against bagworm outbreaks. However the widespread applications by the smallholders need to be formally formulated, strategized and encouraged by the relevant government authorities.

Oecophylla rearing in plantation by smallholders can provide additional benefit as secondary source of income. The brood of the ant larvae can be harvested and sold or even consumed by the farmer themselves (Césard, 2004; Offenberg & Wiwatwittaya, 2010). In Thailand and Philippines the weaver ant brood are sold at high prices for consumption by man and for captive song birds. In Indonesia it is sold for fish baits (Van Mele, 2009). During the course of the field study, it was observed that the number of *Oecophylla* nest per palm trees is always odd. This aspect was never made as the objective of the study a priori but was coincidently observed while sampling for the occupancy patterns. For the sake of science and in the name of science, it merits some form of reporting in this thesis. In this context, observations in this study shows that the number of nests (including all types of nests) per palm tree is always odd ranging from 1 to 13. There are no even numbers of nests found. This is a peculiar biological phenomenon that is intellectually challenging. If conclusively found to be true then it throws insight on the significance of its occurrence by chance. However, the current observations were coincidental and thus the sampling was not design to conclusively affirm the phenomenon. Further intensive study is required to confirm this beyond reasonable doubt. If scientifically and statistically confirm by future studies, this phenomenon is worth reporting in the most esteemed scientific journal.

4.2 General Conclusion

This study confirmed the predatory activities of *O. smaragdina* on the defoliator agents of oil palms, the bagworm, *P. pendula*. The initial findings also affirmatively indicate that the palm trees occupied by *O. smaragdina* shows lower infestation by *P. pendula*, lesser foliar injury and hence greater productivity. The investigation also confirmed that *O. smaragdina* do not prey on the valuable pollinator of palm oil, *E. kamerunicus*. Based on these encouraging findings and as far as the bagworm problem is concerned there is a **promising benefits and advantage of using *O. smaragdina* as a new supplementary bio control agent on oil palm plantations.** It possibly saves the industry huge financial resources and saving the environment as well, albeit intangible to be obviously seen. It is highly recommended that a further study on the **population dynamics** *O. smaragdina* to be conducted under oil palm ecosystem as a prerequisite of using it as a serious bio control agent.

REFERENCES

Adaigbe, V., Odebiyi, J., Omoloye, A., Aisagbonhi, C., & Iyare, O. (2011). Host location and ovipositional preference of *Elaeidobius kamerunicus* on four host palm species. *Journal of Horticulture and Forestry*, 3(5), 163-166.

Ahmad, Y,. & Ho, T. H. (1980). List of economic pests, host plants, parasites and predators in West Malaysia (1920-1978). *Ministry of Agriculture, Malaysia, Bulletin* No. 153, 538.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment*, 74(1), 19-31.

Altieri, M. A., & Nicholls, C. I. (2004). Biodiversity and pest management in agroecosystems. *Biodiversity and pest management in agroecosystems*, (2), 236.

Ambethgar, V., Swamiappan, M., Rabindra, R., & Rabindran, R. (2009). Influence of some herbicides on in vitro vegetative growth of *Beauveria bassiana* (Balsamo) Vuillemin. *Resistant Pest Management Newsletter*, 19(1), 11-14.

Ariffin, D., & Basri, M. (2000). Intensive IPM for management of oil palm pests. *Oil Palm Bulletin* (41), 1-14.

Azuma, N., Ogata, K., Kikuchi, T., & Higashi, S. (2006). Phylogeography of Asian weaver ants, *Oecophylla smaragdina*. *Ecological Research*, 21(1), 126-136.

Bale, J., Van Lenteren, J., & Bigler, F. (2008). Biological control and sustainable food production. Philosophical Transactions of the Royal Society B: *Biological Sciences*, 363(1492), 761-776.

Baloch, G. (1973). Natural enemies of *Axiagastus cambelli* Distant (Hemiptera: Pentatomidae) on the Gazelle Peninsula, New Britain. *Papua New Guinea Agricultural Journal*, 24(1), 41-45.

Barbosa, P. A. (1998). Conservation biological control: *Academic Press*, 396 pp.

Basri, M. W., Abdul, H. H & Zulkifri, M. (1988). Bagworm (Lepidoptera: Psychidae) of Oil Palms in Malaysia. *PORIM* Occasional Paper, Palm Oil Research Institute, Malaysia, 23, 1-23.

Basri, M. W., Abdullah, S. N. A., Ithnin, M., & Kamaruddin, N. (2005). Oil palm. *Handbook of industrial crops*, 335-382.

Basri, M. W. (1993). Life History, Ecology and Economic Impact of the Bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae) on the Oil Palm, *Elaeis guineensis* Jacquin. (Palmae), in Malaysia. Ph.D. Dissertation, University of Guelph, 231 pp.

Basri, M. W., & Kevan, P. (1995). Life history and feeding behaviour of the oil palm bagworm, *M. plana* Walker (Lepidoptera: Psychidae). *Elaeis journal*, 6(2), 82-101.

Basri, M. W., & Norman, K. (2000). Insect pests, pollinators, and barn owls. Advances in Oil Palm Research. *Malaysian Oil Palm Board*, Kuala Lumpur, Malaysia, p 466-541.

Basri, M. W., Norman, K., Idris, A. S., Ariffin, D., Shamala S., Ramle M., & Ramlah, S. A. A. (2003). Handbook of Pests and Diseases of Oil Palm. Published by *Malaysia Palm Oil Board* (MPOB), Ministry of Primary Industries Malaysia, p 5-7.

Begon, M., Harper, J., & Townsend, C. (1990). Ecology, individuals, populations and communities. *Wiley-Blackwell*, (3), 1068.

Bianchi, F., Booij, C., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: *Biological Sciences*, 273(1595), 1715-1727.

Bigger, M. (1981). Observations on the insect fauna of shaded and unshaded Amelonado cocoa. *Bulletin of Entomological Research*, 71(01), 107-119.

Blüthgen, N., & Fiedler, K. (2002). Interactions between weaver ants *Oecophylla smaragdina*, homopterans, trees and lianas in an Australian rain forest canopy. *Journal of Animal Ecology*, 71(5), 793-801.

Boivin, G. (2001). Parasitoïdes et lutte biologique: paradigme ou panacée? *VertigO-la revue électronique en sciences de l'environnement*, 2(2). http://vertigo.revues.org/4096

Britton, N., Partridge, L., & Franks, N. (1996). A mathematical model for the population dynamics of army ants. *Bulletin of mathematical biology*, 58(3), 471-492.

Brown, E. (1959). Immatre Nutfall of Coconuts in the Solomon Islands. *Bulletin of Entomological Research*, 50(01), 97-133.

Caudwell, R. W. (2000). The successful Development and Implementation of an Integrated Pest Management System for Oil Palm in Papua New Guinea, *Integrated Pest Management Reviews*, 5(4), 297-301. .

Césard, N. (2004). Le kroto (*Oecophylla smaragdina*) dans la région de Malingping, Java Ouest, Indonésie: collecte et commercialisation d'une ressource animale non négligeable. *Anthropozoologica*, 39, 15-31.

Chen, S. (1991). The oldest practice of biological control: The cultural and efficacy of *Oecophylla smaragdina* Fabricus in orange orchards. *Acta Entomologica Sinica*, 11, 401-407.

Cheong, Y., Sajap, A. S., Hafidzi, M., Omar, D., & Abood, F. (2010). Outbreaks of bagworms and their natural enemies in an oil palm, *Elaeis guineensis*, plantation at Hutan Melintang, Perak, Malaysia. *Journal of Entomology*, 7(3), 141-151.

Chung, A., Eggleton, P., Speight, M., Hammond, P., & Chey, V. (2000). The diversity of beetle assemblages in different habitat types in Sabah, Malaysia. *Bulletin of Entomological Research*, 90(06), 475-496.

Chung, G. (1989). Spraying and trunk injection of oil palm for pest control. *Planter*, 65 pp.

Chung, G., & Sim, S. (1991). Bagworm Census and Control: A Case Study. *PORIM*, Kuala Lumpur, p 433-442.

Corley, R., & Tinker, P. (2003). The oil palm, 4th ed. *Blackwell Science* ltd., London, 207 pp.

