IMMIGRATION AND ACTIVITY OF *Oryctes rhinoceros* WITHIN A SMALL OIL PALM REPLANTING AREA

NORMAN KAMARUDIN* and MOHD BASRI WAHID*

ABSTRACT

*The pheromone of the rhinoceros beetle (*Oryctes rhinoceros*) has been used for mass trapping and monitoring, integrated with biological control agents. In the current study, pheromone traps were used to monitor the immigration and activity pattern of *Oryctes *adults within a 4.5 ha replanting block. Trapping was initiated after about five months of replanting, for a period of 24 months. The relationships of the trap captures with the heap population, palm damage, rainfall and moon phases were also studied. Infestation of the block occurred almost simultaneously with replanting. The core region of the block was infested between the fourth to seventh month after completion of felling and chipping. It was noted that female beetles were trapped consistently more at the fringes than in the core of the replanting block. There was a significant relationship between the number of adult females trapped (at about 40-60 days before monitoring the population in the heaps) and the number of second instar larvae. There was an increase in the flight activity of the beetle (based on trap captures) during wet weather, likely due to their search for moist breeding sites. Male beetles were more active during the full moon, likely navigating for food and searching for suitable habitats before mating. Cumulative captures of each individual trap and the damage levels of adjacent palms were significantly related. A high proportion (92%) of females captured in the traps were gravid, with a mean of 16 eggs per female. Based on trap captures, there were indications that adult populations were coming from the adjacent mature plantings. This information can be exploited for more effective and targeted control of the pest.*

Keywords: *Oryctes rhinoceros*, pheromone trapping, infestation pattern, activity.

Date received: 20 September 2003; **Sent for revision:** 23 September 2003; **Received in final form:** 3 February 2004; **Accepted:** 8 February 2004.

INTRODUCTION

A national survey conducted on *Oryctes rhinoceros* has indicated that most estates had reports of occurrence of *O. rhinoceros* adults within one to six months after replanting (Norman and Basri, 1997). In the present study, the population of *O. rhinoceros* in a replanting area will be related to the activity of trapping *O. rhinoceros* adults by the use of pheromone traps. Commercially available, the pheromone trap has been used for mass trapping and monitoring (Chung, 1997) and integratedly used with biological control agents, like entomopathogenic fungus and virus (Ho, 1996).

Information on the immigration and activity of the rhinoceros beetle in oil palm is rather lacking. Bedford (1975) had earlier conducted studies on the beetle's activity in coconut areas. In that study, coconut logs were placed on top of tin containers as baits. The study had gathered some information on beetle captures in relation to rainfall, weed growth and the lunar cycle. In Malaysian oil palm conditions, several studies had been conducted on the use of pheromone traps (Ho, 1996; Chung, 1997). However in these studies, pheromone traps were mainly evaluated to reduce palm damage (Chung, 1997) and used integratedly for the dissemination of biocontrol agents (Ho, 1996).

* Malaysian Palm Oil Board,
P. O. Box 10620,
50720 Kuala Lumpur, Malaysia.
E-mail: norman@mpob.gov.my

This study attempted to investigate the use of pheromone traps for monitoring immigration of the beetles into a replanting area and subsequently to relate the trap captures to the developing beetle stages in the decomposing oil palm trunks within the zero-burned replanting area.

A general hypothesis for this study was that the activity of *O. rhinoceros* adults is correlated with the infestation level of *O. rhinoceros* in the oil palm trunk heaps within the replanting area. The number of adults captured with pheromone traps was expected to correlate with the larval population in the decomposing oil palm trunk heaps and the damage levels of the immature palms. In addition, the pheromone trap was expected to measure the flight activity of the beetles, which would also be related to the rainfall. The activity of *O. rhinoceros* would be expected to correlate with the phases of the moon (new or full moon). This was based on the fact that some insects navigate their flight by the position and phases of the moon (Baker, 1987). The relative flight distance of the beetles within the replanting area was also measured by the trap, mark, release and recapture method.

Information from this study would enable us to understand the immigration behaviour of the pest, in order to formulate better control strategies.

MATERIALS AND METHODS

Trial Plot

A replanting area in an oil palm estate (Estate TM) in Sepang, Selangor was selected for the study. The area was chosen due to a previous report of serious *O. rhinoceros* infestation. The 4.5 ha block was surrounded by mature oil palm of 8-22 years old. Felling and chipping was conducted in August 1996 and trapping commenced about five months later, in January 1997. The trapping period was up to about 24 months. Captures were sexed and removed at about fortnightly intervals.

Trapping Layout

A total of 49 pheromone traps (baited with the Sime RB® pheromone) were laid within the area, in a grid of 7 x 7 traps (*Figure 1*). The distance between each trap was about 27 m (three palm rows) and about 45 m (five palms distance) within each row. The aggregation pheromone of *O. rhinoceros*, ethyl 4-methyloctanoate, has been synthetically developed for commercial use (Hallet *et al.*, 1995). It is contained in a polymer sachet and hung in between a metal vane, on top of a plastic bucket trap. The pheromone sachets were replaced after every six weeks. The traps were placed at a height of 1.5 m from the ground, close to the immature palms and decomposing heaps. This was to facilitate the trapping of adults attacking the palms as well as those which emerged from the heaps.

Four traps were placed each inside the adjacent mature blocks surrounding the replanting area, of which one trap is placed at the centre of the mature block (20 palms towards the centre). This was to capture the adults which occurred inside the mature blocks.

Due to logistics, the number of traps was reduced to about half (24 traps) in June 1997 (after 149 days, about five months) and further reduced to only six traps in December 1997 (after 339 days, around six months). Captures were gathered up in December 1998. The total trapping period was about 24 months (716 days). Rainfall was recorded throughout the study. A total of 37 females captured during the later part of the study (March-August 1998) were dissected to check on fecundity.

Sampling of *Oryctes* Population in Heaps of Trunk Chips

Samples of the *O. rhinoceros* population were taken from a subplot measuring approximately 1 m^2, in the heaps of trunk chips. These samples were taken systematically, at every three palms. A total of 27 samples (at nine samples per plot) were gathered for each consecutive sampling. The population of *O. rhinoceros* in the decomposing heaps was monitored bimonthly and was stopped when the mean population for each subplot was less than 1. The data were separated according to trapping zones and the density of *O. rhinoceros* in the heaps was correlated with the number of adults captured. The pre-trapping sampling of *O. rhinoceros* was conducted in December 1996.

Damage Assessment

Damage to the immature palms was monitored at about two- to three-month intervals, starting from April 1997. Four palms adjacent to each trap were assessed. The number of damaged fronds were counted and divided against the total number of fronds to derive the damage percentage.