Crozier, R. H., Newey, P. S., Schluens, E. A., & Robson, S. K. (2010). A masterpiece of evolution—*Oecophylla* weaver ants (Hymenoptera: Formicidae). *Myrmecological News*, 13, 57-71.

Darus, A., & Basri, M. W. (2000). Intensive IPM for management of oil palm pests. *Oil Palm Bulletin*, 41 pp.

Darus, A., Basri, M. W., Sue, T. T., Ho, M. M., Choo, C. S., Weng, C. K., & Omar, W. (2000). Intensive IPM for management of oil palm pests. *Oil Palm Bulletin*, 41 pp.

Debout, G., Schatz, B., Elias, M., & McKey, D. (2007). Polydomy in ants: what we know, what we think we know, and what remains to be done. *Biological Journal of the Linnean Society*, 90(2), 319-348.

Dejean, A., Corbara, B., Orivel, J., & Leponce, M. (2007). Rainforest canopy ants: the implications of territoriality and predatory behavior. *Functional Ecosystem and Communities*, 1, 105-120.

Dejean, A., Djieto-Lordon, C., & Durand, J. L. (1997). Ant mosaic in oil palm plantations of the southwest province of Cameroon: impact on leaf miner beetle (Coleoptera: Chrysomelidae). *Journal of economic entomology*, 90(5), 1092-1096.

Dlussky, G. M., Wappler, T., & Wedmann, S. (2008). New middle Eocene formicid species from Germany and the evolution of weaver ants. *Acta Palaeontologica Polonica*, 53(4), 615-626.

Doak, P., Wagner, D., & Watson, A. (2007). Variable extrafloral nectary expression and its consequences in quaking aspen. *Botany*, 85(1), 1-9.

Exélis Pierre, M., & Azarae. H. I. (2013). Studies on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations in Teluk Intan, Perak (Malaysia). *Asian Myrmecology*, 5, 163-176.

Evans, H. (2008). The endophyte-enemy release hypothesis: implications for classical biological control and plant invasions. Paper presented at the Proceedings of the 12th International Symposium on Biological Control of Weeds. Wallingford, UK: *CAB International*, p 20-25

Finlay, J. C. (1976). Some effects of weather on Purple Martin activity. *The Auk*, p 231-244.

Flint, M. L., & Bosch, R. (1981). Introduction to integrated pest management: *Plenum Press*, XV, 240 pp.

Foster, W. A., Snaddon, J. L., Turner, E. C., Fayle, T. M., Cockeril, T. D., Ellwood, M. D., & Yusah, K. M. (2011). Establishing the evidence for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1582), 3277-3291.

Fowler, J., & Cohen, L. (1986). Statistics for Ornithologists (BTO Guides). *British Trust for Ornithology*, p 68-74.

Friedel, M. (1897). Sur des matières grasses trouvées dans des tombes égyptiennes d'Abydos. *Comptes Rendu*, 24, 648-651.

Garcia, C. E. (1935). A field study on the citrus green bug *Rhynchocoori serratus* Donovan. Philippine *Journal of Agriculture*, 6, 311-325.

Gerritsma, W., & Wessel, M. (1997). Oil palm: domestication achieved? NJAS wageningen *journal of life sciences*, 45(4), 463-475.

Greenslade, P. (1971). Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. *Journal of Applied Ecology*, 323-352.

Gurr, G., Wratten, S., & Barbosa, P. (2000). Success in conservation biological control of arthropods Biological control: Measures of success: *Springer*, 105-132.

Hartley, C. (1977). The Oil Palm (*Elaeis guineensis* Jacq.): London: Longmans, XVIII, 806 pp.

Hartley, C. (1988). The Oil Palm. *Tropical Agriculture Series*: Longman, London, XIV, 761 pp.

Hawkins, B. A., Cornell, H. V., & Hochberg, M. E. (1997). Predators, parasitoids, and pathogens as mortality agents in phytophagous insect populations. *Ecology*, 78(7), 2145-2152.

Ho, C. T. (2002). Ecological studies on *Pteroma pendula* Joannis and *Metisa plana* Walker (Lepidoptera: Psychidae) towards improved integrated management of infestations in oil palm. Fakulti Pertanian, Perpustakaan Sultan Abdul Samad, UPM, PhD Degree. Thesis Call Number FP 2002. Perpustakaan Sultan Abdul Samad, UPM Universiti Putra Malaysia, 879 pp.

Ho, C. T., Khoo, K. C., Ibrahim., Y & Omar, D. (2003). Comparative studies on the use of beneficial plants for natural suppression of bagworms infestation in oil palms. Proceedings of the 2003 PIPOC international palm oil congress. "Palm oil: the power House for the Global Oils and Fats Economy '. *Malaysian Palm Oil Board*, Kuala Lumpur, p 372-424.

Hölldobler, B., & Wilson, E. O. (1977a). Weaver ants. *Scientific American*, 237(6), 146-154.

Hölldobler, B., & Wilson, E. O. (1977b). Colony-specific territorial pheromone in the African weaver ant *Oecophylla longinoda* (Latreille). *Proceedings of the National Academy of Sciences*, 74(5), 2072-2075.

Hölldobler, B., & Wilson, E. O. (1978). The multiple recruitment systems of the African weaver ant *Oecophylla longinoda* (Latreille), (Hymenoptera: Formicidae). *Behavioral Ecology and Sociobiology*, 3(1), 19-60.

Hölldobler, B. (1983). Territorial behavior in the green tree ant (*Oecophylla smaragdina*). *Biotropica*, 241-250.

Hölldobler B., & Wilson E. O. (1990). The Ants. Cambridge: *Springer-Verlag*, 732 pp.

Huang, H., & Yang, P. (1987). The ancient cultured citrus ant. *BioScience*, 37(9), 665-671.

Idris, A. S. (2012). Latest Research and Management of Ganoderma Disease in Oil Palm. Paper presented at the Proceedings of the Fourth IOPRI-MPOB International Seminar: Existing and Emerging Pests and Diseases of Oil Palm Advances in Research and Management. Bandung, Indonesia, p 1-23.

IRHO. (1991). Oil Palm Insect Pests and their Natural Enemies in Southeast Asia, 467 pp.

Kennemore, P. E. (1981). Ecology and outbreaks of a tropical insect pest of the green revolution, the rice brown planthopper, Nilaparvata lugens (Stal). *Dissertation Abstracts International* B, 41 (7) 2471.

Kenne, M., Djiéto-Lordon, C., Orivel, J., Mony, R., Fabre, A., & Dejean, A. (2003). Influence of insecticide treatments on ant-hemiptera associations in tropical plantations. *Journal of economic entomology*, 96(2), 251-258.

Kok, C. C., Eng, O. K., Razak, A. R., Arshad, A. M., & Marçon, P. G. (2012). Susceptibility of Bagworm *Metisa plana* (Lepidoptera: Psychidae) to Chlorantraniliprole. *Pertanika Journal of Tropical Agricultural Science*, 35(1), 149-163.

Kongsager, R., & Reenberg, A. (2012). Contemporary land-use transitions: The global oil palm expansion: GLP International Project Office, 44 pp.

Krishnan, R. (1977). Larval biology of *Crematopsyche pendula* Joannis, bagworm, a crop pest. *Planter*, (Kuala Lumpur) 53, 381-394.

Lacey, L., Frutos, R., Kaya, H., & Vail, P. (2001). Insect pathogens as biological control agents: Do they have a future? *Biological control*, 21(3), 230-248.

Leston, D. (1973). The ant mosaic-tropical tree crops and the limiting of pests and diseases. *International Journal of Pest Management*, 19(3), 311-341.

Lever, R. (1933). Notes on two Hemipterous pests of the coconut in the British Solomon Islands. *Agricultural Gazette of the British Solomon Islands*., 1(3), 2-6.

Lim, G. T. (2007). Enhancing the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), for biological control of a shoot borer, *Hypsipyla robusta* (Lepidoptera: Pyralidae), in Malaysian mahogany plantations. Virginia Polytechnic Institute and State University. http://info.frim.gov.my/cfdocs/infocenter/Highlight/IRPA_2007/Grace.pdf

Lim K. H., Lim S. S., Parish F & Suharto, R. (2012). RSPO Manual on Best Management Practices (BMPs) for Existing Oil Palm Cultivation on Peat. Round Table on Sustainable Palm Oil, Kuala Lumpur supported by British Government-Foreign & Commonwealth Office, 214 pp.

Lokkers, C. (1986). The Distribution of the Weaver Ant, *Oecophylla smaragdina* (Fabricius)(Hymenoptera, Formicidae) in Northern Australia. *Australian Journal of Zoology*, 34(5), 683-687.

Lokkers, C. (1990). Colony dynamics of the green tree ant (*Oecophylla smaragdina* Fab.) in a seasonal tropical climate. *James Cook University*, 301 pp.

Macfarlane, R., Jackson, G., & Marten, K. (1976). Die-back of Eucalyptus in the Solomon Islands. *Commonwealth Forestry Review*, 55(2), 133-139.

Marçon, P. C. R. G., Siegfried, B. D., Spencer, T., & Hutchison, W. (2000). Development of diagnostic concentrations for monitoring *Bacillus thuringiensis* resistance in European corn borer (Lepidoptera: Crambidae). *Journal of economic entomology*, 93(3), 925-930.

Mahadi, N. A., Muhamad, R & Adam, N. A. (2012). Relationship between Bagworm *Pteroma pendula* Joannis (Lepidoptera: Psychidae) Populations, Parasitoids, and Weather Parameters in Oil Palm Plantation. *Journal of Agricultural Science*, 4(12), 13-17.

Markin, G. P., Dillier, J. H., & Collins, H. (1973). Growth and development of colonies of the red imported fire ant, *Solenopsis invicta*. *Annals of the Entomological Society of America*, 66(4), 803-808.

Martin, T. E. (2001). Abiotic vs. biotic influences on habitat selection of coexisting species: climate change impacts? *Ecology*, 82(1), 175-188.

MPOB, DVD. (2012). Latest Findings on Biological Control of Ganoderma Disease in Oil Palm. Bangi Kuala Lumpur: *Malaysian Palm Oil Board*.

Miller, P. (2010). The Smart Swarm. How understanding flocks, schools, and colonies can make us better at communicating, decision making, and getting things done. *Avery Publishing Group, Inc*, pp 304.

Murdoch, W. W. (1994). Population regulation in theory and practice. *Ecology*, 75(2), 271-287.

Murphy, S., & Briscoe, B. (1999). The red palm weevil as an alien invasive: biology and the prospects for biological control as a component of IPM. *Biocontrol news and information*, 20, 35N-46N.

Murray, G. H. (1937). Outbreak *Promecotheca antiqua*-Lindenhafen Estate. *New Guinea Agricultural Gazette*., 3(2), 1-2.

Needham, J. (1986). Science and civilisation in China. Vol. 6. Biology and biological technology. Part 1. *Botany. Cambridge Univ. Press*: Cambridge, 718, 448-450.

Norman, H. K, Ahmad, S. N., Arshad, O., & Basri, M. W. (2010). Pheromone mass trapping of bagworm moths, *Metisa plana* Walker (Lepidoptera: Psychidae), for its control in mature oil palms in Perak, Malaysia. *Journal of Asia-Pacific Entomology*, 13(2), 101-106.

Norman, H. K, & Basri, M. W. (1994). Common bagworm pests (Lepidoptera: Psychidae) of oil palm in Malaysia with notes to related South-east Asian species. *Malayan Nature Journal*, 48 pp.

Norman, H. K, & Basri, M. W. (1995). Control methods for rhinoceros beetle, *Oryctes rhinoceros* (L) (Coleoptera: Scarabaeidae). *Palm Oil Research Institute Malaysia Occasional Paper*, 35, 1-30.

Norman, H. K, & Basri, M. W. (2007). Status of common oil palm insect pests in relation to technology adoption. *Planter*, 83(975), 371-385.

Norman, H. K, & Basri, W. M. (2010). Interactions of the bagworm, *Pteroma pendula* (Lepidoptera: Psychidae), and its natural enemies in an oil palm plantation in Perak. *Journal of Oil Palm Research*, 22(April), 758-764.

Norman, H. K, Nurulhidayah, S. A., Othman, A & Basri, M. W. (2009). Pheromone mass trapping of bagworm moths, *Metisa plana* Walker (Lepidoptera:Psychidae), for its control in mature oil palms in Perak, Malaysia. *Journal of Asia-Pacific Entomology* 13, 101-106.

Norman, H. K., & Othman, A. (2006). Potentials of Using the Pheromone Trap for Monitoring and Controlling the Bagworm, *Metisa plana* Wlk (Lepidoptera: Psychidae) on Young Oil Palm in a Smallholder Plantation. *Journal of Asia-Pacific Entomology*, 9(3), 281-285.

Norman, H. K, Robinson., G. S & Basri, M. W. (1994). Common bagworm pests (Lepidoptera: Psychidae) of oil palm, with notes on related South-East Asian species. *Malayan Nature Journal*, 48, 93-123.

Norman, H. K & Wahid. M. B. (1992). A survey of current status and control of nettle caterpillars (Lepidoptera: Limacodidae) in Malaysia (1981-1990). *PORIM Occasional Paper*, 27 pp.

Offenberg, J. (2004). Observations on the Ecology of Weaver Ants (*Oecophylla smaragdina* Fabricius) in a Thai Mangrove Ecosystem and Their Effect on Herbivory of *Rhizophora mucronata* Lam. *Forest Research*, *36*(3), 344-351. Retrieved from http://www.bioone.org/perlserv/?request=getabstract&doi=10.1646%2F03158

Offenberg, J., & Wiwatwitaya, D. (2010). Sustainable weaver ant (*Oecophylla smaragdina*) farming: harvest yields and effects on worker ant density. *Asian Myrmecology*, 3, 55-62.

O'Sullivan, D. (1973). Observations on the coconut spathe bug *Axiagastus cambelli* Distant (Hemiptera: Pentatomidae) and its parasites and predators in Papua New Guinea. *Papua New Guinea Agricultural Journal*, 24(3), 79-86.

Parrella, M., & Lewis, T. (1997). Integrated pest management (IPM) in field crops. Thrips as crop pests, 595-614.

Pelini, S. L., Boudreau, M., McCoy, N., Ellison, A. M., Gotelli, N. J., Sanders, N. J., & Dunn, R. R. (2011). Effects of short-term warming on low and high latitude forest ant communities. *Ecosphere*, 2(5), art62.

Peng, R., & Christian, K. (2004). The weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), an effective biological control agent of the red-banded thrips, *Selenothrips rubrocinctus* (Thysanoptera: Thripidae) in mango crops in the Northern Territory of Australia. *International Journal of Pest Management*, 50(2), 107-114.

Peng, R., & Christian, K. (2005). Integrated pest management in mango orchards in the Northern Territory Australia, using the weaver ant, *Oecophylla smaragdina*, (Hymenoptera: Formicidae) as a key element. *International Journal of Pest Management*, 51(2), 149-155.

Peng, R., & Christian, K. (2006). Effective control of Jarvis's fruit fly, *Bactrocera jarvisi* (Diptera: Tephritidae), by the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), in mango orchards in the Northern Territory of Australia. *International Journal of Pest Management*, 52(4), 275-282.

Peng, R., Christian, K., & Gibb, K. (1999). The effect of colony isolation of the predacious ant, *Oecophylla smaragdina* (F.). (Hymenoptera: Formicidae), on protection of cashew plantations from insect pests. *International Journal of Pest Management*, 45(3), 189-194.

Peng, R., Christian, K., & Gibb, K. S. (2004). Implementing Ant Technology in Commercial Cashew Plantations and Continuation of Transplanted Green Ant Colony Monitoring: A Report for the Rural Industries Research and Development Corporation: *Rural Industries Research and Development Corporation Canberra*, Australia. Government of Australia: iii, vi-1-14

Pfeiffer, M., Ho, C. T., & The, C. L. (2007). Exploring arboreal ant community and co-occurrence patterns in plantations of oil palms (*Elaeis guineensis*) in Borneo and Peninsular Malaysia. In structuring of animal communities: Interspecific interactions and habitat selection among ants and small mammals. für Habilitationsschrift zur Erlangung der Venia Legendi an der Universität Ulm. *Fakultät Naturwissenschaften*. http://www.antbase.net/pdf/pfeiffer-habil.pdf.