Estimation of Flight Range

The flight range of the beetle was estimated by a capture, mark, release and recapture method (Southwood, 1971). The captured adult was marked with the trap number on its elytra using a waterproof paint. The adults were then released on the ground below the trap. When the marked adults were recaptured in a different trap, their flight distance could then be estimated. Recaptured adults were counted between five to nine days after release.

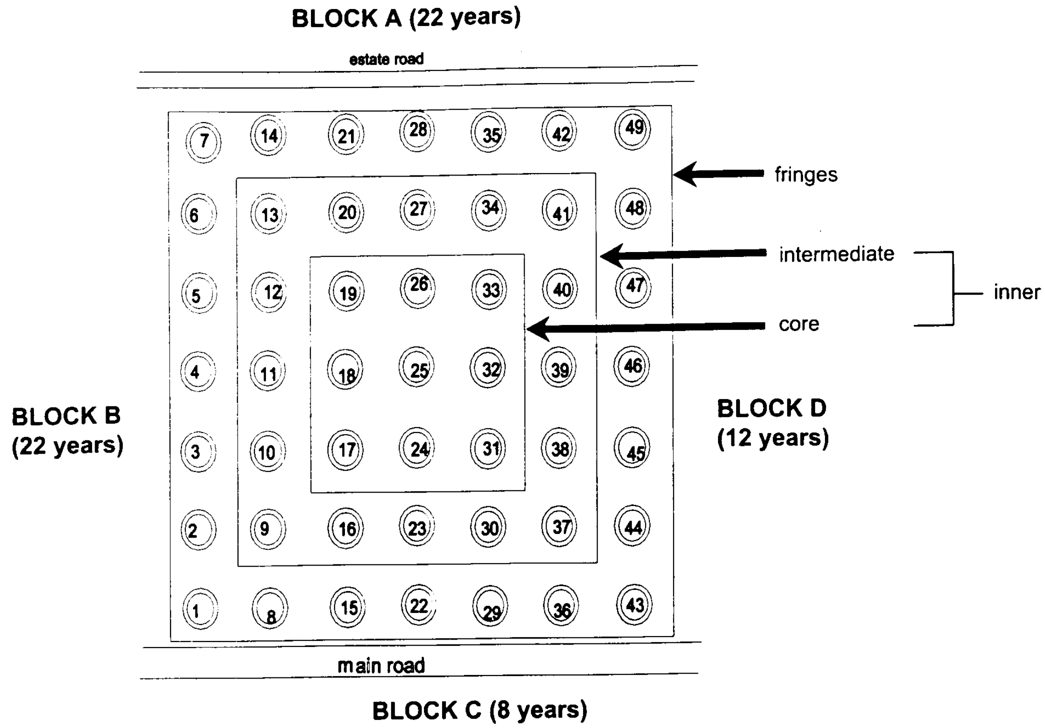

Figure 1. Layout of pheromone traps at TM Estate at Sepang, Selangor.

Effects of Moon Phase on Beetle Activity

The overall trapping data was sorted according to the date of capture and later matched with either of two phases of the moon: the new and full moon. The phases of the moon were pre-determined by the Islamic lunar calendar. The first to the seventh day of each month was considered as having a new moon, and consecutively, the 15th to 21st day as having a full moon.

Effects of Rainfall on Fecundity of Female Beetles

Rainfall data was also gathered to determine any significant relationships. Random samples of female beetles captured were dissected to determine their fecundity.

RESULTS

Captures of *O. rhinoceros* According to Trapping Zone

Although the number of traps was gradually reduced over time, the mean capture per trap was not significant ($p<0.05$) among the three trap densities (49, 24 and six traps). Therefore, the overall data gathered throughout the trapping period were considered representative.

Trap captures were sorted according to the three trapping zones, namely, fringes (F), intermediate (I) and core (C) (*Figure 1*). The mean numbers of adults (male and female) captured for each trapping zone are presented in *Table 1*. It was noted that captures of males were significantly higher ($p<0.05$) at the fringes only at 100 and 170 days from commencement of trapping (DFCT) while female beetles were trapped consistently higher at the fringes, consecutively between 22 to 226 DFCT. This suggests that the female beetles immigrate constantly into the replanting block, in search of breeding sites. There were no significant difference ($p>0.05$) between the intermediate and core trapping zones for both male and female captures (*Table 1*). The captures at the fringes were always higher than in the inner (intermediate and core) zones (*Figure 2*), suggesting that most of the immigrant beetles concentrate at the fringes rather than fly straight into the centre of the block for breeding.

Bedford (1975) calculated the immigration rate as the average number of beetles found per palm. In this study, the immigration rate was determined based on the mean number of beetles captured per trap, per night. The rates of capture for traps in the inner region and fringes, from one to 716 DFCT, are shown in *Figure 3*. In general, there were several peaks in captures at the fringes, which were always higher than in the inner zone (*Figure 3*). This also suggests that most of the immigrant beetles tended to concentrate in the fringes, before moving into the block. However, there were higher rates of capture in the inner region of the block at 110, 280, 430 and 543 DFCT (*Figure* 3). These peaks consisted of mixtures of newly emerged adults from the decomposing palm heaps and immigrating adults from the adjacent blocks. Further analysis and suggestions of these peaks will be discussed later. The capture pattern in the adjacent mature blocks showed several distinct peaks at 186, 214, 255 and 430 DFCT (*Figure* 4). The sex ratio (male: female) for the whole duration of trapping was between 0.1 to 1.0 (*Figure* 5).

Captures of *Oryctes* Adults in Adjacent Mature Areas Surrounding the Replanting Area

Table 2 shows higher captures at two sides (Block A and Block B) of the surrounding mature area, at trapping intervals of 11-20 and 21-30 days. Captures at the fringes facing the two blocks were also correspondingly higher (*Figure* 6), indicating immigration of the adults from the two adjacent blocks (Blocks A and B).

TABLE 1. CAPTURES OF *Oryctes* ADULTS IN DIFFERENT TRAPPING ZONES AGAINST TIME IN A REPLANTING BLOCK AT SEPANG, SELANGOR*

		Mean cumulative trap captures (per trap per night)					
		Days from commencement of trapping (DFCT)					
Sex	**Trapping zone**	**7**	**22**	**100**	**170**	**226**	**254**
Female	Fringe	0.29a	0.28b	0.19b	0.17b	0.17b	0.17a
	Intermediate	0.21a	0.18a	0.13a	0.12ab	0.12ab	0.12a
	Core	0.14a	0.13a	0.10a	0.09a	0.10a	0.09a
Male	Fringe	0.08a	0.09b	0.05b	0.06b	0.07a	0.08a
	Intermediate	0.02a	0.05a	0.04a	0.03a	0.04a	0.05a
	Core	0.03a	0.06ab	0.03a	0.03a	0.04a	0.04a

Note: Means with different letters within a columns are significantly different by one-way ANOVA and Tukey test/Mann-Whitney Rank sum test/Kruskal-Wallis One-Way Analysis of Variance on Ranks ($p<0.05$).

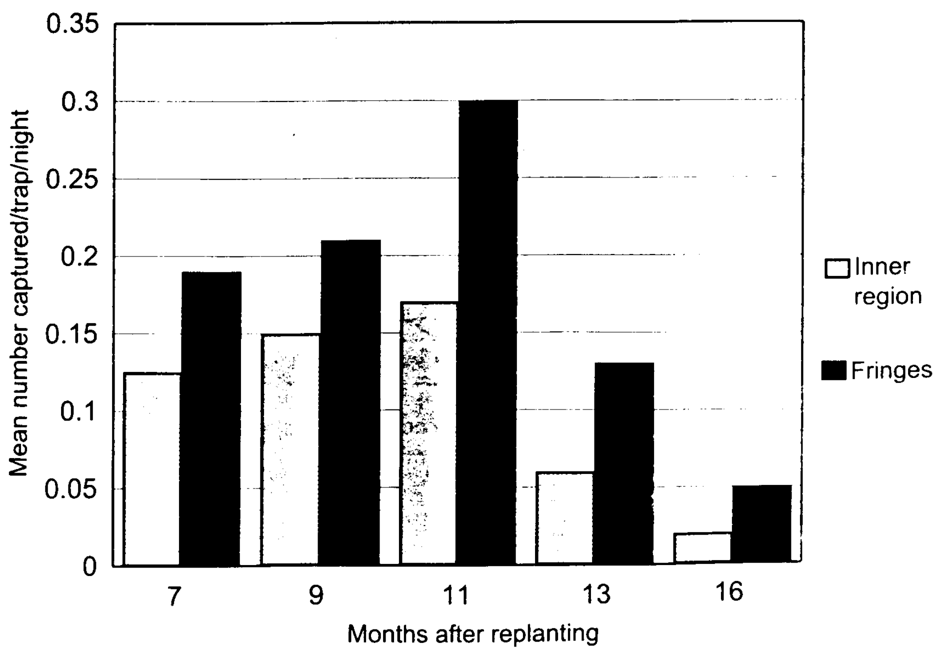

Figure 2. Mean captures of Oryctes *by pheromone traps in different zones in an infested oil palm block.*

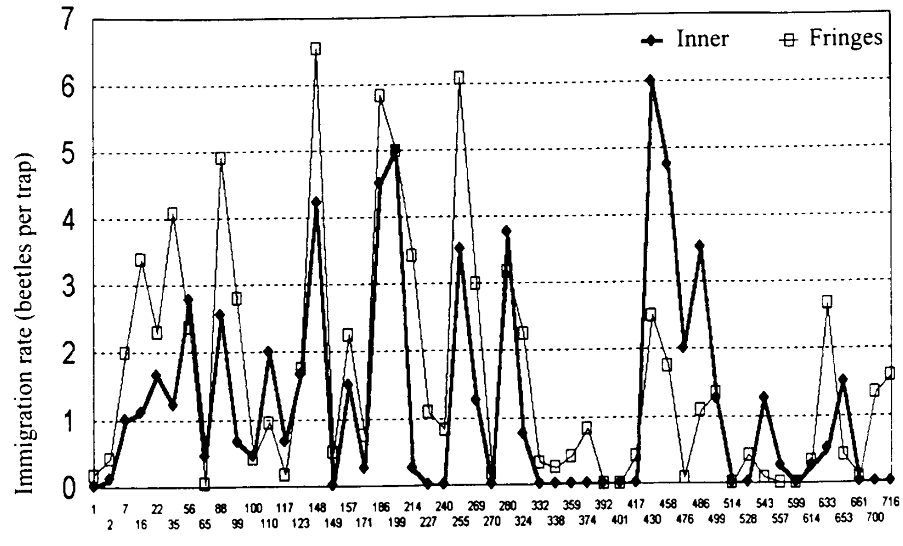

Figure 3. Immigration rate of O. rhinoceros *at the fringes and inner region of the replanting oil palm block.*

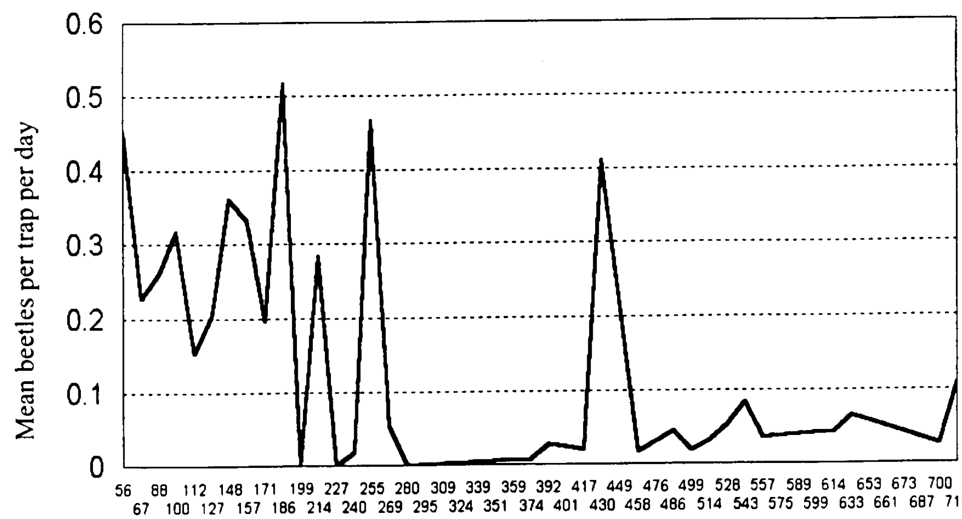

Figure 4. Capture pattern of O. rhinoceros *in a mature oil palm block adjacent to a new replanting block.*