Pfeiffer, M., Cheng Tuck, H., & Chong Lay, T. (2008). Exploring arboreal ant community composition and co-occurrence patterns in plantations of oil palm *Elaeis guineensis* in Borneo and Peninsular Malaysia. *Ecography*, 31(1), 21-32.

Phillips, J. S. (1940). Immature nutfall of coconuts in the Solomon Islands. *Bulletin of Entomological Research*, 31(03), 295-316.

Philpott, S. M., Arendt, W. J., Armbrecht, I., Bichier, P., Diestch, T. V., Gordon, C. Soto-Pinto, L. (2008). Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conservation Biology*, 22(5), 1093-1105.

Philpott, S. M., & Armbrecht, I. (2006). Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecological Entomology*, 31(4), 369-377.

Ramlah, S. A. A., Ahmad, M. N., Masri, M. M. M., & Basri, M. (2012). Field Efficacy of MPOB in Ecobac-1 (EC) for Controlling Bagworm, *Pteroma pendula* Annual (Lepidoptera: Psychidae) Outbreak Oil Palm Plantation. UMT 11th International Symposium on Sustainability Science and Management 09th – 11th July 2012, Terengganu, Malaysia. http://fullpaperumtas2012.umt.edu.my/files/2012/07/AG17-ORAL-PP-170-176.pdf

Ramlah Ali, A., Basri, W. M., & Ramlee, M. (1996). Isolation and amplification baculovirus as a biocontrol agent for bagworms and nettle caterpillars of palm oil. *Elaeis,* 8(1), 1-9. .

Ramlah, S. A. A; Norman, K; Basri, M. W; Mohd Najib, A; Mohd, N. A., Mohd Mazmira, M. M., & Kushairi, A. D. (2007). Sistem Pengurusan Perosak Bersepadu bagi Kawalan Ulat Bungkus di Ladang Sawit. Lembaga Minyak Sawit Malaysia (MPOB). *Kementerian Perusahaan Perladangan dan Komoditi Malaysia*, p 1-23.

Ribeiro, S. P., Santo, N. B. E., Delabie, J. H., & Majer, J. D. (2013). Competition, resources and the ant (Hymenoptera: Formicidae) mosaic: a comparison of upper and lower canopy. *Myrmecological News*, 18, 113-120.

Room, P., & Smith, E. (1975). Relative abundance and distribution of insect pests, ants and other components of the cocoa ecosystem in Papua New Guinea. *Journal of Applied Ecology*, p 31-46.

Roseleena, J., Nursuriati, J., Ahmed, J., & Low, C. (2011). Assessment of palm oil fresh fruit bunches using photogrammetric grading system. *International Food Research Journal*, 18(3), 999-1005.

Roy, G. V. D., & Thomas, S. B. (1996). Biological Control. First edition. *Chapman & Hall*, 245 pp.

Sankaran, T. (1970). The oil palm bagworms of Sabah and the possibilities of their biological control. *International Journal of Pest Management*, 16(1), 43-55.

Sankaran, T., & Syed, R. (1972). The natural enemies of bagworms on oil palms in

Sabah, East Malaysia. *Pacific Insects*, 14(1), 57-71.

Singh, R. P., Ibrahim, M. H., Esa, N., & Iliyana, M. S. (2010). Composting of waste from palm oil mill: a sustainable waste management practice. *Reviews in Environmental Science and Bio/Technology*, 9(4), 331-344.

Sporleder, M., & Rapp, G. (1998). The effect of *Oecophylla longinoda* (Latr.) (Hym., Formicidae) on coconut palm productivity with respect to *Pseudotheraptus wayi* Brown (Hem., Coreidae) damage in Zanzibar, *Journal of Applied Entomology*, 122(1-5), 475-481.

Stapley, J. H. (1973). Insect pests of coconuts in the Pacific region. *Outlook on Agriculture*, 7(5), 211-217.

Stapley, J. H. (1980). Using the predatory ant, *Oecophylla smaragdina*, to control insect pests of coconuts and cocoa. *Information Circular. South Pacific Commission*, 85, 7 pp.

Strickland, A. (1951). The entomology of swollen shoot of cacao. *Bulletin of Entomological Research*, 41(04), 725-748.

Stuble, K. L., Pelini, S. L., Diamond, S. E., Fowler, D. A., Dunn, R. R., & Sanders, N. J. (2013). Foraging by forest ants under experimental climatic warming: a test at two sites. *Ecology and evolution.* 3(3), 482–491.

Supaiya, M., & Pereira, T. (2012). Wake-up call for Malaysian palm oil industry. *Business Times*. www.btimes.com.my/Current_News/BTIMES/articles/fledass/Article/#

Syed, R. A., Law, I. H., & Corey, T. H. (1982). Insect pollination of oil palm: Introduction establishment and pollinating efficiency of *Elaeidobius kamerunicus* Faust in Malaysia. *Planter*, Kuala Lumpur, 58, 561-574.

Szent-Ivany, J. (1961). Insect pests of *Theobroma* cacao in the Territory of Papua and New Guinea. *Papua New Guinea Agricultural Journal*, 13, 127-147.

Tan, K., Lee, K., Mohamed, A., & Bhatia, S. (2009). Palm oil: addressing issues and towards sustainable development. *Renewable and Sustainable Energy Reviews*, 13(2), 420-427.

Thomas, M. B., & Blanford, S. (2003). Thermal biology in insect-parasite interactions. Trends in *Ecology & Evolution*, 18(7), 344-350.

Tsuji, K., Hasyim, A., & Nakamura, K. (2004). Asian weaver ants, *Oecophylla smaragdina*, and their repelling of pollinators. *Ecological Research*, 19(6), 669-673.

Van Driesche, R. G., Carruthers, R. I., Center, T., Hoddle, M. S., Hough-Goldstein, J., Morin, L., & Van Klinken, R. D. (2010). Classical biological control for the protection of natural ecosystems. *Biological Control*, *54*, S2-S33.

Van Mele, P. (2008). A historical review of research on the weaver ant *Oecophylla* in biological control. *Agricultural and Forest Entomology*, 10(1), 13-22.

Van Mele, P., Cuc, N. T. T., Seguni, Z., & Camara, K. (2009). Multiple sources of local knowledge: a global review of ways to reduce nuisance from the beneficial weaver ant *Oecophylla*. *International journal of agricultural resources, governance and ecology*, 8(5), 484-504.

Van Mele, P., & Cuc, N. (2000). Evolution and status of *Oecophylla smaragdina* (Fabricius) as a pest control agent in citrus in the Mekong Delta, Vietnam. *International Journal of Pest Management*, 46(4), 295-301.

Vanderplank, F. (1960). The bionomics and ecology of the red tree ant, *Oecophylla* sp., and its relationship to the coconut bug *Pseudotheraptus wayi* Brown (Coreidae). *The Journal of Animal Ecology*, p 15-33.

Voûte, A. D. (1935). *Cryptorrhynehus gravis* F. and the causes of its multiplication in Java. *Archives Néerlandaises de Zoologie*, 2, 112-42.

Wahid, M. B., Hassan, A. H., & Masijan, Z. (1988). Bagworms (Lepidoptera: Psychidae) of Oil Palms in Malaysia. *PORIM Occasional Paper* 23, p 37.

Way, M. (1953). The relationship between certain ant species with particular reference to biological control of the coreid, Theraptus sp. *Bulletin of Entomological Research*, 44(04), 669-691.

Way, M., & Khoo, K. (1989). Relationships between *Helopeltis theobromae* damage and ants with special reference to Malaysian cocoa smallholdings. *Journal of Plant Protection in the Tropics*, 6(1), 1-11.

Way, M., & Khoo, K. (1992). Role of ants in pest management. *Annual Review of Entomology*, 37(1), 479-503.

Wielgoss, A., Tscharntke, T., Buchori, D., Fiala, B., & Clough, Y. (2010). Temperature and a dominant dolichoderine ant species affect ant diversity in Indonesian cacao plantations. *Agriculture, Ecosystems & Environment*, 135(4), 253-259.

Wilson, E. O. (1971). The insect societies. *Belknap Press of Harvard University Press*. Cambridge. Massachusetts, 548 pp.

Wilson, S., & O'Brien, L. (1987). Survey of planthopper pests of economically important plants (Homoptera: Fulgoroidea). Paper presented at the Proceedings of 2nd International Workshop on Leafhoppers and Planthoppers of Economic Importance: Brigham Young University, Provo, Utah, USA, 28th July-1st August 1986/edited by MR Wilson, LR Nault, 343-360.