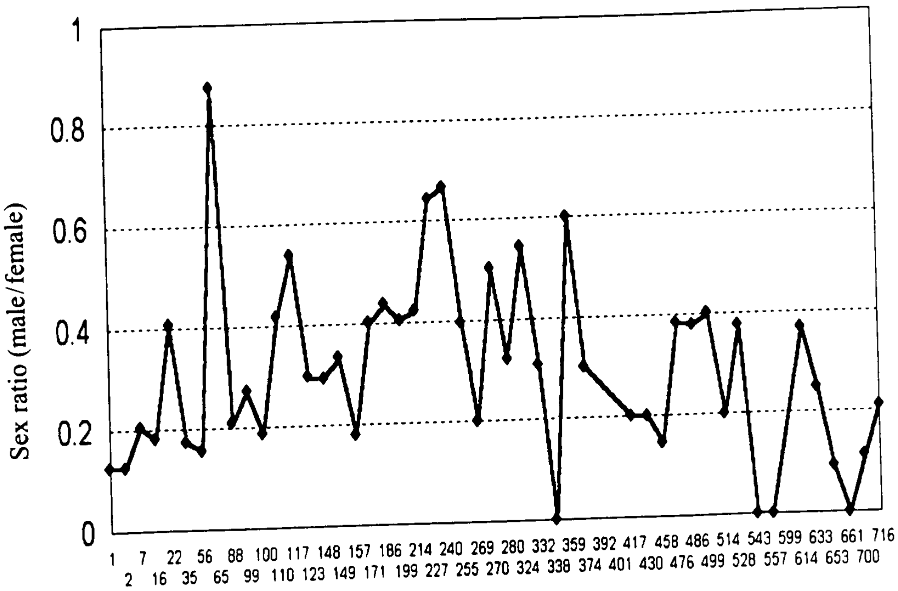

Figure 5. Fluctuation in the sex ratio of O. rhinoceros *throughout the trapping session.*

TABLE 2. CAPTURES OF *Oryctes* ADULTS IN DIFFERENT TIME PERIODS IN THE MATURE OIL PALM BLOCKS SURROUNDING A REPLANTING BLOCK AT SEPANG, SELANGOR

	Mean trap captures (per night)		
	Trapping period (days)		
Mature block (yr)	**1-10 (N=6)**	**11-20 (N=14)**	**21-30 (N=7)**
A (22)	1.33a	4.43b	3.00b
B (22)	4.50a	4.64b	7.29b
C (8)	1.83a	0.36a	1.29a
D (12)	2.33a	0.36a	0.57a

Note: Means with the same letter within a column are not significantly different by one-way ANOVA and LSD test ($p>0.05$).

Relationship of Trap Numbers and Population of *Oryctes* in the Decomposing Heaps of Trunk Chips

Pre-trapping monitoring was conducted in the decomposing heaps in December 1996. Out of the seven heaps within the area, only three were chosen for each consecutive sampling period. The data for the captures in the intermediate (I) and core (C) zones were combined due to no significance ($p>0.05$) during the trapping sessions.

Generally, there was no significant difference ($p>0.05$) between the overall population of *Oryctes* at the fringes and in the inner (*Table 3*). However, initial infestation was located at the fringes within four months after replanting (*Table 3*). At this time, most of the larvae were third instars. There were also some pupal stages and male adults. Infestation in the inner areas was only noted at seven months of replanting (*Table 3*). There was a significant relationship between the number of adult females trapped (at about 40-60 days before monitoring the population in the heaps) and the number of second instar larvae (*Figure 7*). This suggests that the remaining female beetles which had escaped trapping, had laid eggs in the decomposing heaps.

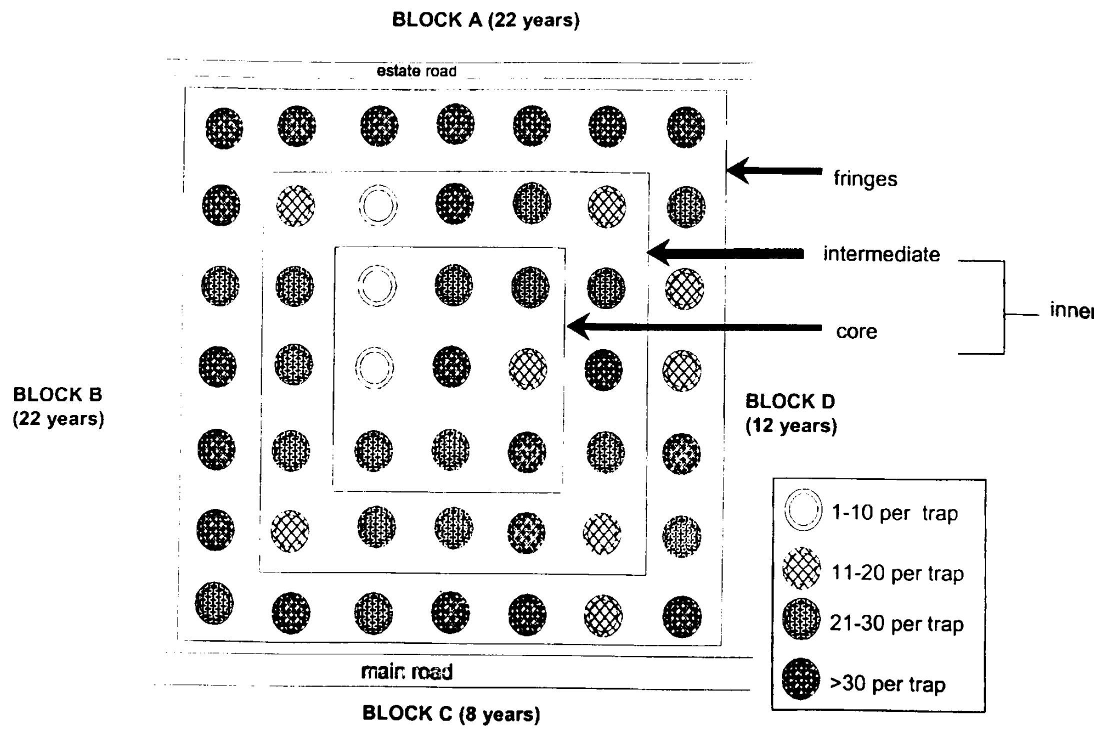

Figure 6. Captures in pheromone traps at TM Estate, Sepang, at 148 DFCT.