Wojtusiak, J., Godzińska, E., & Dejean, A. (1995). Capture and retrieval of very large prey by workers of the African weaver ant, *Oecophylla longinoda* (Latreille 1802). *Tropical Zoology*, 8(2), 309-318.

Wood, B., & Nesbit, D. (1969). Caterpillar outbreaks on oil palms in eastern Sabah. *Planter*, Kuala Lumpur, 45(518), 285-299.

Wood, B. J. (1968). Pests of oil palms in Malaysia and their control: *Cambridge University Press*, 204 pp.

Wood, B. J. (1971). Development of integrated control programs for pests of tropical perennial crops in Malaysia Biological control: *Springer*, 422-457

Wood, B. J. (1973). Integrated control: critical assessment of case histories in developing economies. Insects: studies in population management, 196, 220.

Wood, B. J. (1976). Pests – introduction and ecological considerations In: Corley, R.H.V.; Hardon, J.J.; Wood, B.J. Oil palm research.Amsterdam, Netherlands; *Elsevier*, 20, 333-346.

Wood, B. J. (2002). Pest control in Malaysia's perennial crops: a half century perspective tracking the pathway to integrated pest management. *Integrated pest management reviews*, 7(3), 173-190.

Yang, P. (1982). Biology of the yellow citrus ant, *Oecophylla smaragdina* and its utilization against citrus insect pests. *Acta Scientiarum Naturalium Universitatis Sunyatseni*, 3, 102-105.

Young, S. (1971). Some pests of oil palm on the east coast of Sabah. Crop Protection in Malaysia, Wastie, RL and BJ Wood (Eds.). *ISP*, Kuala Lumpur, 107-114.

Yunus, A. (1966). Pests and diseases in the Oil Palm in Malaya. *Ministry of Agriculture and Co-operatives Kuala Lumpur*, Malaysia. (7), 87-91.

Yunus, A., & Ho, T. H. (1980). List of economic pests, host plants, parasites and predators in West Malaysia (1920-1978). *Bulletin, Ministry of Agriculture, Malaysia*, pp 153.

Zeven, A. C. (1967). The semi-wild oil palm and its industry in Africa. *Proefschrift Landbouwhogeschool Wageningen*, 178 pp.

Zhang, W., & Swinton, S. M. (2006). A Natural Enemies-Adjusted Economic Threshold for Pest Control. Paper presented at the 8th Annual BIOECON Conference, Kings College, Cambridge, United Kingdom.
http://www.ucl.ac.uk/bioecon/8th_2006/Zhang_Swinton.pdf
http://www.aec.msu.edu/theses/fulltext/zhang_phd.pdf

Appendix 2.2.1. Variation in *P. pendula* population and parasitism. Date of sampling: 25-26/06/2010

Block/Plot	Mean/frond)		Total larvae	Mean/frond		Total Live pupae	Total frond sampled
	Live larvae	Dead larvae		Live pupae (♂)	Live pupae (♀)		
Block B							
Plot 1	0.00	1.40	7	0.00	0.20	1	5
Plot 2	0.00	1.20	6	0.00	0.00	0	5
Plot 3	3.40	0.00	17	0.00	0.00	0	5
Total	**3.40**	**2.60**	**30**	**0.00**	**0.20**	**1**	**15**
Mean	**1.13**	**0.87**	**10.00**	**0.00**	**0.07**	**0.33**	**5**
Block 3A							
Plot 1	3.40	1.00	22	0.20	0.60	4	5
Plot 2	0.00	5.00	25	0.00	1.80	9	5
Plot 3	0.00	0.40	2	0.00	0.00	0	5
Total	**3.40**	**6.40**	**49**	**0.20**	**2.40**	**13**	**15**
Mean	**1.13**	**2.13**	**16.33**	**0.07**	**0.80**	**4.33**	**5**
Block 2B							
Plot 1	0.00	1.40	7	0.00	0.00	0	5
Plot 2	0.00	2.60	13	0.00	0.20	1	5
Plot 3	0.20	1.20	7	0.00	1.60	8	5
Total	**0.20**	**5.20**	**27**	**0.00**	**1.80**	**9**	**15**
Mean	**0.07**	**1.73**	**9.00**	**0.00**	**0.60**	**3.00**	**5**
Block 3B							
Plot 1	0.00	0.40	2	0.00	0.00	0	5
Plot 2	0.00	0.00	0	0.00	0.00	0	5
Plot 3	0.00	0.40	2	0.00	0.00	0	5
Total	**0.00**	**0.80**	**4**	**0.00**	**0.00**	**0**	**15**
Mean	**0.00**	**0.27**	**1.33**	**0.00**	**0.00**	**0.00**	**5**
Block 1A							
Plot 1	0.00	0.20	1	0.00	0.00	0	5

Plot 2	0.00	0.00	0	0.00	0.00	0	5
Plot 3	0.00	0.00	0	0.00	0.00	0	5
Total	**0.00**	**0.20**	**1**	**0.00**	**0.00**	**0**	**15**
Mean	**0.00**	**0.07**	**0.33**	**0.00**	**0.00**	**0.00**	**5**
Block 2A							
Plot 1	0.00	1.40	7	0.00	0.00	0	5
Plot 2	0.00	0.00	0	0.00	0.00	0	5
Plot 3	0.00	0.80	4	0.00	0.00	0	5
Total	**0.00**	**2.20**	**11**	**0.00**	**0.00**	**0**	**15**
Mean	**0.00**	**0.73**	**3.67**	**0.00**	**0.00**	**0.00**	**5**

(Primary data for the month of June 2010: MPOB sources)

Location : "Stesen" MPOB Teluk Intan, Perak

Date sampling : 25-26/11/2010

Block/Plot	Mean/frond)		Total larvae	Mean/frond		Total Live pupae	Total frond sampled
	Live larvae	Dead larvae		Live pupae (♂)	Live pupae (♀)		
Block B							
Plot 1	79.40	0.60	400	0.00	1.80	9	5
Plot 2	86.40	0.00	432	0.00	0.00	0	5
Plot 3	113.20	0.40	568	0.00	0.20	1	5
Total	**279.00**	**1.00**	**1400**	**0.00**	**2.00**	**10**	**15**
Mean	**93.00**	**0.33**	**466.67**	**0.00**	**0.67**	**3.33**	**5**
Block 3A							
Plot 1	1.00	0.60	8	0.00	0.00	0	5
Plot 2	0.00	3.00	15	0.00	4.40	22	5
Plot 3	0.00	0.80	4	0.00	2.40	12	5
Total	**1.00**	**4.40**	**27**	**0.00**	**6.80**	**34**	**15**
Mean	**0.33**	**1.47**	**9.00**	**0.00**	**2.27**	**11.33**	**5**

Block 2B							
Plot 1	162.80	0.00	814	0.00	2.80	14	5
Plot 2	56.60	0.00	283	0.00	0.60	3	5
Plot 3	262.40	0.00	1312	0.00	0.40	2	5
Total	**481.80**	**0.00**	**2409**	**0.00**	**3.80**	**19**	**15**
Mean	**160.60**	**0.00**	**803.00**	**0.00**	**1.27**	**6.33**	**5**
Block 3B							
Plot 1	519.00	0.00	1590	0.40	0.00	2	5
Plot 2	8.40	0.00	42	0.00	0.00	0	5
Plot 3	55.00	0.20	276	0.00	0.40	2	5
Total	**582.40**	**0.20**	**1908**	**0.40**	**0.40**	**4**	**15**
Mean	**215.26**	**0.07**	**636.00**	**0.13**	**0.13**	**1.33**	**5**
Block 1A							
Plot 1	95.00	0.00	95	0.00	3.40	17	5
Plot 2	89.80	0.20	450	0.00	0.00	0	5
Plot 3	164.20	1.00	826	0.00	0.80	4	5
Total	**349.00**	**1.20**	**1371**	**0.00**	**4.20**	**21**	**15**
Mean	**116.33**	**0.40**	**457.00**	**0.00**	**1.40**	**7.00**	**5**
Block 2A							
Plot 1	2.40	0.40	14	0.00	0.00	0	5
Plot 1	2.40	0.40	14	0.00	0.00	0	5
Plot 3	12.80	1.80	73	0.00	0.20	1	5
Total	**42.60**	**2.20**	**224**	**0.00**	**0.20**	**1**	**15**
Mean	**14.20**	**0.73**	**74.67**	**0.00**	**0.07**	**0.33**	**5**