TABLE 3. POPULATIONS OF *Oryctes* IN THE DECOMPOSING HEAPS

Month	MAR	Zone	Mean number of individuals per m^2								
			n	L	L2	L3	Pp	Pupa	Male	Female	Overall mean
Dec 96	4	I	5	0	0	0	0	0	0	0	0
		F	22	0.1	3.0	4.0	0.1	0.1	0.1	1.0	7.2
Mar 97	7	I	15	0	0.5	4.1	0.2	0.4	0.2	0.1	5.6
		F	12	0.2	0.8	5.0	0.2	0.5	0.2	0.1	7.0
May 97	9	I	15	0.1	1.2	2.3	0	0	0	0.1	3.6
		F	12	1.4	2.7	2.0	0.3	0.1	0	0	6.4
July 97	11	I	5	0	0	1.2	0.4	0	0	0	1.6
		F	22	0.1	2.0	4.0	0.1	0	0.1	0.1	6.1
Sep 97	13	I	15	0.1	0.2	2.2	0.1	0	0.1	0.3	2.9
		F	12	0	0	1.0	0	0.1	0.4	0.7	2.2
Dec 97	16	I	15	0	0	0.3	0	0	0	0	0.3
		F	12	0	0.1	0.6	0	0	0	0	0.7

Notes: L1-L3: larval instars 1-3; Pp: prepupa; I: inner (core+intermediate); F: fringes; MAR = months after replanting.

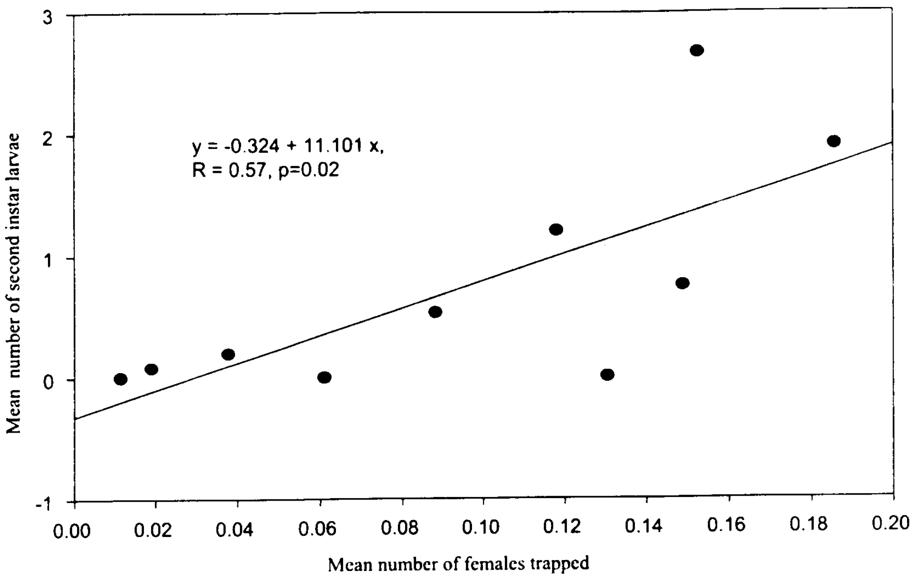

Figure 7. Relationship between the number of females trapped and second instar larvae in the heaps at one to two months after trapping.

Effects of Rainfall and Moon Phases on the Flight Activities of *O. rhinoceros*

Based on the number of traps and captures, the flight occurrence for *Oryctes* was derived from the percentage of traps having captures (>1 beetle/trap) from each of the sampling occasion. This will indicate the flight activity of *O. rhinoceros* in a certain period of time (Taylor, 1963). These values were then related to the total rainfall accumulated for the period. It was observed that there was a significant relationship between rainfall and the flight occurrences (*Figure 8*), which likely indicates that rainfall may have induced the beetle to fly searching for moist, breeding sites.

It was also observed that more male beetles were trapped during the full moon period, compared to the new moon ($p<0.05$) (*Table 4*). There were no significant differences between captures of female beetles for both moon phases. This may indicate that the male beetles were probably more sensitive towards moonlight for navigational purposes, especially for locating palms for food sources and breeding sites. It has been noted that male beetles locate the breeding sites much earlier than the females (Norman, unpublished data). In one empty fruit bunch (EFB) heap, four male beetles were discovered, without the presence of other developing stages. This indicates that males pioneered the breeding habitat and later produces pheromones to attract the female for mating purposes. This mating behaviour has been reported by de Chenon (1999).

Relationship of *Oryctes* Numbers and Damage on Palms

There was a significant relationship ($p<0.05$) between the cumulative number of *Oryctes* trapped and the damage caused to the palms, adjacent to the traps (*Figure 9*). The fluctuating trend of trapping and damage caused to the young palms are shown in *Figure 10*. This suggests that the trapping numbers can indicate the relative density of adults inflicting damage to the palms close to the traps. Therefore, this can enable us to monitor *hot-spots* for more targeted chemical or biological control.

The Occurrence of Reproductive Females in Trap Captures

Based on a sample of 37 females collected between March to August 1998 in the area, a high proportion (91.9%) of females captured in the traps were gravid. The range of eggs found per female was 2-42 with a mean of 14.5 ± 1.6 eggs per female. This suggests that the traps were attracting mature female beetles. With this, pheromone trapping is expected to reduce the chances of breeding by *O. rhinoceros*.

Flight Range of Beetles in a Replanting Area

Based on the capture, mark, release and recapture experiment using pheromone traps, the beetle's ability to fly was estimated at about 19 m day^{-1} or more than 130 m in a week (*Table 5*). The range covered was estimated at 10-23 m day^{-1}. This suggests that the flight of beetles within a replanting area is quite limited because of the abundance of food and breeding sites.

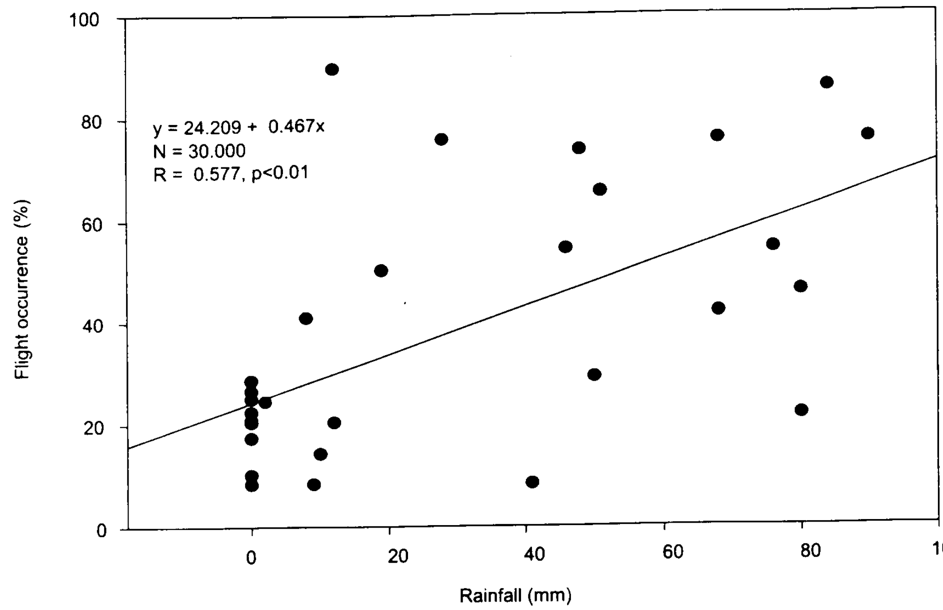

Figure 8. Relationship between rainfall and flight occurrence of Oryctes rhinoceros.