(Primary data for November 2010: MPOB sources)

Appendix 2.3.2a Average monthly pest density (mean live larvae) of *P. pendula* monitored from June 2010 to May 2012

Period (year/month)	Monthly Rainfall average (mm)	Mean dead larvae/frond for each block					
		2B	3B	B	1A	2A	3A
June 2010	168.6	1.7	0.3	1	0.1	0.7	2.1
July	132.6	0.5	9.1	9	3.6	2.8	19.1
August	72.2	0.3	0	0.3	0	0	0.1
September	97.8	0	0	0	0	0	0
October	66	0	0	0	0	0	0
November	218.6	0	0.1	0.3	0.4	0.7	1.5
December	92.1	3.1	0.6	4.1	1	4.3	0.3
January 2011	130.4	0.7	4.3	3.3	3.7	1	1
February	75.3	1	1.7	2.4	0.5	0.3	0
March	105.1	2.8	10.5	7.2	3	0.5	0
April	197.2	0.1	0.3	0.3	0.1	0.1	0.1
May	219.2	0.3	0	2.7	0.5	0.3	0
June	50.60	0	0	1	0	0.3	0.5
July	81.9	0	1.4	0.5	1	0	2.3
August	138.3	0	0	0	0	0	0
September	163.4	0	0	0	0	0	0
October	434.5	1	0	0.5	0.3	1.6	2.7
November	422	0	0	0.1	0	0	0.1
December	204.7	0	0	0	0	0	0
January 2012	169.8	0	0	0	0	0.7	0
February	152.1	0.1	0.3	0.6	0.3	0	0
March	170	0	0	0	0	0	0
April	164.6	0	0	0	0	0	0
May	137.6	0	0	0	0	0	0

(Data extracted and calculated from primary MPOB data source)

Appendix 2.3.2b.

Average monthly pest density (mean dead larvae) of *P. pendula* monitored from June 2010 to May 2012.

Period (year/month)	Monthly Rainfall average (mm)	Mean live larvae/frond for each block					
		2B	3B	B	1A	2A	3A
June 2010	168.6	0.07	0	0	0	1.13	1.13
July	132.6	0	0	0	0.8	4	0.13
August	72.2	0.07	7.8	0.8	7.67	10.6	0
September	97.8	1.8	5.07	3	5.47	12.07	7.73
October	66	15.33	29.53	2.8	16.73	32.73	15.6
November	218.6	160.6	14.2	164.2	127.13	0.33	93
December	92.1	0	1.33	0	0.07	0	0
January 2011	130.4	75.13	27.27	51.53	5.07	9.4	87.6
February	75.3	0	0.67	0.07	0	0	0
March	105.1	11.53	2.67	29.2	35.07	0	80.27
April	197.2	0	0	0	0	0	0
May	219.2	0	0	0	0	0	0
June	50.60	0	0	0	0	0	0
July	81.9	0	0	0	0	0	0
August	138.3	1.67	4.07	7.4	0.2	0.73	7
September	163.4	2.7	2.5	3	1.8	2	3
October	434.5	4.4	3.47	6.47	2.2	5.93	5.93
November	422	141.27	84.8	138.47	58.87	34.93	177.53
December	204.7	3.07	0.33	9.33	3.73	2.4	4.2
January 2012	169.8	8.474	4.13	8.47	11.27	4.47	14.47
February	152.1	0	0	0	0	0	0
March	170	10.27	16.27	12.53	9.4	10.93	11.13
April	164.6	2.67	9.27	2.8	0.13	6.53	3.73

May	137.6	1.87	0.07	0.53	0.13	0	2.33

(Data extracted and calculated from primary MPOB data source)

2.3.2c Appendix Statistical analysis with Sigma Plot 12 software.

Data source: Combined Data Rainfall versus Pest Density (oil palm plantations at MPOB Teluk Intan, Perak).

Cell Contents: Combined data of Mean live larvae

Pearson Correlation Coefficient r: r=0.474; P Value: P=0.0193; Number of Samples: 24 replicates

Data source: Relative Humidity % versus Pest Density (oil palm plantations at MPOB Teluk Intan, Perak).

Cell Contents:
Correlation Coefficient r (Pearson)
P Value
Number of Samples: 24 replicates or 24 months monitoring census carried out

	2B	**2A**	**1A**	**3B**	**3A**	**B**
Relative Humidity %						
R:	0.315	0.0805	0.331	0.284	-0.146	0.349
P:	0.134	0.708	0.114	0.179	0.497	0.0944
	24	**24**	**24**	**24**	**24**	**24**
2B		0.719	0.987	0.879	0.879	0.879
		0.0000756	5.545E-019	0.0000000165	0.0489	0.0000000160
		24	**24**	**24**	**24**	**24**
2A			0.675	0.450	0.851	0.832
			0.000294	0.0272	0.000000138	0.000000453
			24	**24**	**24**	**24**
1A				0.922	0.346	0.878
				0.000000000162	0.0976	0.0000000176
				24	**24**	**24**

3B					0.224	0.709
					0.292	0.000104
					24	**24**
3A						0.518
						0.00952
						24
B						

Data source: Combined Data RH versus Mean Pest Density of larvae

Cell Contents:

Correlation Coefficient r: 0.309

P Value: 0.142

Number of Samples: 24

Pearson Product Moment Correlation matrix.

Data source: RH versus Dead larvae at MPOB Teluk Intan Perak, oil palm plantations.

Cell Contents:

Correlation Coefficient R
P Value
Number of Samples: 24

BLOCKS	**2B**	**2A**	**1A**	**3B**	**3A**	**B**
R:	0.501	0.372	0.334	0.220	-0.0700	0.266
P:	0.0127	0.0734	0.110	0.302	0.745	0.209
	24	**24**	**24**	**24**	**24**	**24**
2B		0.655	0.438	0.480	0.0393	0.607
		0.000513	0.0323	0.0177	0.855	0.00164
		24	**24**	**24**	**24**	**24**
2A			0.467	0.335	0.499	0.613
			0.0214	0.110	0.0130	0.00144

	24	**24**	**24**	**24**
1A		0.894	0.576	0.864
		0.00000000411	0.00320	0.0000000546
		24	**24**	**24**
3B			0.581	0.905
			0.00288	0.00000000126
			24	**24**
3A				0.660
				0.000452
				24

Appendix 3.1.3

Tropical agriculture and forestry insect pests controlled by green ants

Crop	Name of insect pest	Order / Family	Country	Reference
Tropical Agriculture				
Cassava	*Amblypelta l. lutescens* (Distant)	Hemiptera / Coreidae	Australia	Peng unpublished
	Amblypelta l. papuensis (Brown)	Hemiptera / Coreidae	Papua New Guinea	Peng unpublished
Cashew	Helopeltis *pernicialis* (Stondahl et al.)	Hemiptera / Miridae	Australia	Peng, Christian & Gibb 1995
	Amblypelta l. lutescens (Distant)	Hemiptera / Coreidae	Australia	1997a, b, c; 1998a; 1999a, b
	Penicillaria Jocosatrix (Guenee)	Lepidoptera / Noctuidae	Australia	Peng, Christian & Gibb 1995;
	Anigraea ochrobasis (Hampson)	Lepidoptera / Noctuidae	Australia	1997a, b, c; 1998a; 1999a, b
	Nezara viridula (Fab.)	Hemiptera / Pentatomidae	Australia	Peng et al. 1999a
	Monolepta australis (Jac.)	Coleoptera / Chrysomelidae	Australia	Peng unpublished
	Amblypelta l. papuensis (Brown)	Hemiptera / Coreidae	Papua New Guinea	Peng unpublished
	Eggs of Helopeltis antonii (Sign.)	Hemiptera/ Miridae	Sri Lanka	Jeevaratnam et al. 1981
Citrus	*Rhynchocoris humeralis* (Thunberg)	Hemiptera / Pentatomidae	China	Chen 1962; Yang 1982; 1984 a, b
	Podagricomela nigricollis (Chen)	Lepidoptera / Gracillariidae	China	Chen 1962; Yang 1984b
	Hypomeaes sqamosus (F.)	Coleoptera / Curculionidae	China	Chen 1962
	Anomala cupripes (Hope)	Coleoptera / Scarabaeidae	China	Chen 1962
	Sympiezomia cityi (Chao)	Coleoptera / Curculionidae	China	Yang 1984a, b
	Holotrichia sinensis (Hope)	Coleoptera / Scarabaeidae	China	Yang 1984b
	Chelidonium argentatum (Dalm.)	Coleoptera / Curculionidae	China	Yang 1984b
	Papilio xuthus (L)	Lepidoptera / Papilionidae	China	Yang 1984b
	Nezara viridulu (L.)	Hemiptera / Pentatomidae	China	Yang 1984b
	Agrilus auriventris (Saund)	Coleoptera / Agriidae	China	Yang 1984b
	Anoplophora Chinensis (Forst)	Coleoptera / Cerabycidae	China	Yang 1984b
	Tessaratoma papillosa (Dru.)	Hemiptera / Pentatomidae	China &Philippines	Groff et al. 1924; Leston 1973

Rhynchororis serratus (Don.) Hemiptera / Pentatomidae
Philippines Garcia 1935
Various caterpillars Lepidoptera
Philippines Garcia 1935
Anoplophora versteegii Coleoptera / Cerambycidae Indian
Phukan, et al. 1995
Stromatium barbatum Coleoptera / Cerambycidae Indian
Phukan, et al. 1995
Improve fruit quality
Vietnam Barzman et al, 1996

Cocoa *Pantorhytes biplagiatus* (Guer.) Coleoptera / Cerambycidae
Solomon Islands Stapley 1980

Papua New Guinea Friend 1973
Amblypelta theobromae (Brown) Hemiptera / Coreidae
Papua New Guinea Szent-Ivany 1961
Helopeltis theobromae (Water.) Hemiptera / Miridae
Malaysia Way et al. 1989; 1992
Helopeltis clavifer (Walk.) Hemiptera / Miridae
Papua New Guinea Szent-Ivany 1961
Pseudodoniella laensis (Mill.) Hemiptera / Miridae
Papua New Guinea Szent-Ivany 1961
Parabryocoropsis typicus (China &Carv.) Hemiptera / Miridae
Papua New Guinea Dun 1954
Pantorhytes plutus (Oberth.) Coleoptera / Cerambycidae
Papua New Guinea Szent-Ivany 1961
Pantorhytes spp Coleoptera / Cerambycidae
Papua New Guinea Szent-Ivany 1961
Rodents
Malaysia Way & Khoo 1992

Coffee Various insect pests Sri Lankan Leela 1961

Coconut *Promecotheca* spp Coleoptera Papua New Guinea Murry 1937
Amblypelta cocophaga (China) Hemiptera / Coreidae Solomon Islands
Philips 1940; Brown 1959a;
Axiagastus campbelli (Distant) Hemiptera / Pentatomidae Solomon Islands
Greenslade 1971; Stapley 1972b,
Brontispa longissima (Gestro) Coleoptera / Chrysomelidae
Solomon Islands 1980; Baloch 1973;
Amblypelta cristobalensis (Brown) Hemiptera / Coreidae
Solomon Islands O'Sullivan 1973; Brown 1959a
Amblypelta l. papuensis (Brown) Hemiptera / Coreidae
Papua New Guinea Szent-Ivany & Catley

Lychee *Rhynchocoris humeralis* (Thunberg) Hemiptera / Pentatomidae
China Chen 1962
Tessaratoma papillosa (Dru.) Hemiptera / Pentatomidae
China Swingle 1942

Mango Cryptorrhynchus *gravis* (F.) Coleoptera / Curculionidae
Indonesia Voute 1935
Sternochetus gravis (Fab.) Coleoptera / Curculionidae
India De et al. 1988

Amblypelta l. lutescens (Distant) Hemiptera / Coreidae
Australia Peng unpublished
Penicillaria Jocosatrix (Guenee) Lepidoptera / Noctuidae
Australia Peng unpublished
Selenothrips rubrocinctus (Giard) Thysanoptera / Thripidae
Australia Peng et al. unpublished
Various caterpillars Lepidoptera
Australia Peng unpublished

Oil palm *Cremastopsyche pendula* (Joannis) Lepidoptera /Psychidae
Malaysia Way & Khoo 1992
Other caterpillars Lepidoptera
Malaysia Way & Khoo 1992

Tea *Poecilocoris latus* (Dall.) Hemiptera / Pentatomidae India
Das 1959

Tropical forestry

Eucalyptus *Amblypelta cocophaga* (Brown) Hemiptera / Coreidae
Solomon Islands Macfarlane et al. 1976
Hoop Pine *Milionia isodoxa* (Prout) Lepidoptera / Geomitridae
Papua New Guinea Wylie 1974

Appendix 3.3.3
Economic Thresholds of Important Pests of Oil Palms

Name of insect pest **Order / Family** **Economic threshold**
References **Scientific Name**

Bagworms
Lepidoptera: Psychidae

Wood (1971) *Metisa plana* 10 larvae/frond
IRHO (1991) *Pteroma pendula* 30-60 larvae/frond
Basri (1993) *Metisa plana* 8-47 larvae/frond

Mahasena corbetti 5 larvae/ frond
Wood (1971)
Nettle caterpillars Lepidoptera: Limacodidae
Dama trima 10 larvae/ frond
Wood (1971) 30-60 larvae/ frond
IRHO (1991) *Setosa nitens* 5-10 larvae/ frond
IRHO (1991) *Dama diducta* 10-20 larvae/ frond
IRHO (1991) *Setothosea asigna* 5 larvae/ frond
Hoong and Hoh (1992)
Rhinoceros beetles Coleoptera: Scarabaeidae
Oryctes rhinoceros 10 % palms
Wood (1968)
With damage 3-5 adults/ha

IRHO (1991)		
Bunch Moths	Lepidoptera: Pyralidae *Tirathaba rufivena*	
		30 % of the palms with at least one bunch > 50% attacks in young plantings and 60% in older plantings
IRHO (1991)		
Cockchafers	Coleoptera: Scarabaeidae	
	Adoretus	5-10 adults/ palms
IRHO (1991)	*Apogonia*	10-20 adults/ palms
IRHO (1991)		
Rats	Rodentia: Muridae	
	Rattus spp	< 20% bait acceptance,
Wood (1968)		20% bunches with damage
Cheong, SP (pers comm)		

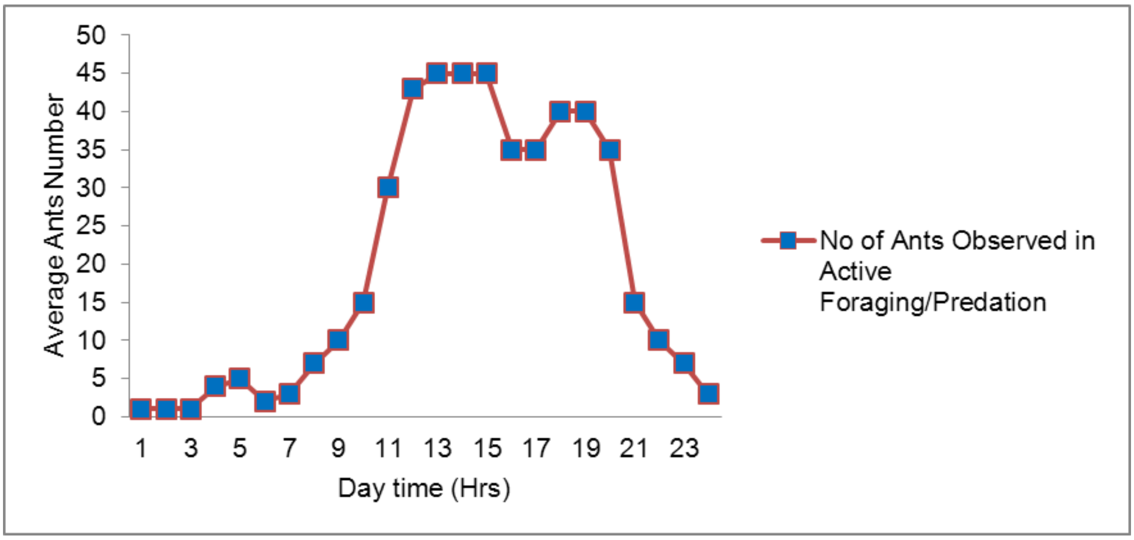
Appendix 3.4.2.1a

Average ants patrolling in oil palm fronds based on 24 hours observations (24 x 7)