TABLE 4. CAPTURES OF *O. rhinoceros* ACCORDING TO MOON PHASES

Moon phase	Mean capture of beetles			
	n	Female	Male	Total
New moon	19	1.82± 0.29a	0.65± 0.15a	2.47± 0.40a
Full moon	18	2.59± 0.49a	1.21± 0.23b	3.80± 0.69a

Note: Means in columns with the same letter are not significantly different by Student's t-test (p>0.05).

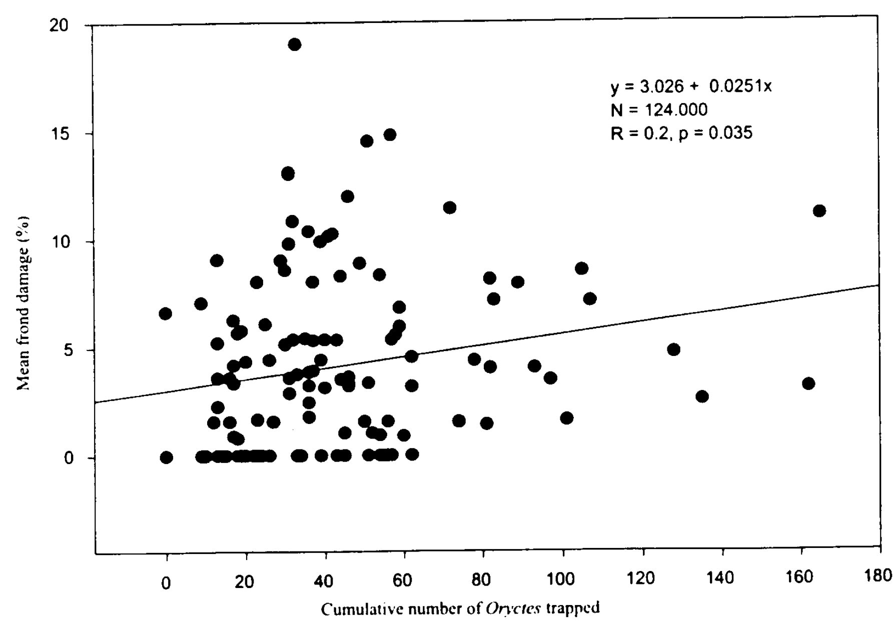

Figure 9. Relationship between cumulative trap captures and palm damage.

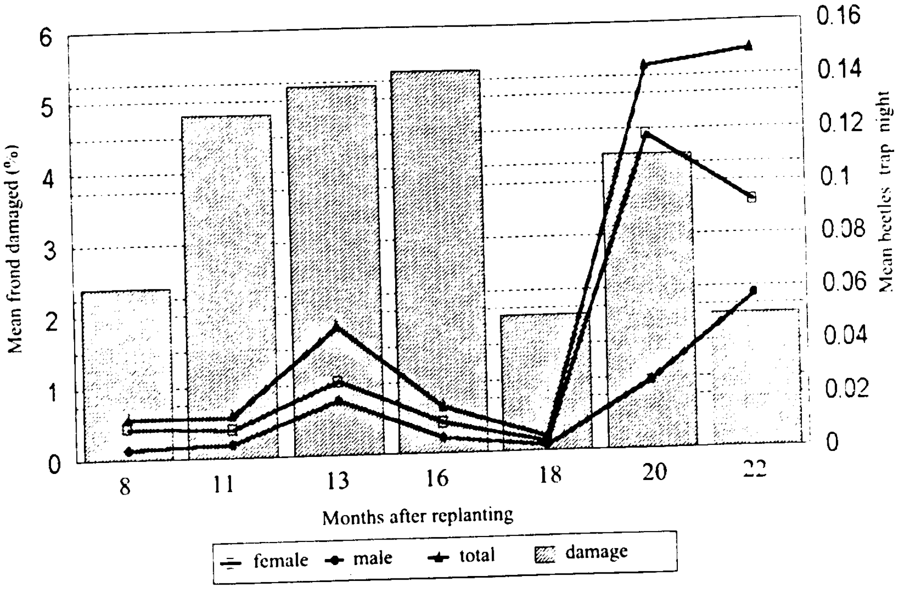

Figure 10. Fluctuations in trap captures and frond damage at an oil palm plantation in Sepang.

TABLE 5. ESTIMATION OF THE FLIGHT RANGE OF BEETLES

Trapping point	Approximate distance travelled (m)	days	m day^{-1}
6-14	51	5	10
37-33	89	5	18
48-16	186	9	21
7-9	140	6	23
23-28	135	6	23
23-44	108	6	18
Mean	118.2	6.2	19

DISCUSSION

There was a distinct direction of the adults captured at the boundaries of the replanting block. This also relates strongly to the numbers that were caught at the adjacent mature plantings. There was a stronger immigration pressure from the two adjacent old blocks, Blocks A and B (aged 22 years), as reflected in the trap captures along the fringes of the replanting area bordering the two blocks (*Table* 2 and *Figure* 6). Based on the trap captures of the mature blocks, there were indications that the adult population was coming from the mature areas to infest the replanting block. This phenomenon was also supported by the higher mean captures of beetles at the fringes compared to the inner block (*Figure* 2). This indicates the immigration of beetles from the mature blocks to the replanting area. As the nearby replanting blocks became more mature, the breeding sites were also becoming less attractive due to the establishment of ground cover.

Southwood (1962) reported two categories of habitats, *permanent* and *temporary*. A permanent habitat consists of an area with a high carrying capacity, whereas a temporary habitat is one which is ephemeral and which occurs for a short period with a low carrying capacity. In his example, migration was inversely related to the occurrence of habitat. In this study, it is suggested that a mature block acts as a permanent habitat and the replanting area a temporary habitat over a period of time. Mature oil palm areas may harbour *Oryctes* in rotting trunks due to *Ganoderma*, dead standing trunks or EFB applied as mulch. In this study, the mature areas surrounding the replanting varied from eight to 22 years of planting. The older areas had a more moderate incidence of *Ganoderma*. The rotting base of an infected palm is often attractive for the breeding of *Oryctes*. In India, the infestation of oil palm was more prevalent in a mature plantation (10-15 years old) compared to immature or younger plantings (Dhileepan, 1988). Among the breeding sites identified in the mature areas were rotten inflorescences, rotten oil palm trunks, EFB and unpruned fronds (Dhileepan, 1988).