Time	Category	No. of ants observed (active)
6	Morning	2
7		3
8		7
9		10
10		21
11	Afternoon	35
12		43
13		45
14		45
15		45
16	Evening	38
17		38
18		41
19		41
20	Night	36
21		25
22		10
23		7
24		3
1		1
2		1
3		1
4		4
5		1
TOTAL		**50**

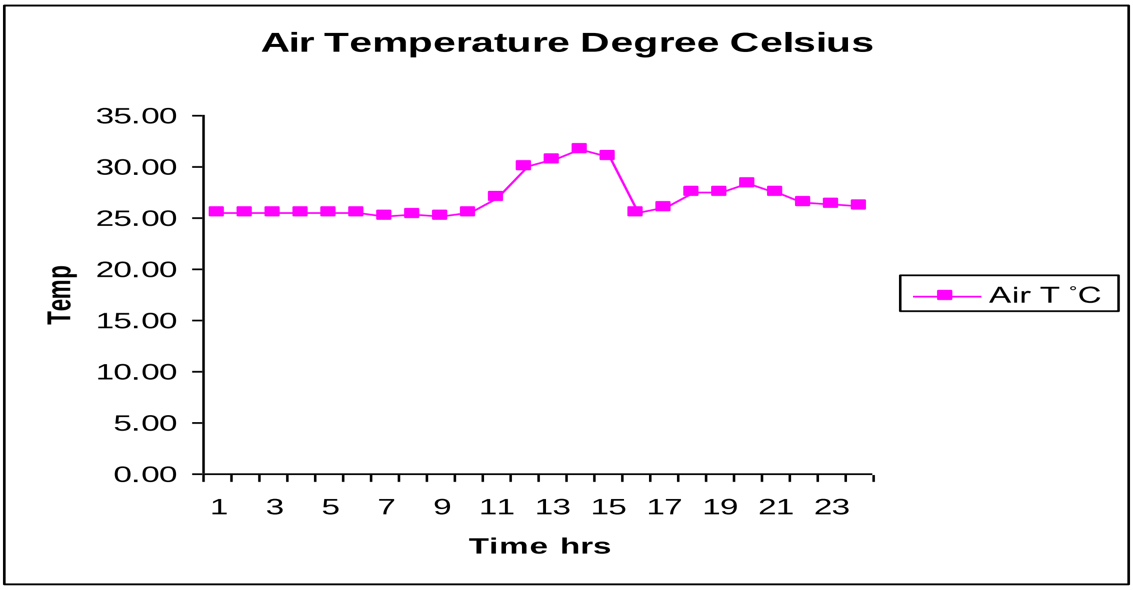
Note: 7 intensive observations carried out on 24 hours basis within 3 months (April 2011-May 2011 & January 2013) for a total 168 hours in the field, coupled with 1 month and half of a pilot intensive observation in open air.

Appendix 3.4.2.1b



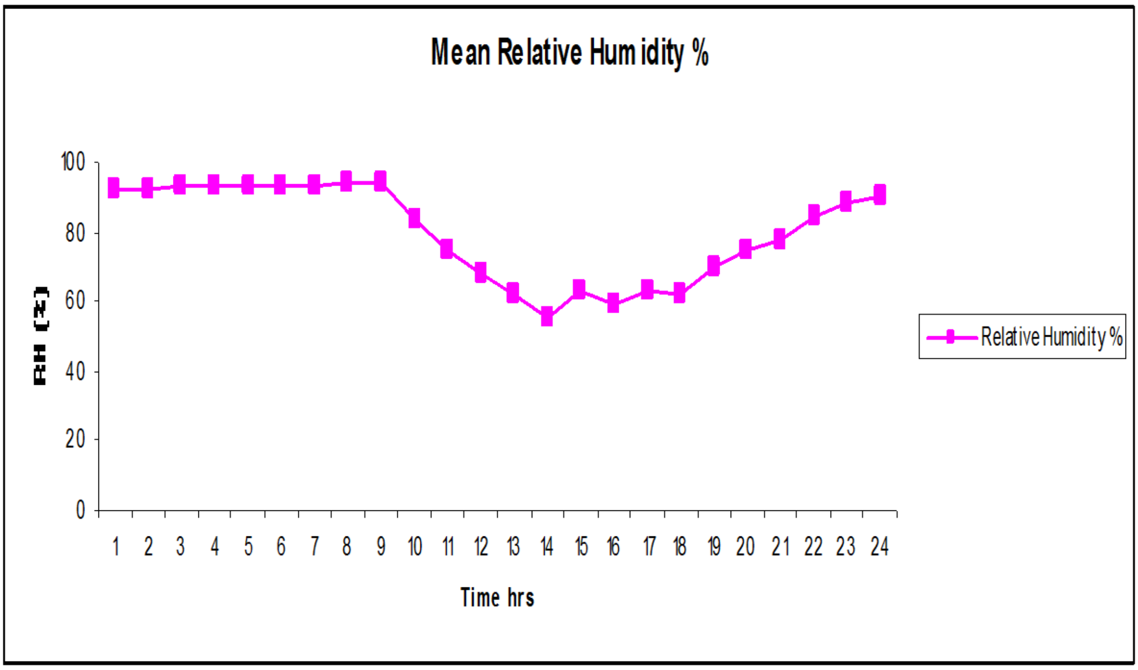
The graph shows a bimodal peak active period around 1200-1500 and 1800-1900 for the weaver ants at the study area.

Appendix 3.4.2.1c



The graphs clearly show that the first and highest peak period (blue graph) coincide with the peak of the daily air temperature (pink graph).

Appendix 3.4.2.1d



The graphs clearly show that the first and highest peak period (blue graph) negatively coincide with the ebb of the daily relative humidity (pink graph)

Appendix 3.4.2.2
Predation behaviour and rate of *O. smaragdina* in presence of larvae and pupae of *P. pendula*

Evaluation of attack duration and removal of *P. pendula* by major workers

Time (mins)	Average No of pupae taken	Average No of larvae taken
0	15	0
5	2	0
10	4	0
15	6	0
20	9	0
25	10	0
30	11	0
45	13	0
60	15	1
90	0	0

Appendix 3.4.4.3

Logrank and Wilcoxon tests for survival analysis based on the mortality ratio between pupae and larvae

Log-rank (Peto):

For group 1 (A = 1)

Observed deaths = 15

Extent of exposure to risk of death = 12.889286

Relative rate = 1.163757

For group 2 (A = 2)

Observed deaths = 1

Extent of exposure to risk of death = 3.110714

Relative rate = 0.32147

Test statistics:

2.110714 -2.110714

Variance-covariance matrix:

0.766711	-1.304273
-1.304273	1.304273

Chi-square for equivalence of death rates = 3.415784; P = 0.0646 (significant value)

Hazard Ratio (approximate 95% confidence interval)

Group 1 vs. Group 2 = 3.620116 / (1.049573 to 12.486257)

Conditional maximum likelihood estimates:

Hazard Ratio = infinity

Exact Fisher 95% confidence interval = 0.679848 to infinity

Exact Fisher one sided P = 0.0625, two sided P = 0.0854

Exact mid-P 95% confidence interval = 0.902637 to infinity

Exact mid-P one sided P = 0.0313, two sided P = 0.0625

<u>Generalised Wilcoxon (Peto-Prentice):</u>

Test statistics:

0.882353 -0.882353

Variance-covariance matrix:

2.580357	-0.387543
-0.387543	0.387543

Chi-square for equivalence of death rates = 2.008929; P = 0.1564

Log-rank tests demonstrated a statistically significant difference in survival experience between pupae and larvae at P = 0.0646

Wilcoxon tests demonstrated a statistically significant difference in survival experience between pupae and larvae at p = 0.156, therefore not so significant

Statsdirect was used to calculate the survival analysis. The test performed both for log-rank and wilcoxon; but the result shows a chi-square value for log-rank is more statistically significance. Only the result for log-rank is relevant here and reported in the manuscript.