The migration of beetles from the mature block to the replanting areas was suggested as there were corresponding peaks of trapping at the fringes of the replanting area and in the adjacent mature block (at 148, 186 and 255 DFCT) (*Figure 4*). On average, the sex ratio (male:female) for this study was 0.4 (*Figure 5*). The sex ratio on coconut was between 0.31 to 1.53 (Cumber, 1957; Hinckley, 1973; Bedford, 1975). This phenomenon occurred probably due to more female beetles flying in search of breeding sites (Bedford 1975). In addition, the constant trapping of female beetles at the fringes (*Table 1*) likely indicates that they immigrate into the replanting area for food and breeding. In the conifer pest, the female beetle is first attracted by the odour of the tree (Dingle, 1996), followed by the male beetle which is attracted by the faeces of the feeding female. However, the opposite seems true for *O. rhinoceros* as it has been observed in the field that the males occupy the breeding habitats (EFB) earlier than the females (Norman, unpublished data). Naturally, it has been reported that the male will stridulate the abdomen with the elytra to produce a *clicking* sound to attract the female (de Chenon, 1999).

At the fringes, the presence of pupa and male adults after four months of replanting (MAR) indicates that infestation may have been at the onset of felling and chipping of the trunks (*Table 3*) with the abundance of the breeding sites. However, in the inner region, no population was detected in the heaps at four MAR and third instar larvae of *Oryctes* was only detected in the heaps at seven MAR (*Table 3*). This suggests that initial oviposition might only have taken place after fourth MAR.

In both the outer and inner regions, the captures peaked in almost perfect synchrony (*Figure 3*). However, based on the suggestions, peaks resulting from the emergence of adults can now be deduced. The development from the first instar to adults takes about six months in trunk heaps, in laboratory conditions (Norman *et al*., 2001). However, in field conditions, the duration may be quicker, as pupa and adults were already found in the trunk heaps at the fringes at four MAR (*Table 3*).

Therefore, the following peaks in the inner region (*Figure 3*) listed below suggest the proportions of newly emerged adults and immigrants:

- trapping day 56 (5.5 MAR) – only immigrants coming in to feed and breed in the inner region;
- trapping day 88 (7 MAR) – higher proportion of immigrants, with some newly emerged beetles;
- trapping day 110 (7.5MAR) – newly emerged beetles gradually increase in proportion;
- trapping day 148 (9 MAR) - increased proportion of newly emerged beetles;
- trapping day 199 (10.5 MAR) - highest proportion of newly emerged beetles;
- trapping day 255 (12.5 MAR) - higher proportion of breeding immigrants;
- trapping day 280 (13.5 MAR) - highest proportion of newly emerged beetles;
- trapping day 430 (18.5 MAR) - higher proportion of feeding immigrants. Heaps no longer suitable for breeding;
- trapping day 543 (22 MAR) - only feeding immigrants. No population found in heaps; and
- trapping day 653 (26 MAR) - only feeding immigrants.

As indicated, the heaps had become less attractive for breeding after about 16 MAR. This was based on the significant reduction ($p<0.05$) in *O. rhinoceros* population after that period (*Table 3*). Due to the absence of *O. rhinoceros* population in the heaps after that period (*Table 3*), it is suggested that the captures from 332 DFCT (16 MAR) onwards might have consisted of immigrants searching for food and emigrants finding other breeding sites (*Figure 3*). The peak capture which occurred at 430 DFCT (18.5 MAR) in the inner region of the replanting block (*Figure 3*) coincided with the peak in the adjacent replanting block (*Figure 4*). Therefore, it is suggested that the peak captures occurring at 19 and 23 MAR consisted mainly immigrants searching for food in the replanting area.

The immigration of *O. rhinoceros* into the replanting area seems to be in several phases and therefore a strategy to control *O. rhinoceros* would be to trap them at the borders. This technique has been proven effective earlier by Turner (1973) using coconut log traps, while Chung (1997) used a similar type of pheromone traps. The adjacent mature plantings can be monitored for any known levels of infestation and trapping along the borders of the infested area may reduce their immigration into the replanting block.

From this study, the female numbers trapped can also be used as an indicator for the next population developing in the decomposing heaps. The numbers of second instar larvae in the heaps was significantly related to the number of adult females trapped (at one to two months earlier). This confirmed that the female beetles had laid eggs inside the heaps. The developmental period for the immature phase of the beetle within the heaps was estimated around six months as indicated by the higher emergence of adults in March and September 1997, at seven and 13 MAR respectively (*Table 3*). With this information, we can predict the occurrence of the next generation of adults emerging from the heaps and plan for control measures.

The increased activity during the wet season (*Figures 4* and *5*) seems to indicate the instinct of the beetle to look for breeding sites which are moist and suitable for the larvae to develop. The phenomenon of rainfall affecting fecundity is a strategy for insects to ensure the survival of their subsequent generations. For the palm leaf miner, *Coelanomenodera minuta*, its fecundity was increased during heavy rainfall (Mariau, 1999). Bedford (1975) and Zelazny and Alfiler (1987) reported a similar phenomenon on coconut - nightly rainfall increased captures in coconut log traps. This likely indicates that the coconut log acts as a suitable breeding substrate.

Earlier studies did not show any significant relationship between the moon phases and activity of *O. rhinoceros* (Barlow and Chew, 1970; Bedford, 1975). However, in this study there was increased activity of the male beetles during full moon compared to the new moon. This suggests that the male beetle would likely be searching for food and mates during this period. It was earlier reported that *O. rhinoceros* locates palms by their silhouettes, rendering taller palms more easily detectable (Bedford, 1980). Other insects like *Agrotis* (Lepidoptera), depended on moonlight to navigate and orientate its flight (Baker, 1987). The phenomenon of increased activity during the full moon was also reported for other insects like *Helicoverpa zea*, *H. armigera* and *Heliothis virescens* (Lepidoptera) (Boring *et al.*, 1999); *Scotinophora, Nephotettix, Nilaparvata, Scirpophaga* (Heteroptera) (Srinivasa *et al.*, 1990) and *Aedes, Culex, Anopheles* (Diptera) (Janousek and Olson, 1994).

In this study, 91.9% of the 37 female beetles dissected were gravid. This supports the findings of Bedford (1975), that under coconut in New Britain, 92% of the females trapped were mated with the remains of spermatophores in their bursa copulatrix. This also suggests that trapping with pheromones can reduce the chances of breeding by capturing the gravid females. In this particular study, the population density of *Oryctes* in the heaps along the fringes was reduced significantly at about 16 MAR, in December 1997 (*Figure 3*). The population density after 13 MAR was already negligible (less than one individual per square metres).

In earlier studies, female beetles were found to have an average of between 22 to 25 eggs per female (Hinckley, 1973; Bedford, 1975). The average number of eggs found in this current study was slightly lower (16 eggs per female). Females reared in the laboratory had higher fecundity (between 49 to 60 eggs per female) (Hurpin and Fresneau, 1973). This lower fecundity might be attributed to the environmental factors or lower nutritional conditions in the field. Another possible factor was that the females might have oviposited some of their eggs in the breeding sites. A female beetle is likely to oviposit three-four clutches, with an average clutch size of 27 eggs (Gressit, 1953; Hinckley, 1973).

Damage to the adjacent palms relates significantly to the numbers caught in the trap (*Figure 6*). This shows that trap captures can be used as an indicator of a damaging beetle population. In this manner, we could target control measures (*i.e.* chemical application) to the palms close to the *hot spots* (high trap numbers).

Earlier reports have suggested the ability of the beetle to fly considerably long distances (Nirula, 1955; Hinckley, 1973). A distance recorded in the field was about 700 m (Monty, 1974). However, a laboratory experiment has indicated that the beetle can fly up to 2 to 4 km in 2 to 3 hr (Hinckley, 1973). Liau and Ahmad (1991) reported a flying distance of 140 m into a replanting area. This was in the case of migration to new breeding areas. But in this study, which was done within a replanting area, the beetle was noted to fly less (estimated around 19 m day^{-1}, and about 133 m a week) (*Table 5*). These values may be below the actual flight potential as their flights were monitored using pheromone traps. However, the conducive environment, availability of food and abundant breeding sites in the replanting area logically play a role in the flight distance.

Control Strategies

Having all this information, several strategies can be formulated for the control of *O. rhinoceros* during replanting:

- pheromone traps should be placed early (at around 6-12 months before replanting) in the mature areas, around the replanting block. This would reduce the endemic population in these blocks, and therefore reduce the chances of immigration once replanting starts;
- after felling and chipping of the trunks, maintain pheromone trapping at the borders and within the mature surrounding blocks. Do not immediately place traps in the replanting area, as this would attract more beetles. By having traps at the borders (say, one every 15 rows), these would further capture immigrants as well as those which emerge later from the decomposing heaps. If the damage is high within the block, place traps

only after about six months to coincide with the emergence of adults from the decomposing heaps;

- beetles are most active during the rainy period. The breeding sites must be made less conducive for breeding by spreading the heaps to a single layer, to facilitate drying;
- to avoid constant immigration of beetles, the surrounding areas should be checked for any possible breeding sites. Mature plantings could also harbour *O. rhinoceros*; in the bases of *Ganoderma* infected palms, dead standing trunks, EFB heaps placed as inter-row mulch or aborted inflorescences and bunches. Ideally, replanting within a plantation should be staggered to two-year intervals, to avoid the constant immigration of beetles from nearby breeding areas; and
- pheromone traps can also be used to determine hot spots for targeted chemical control. This can avoid blanket application of chemicals which can save management costs. Chemical control at the early replanting stage should only be focussed on palms along the fringes.

CONCLUSION

Based on pheromone trappings, some interesting findings were revealed. There was a distinct direction from where the beetle migrates from the adjacent mature planting towards the replanting block. With this observation, trapping can be used to monitor the incoming population and to carry out initial control measures at the borders. The pheromone trap is also useful as a control method as it captures gravid females, which reflect the onset of breeding. Beetle activity can be related to rainfall and the moon phases. Pheromone trapping can therefore be useful to monitor immigration and subsequently to refine chemical or biological control methods.

ACKNOWLEDGEMENT

The authors thank the Director-General of MPOB for permission to publish this paper. Thanks also to Dr Zaidi Mohd Isa and Dr Maimon Abdullah for their guidance and support. Last, but not least, a round of thanks to the staff of Entomology Laboratory 1, MPOB, for the field sampling and trapping.

REFERENCES

BAKER, R R (1987). Integrated use of moon and magnetic compasses by the heart and dart moth, *Agrotis exclamationis. Animal Behavior, 35(1)*: 94-101.

BARLOW, H S and CHEW, P S (1970). The rhinoceros beetle *Oryctes rhinoceros* in young oil palms replanted after rubber on some estates in Western Malaysia. *Proc. of the Malaysian Crop Protection Conference 1970*. p. 133-144.

BEDFORD, G O (1975). Trap catches of the coconut rhinoceros beetles, *Oryctes rhinoceros* (L.) (Col. Scarabaeidae, Dynastinae) in New Britain. *Bulletin of Entomological Research, 65*: 443-451.

BORING, E P; PARAJULEE, M N; SLOSSER, J E; DUGGER, P and RICHTER, D (1999). Bollworm and budworm moth activity in the Texas rolling plains. *Proc. of the Beltwide Cotton Conferences, 2.* p. 1172-1175.

CHUNG, G F (1997). The bioefficacy of the aggregation pheromone in mass trapping of *Oryctes rhinoceros* (L) in Malaysia. *The Planter, 73(852)*: 119-127.

CUMBER, R A (1957). Ecological studies of the rhinoceros beetle *Oryctes rhinoceros* (L.) in Western Samoa. *Technical Paper of South Pacific Commission No. 107*: 32 pp.

DE CHENON, D (1999). The use of pheromone for the management of the rhinoceros beetle in oil palm plantations. Paper presented at the Selangor Planters Association. Radisson Hotel, Shah Alam. 26 October 1999.

DHILEEPAN, K (1988). Incidence and intensity of rhinoceros beetle infestation in oil palm plantations in Kerala. *Journal of Plantation Crops, 16*: 126-129.

DINGLE, H (1996). *Migration, the Biology of Life on the Move.* Oxford University Press, London.

GRESSITT, J L (1953). The coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. *B.P. Bishop Bulletin, 212*: 157.

HALLET, R H; PEREZ, A L; GRIES, G; GRIES, R; PIERCE JR H D; YUE, J; OEHLSCHLAGER, C; GONZALEZ, L M and BORDEN, J H (1995). Aggregation pheromone of the coconut rhinoceros beetle *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae). *Journal of Chemical Ecology, 21*: 10, 1549-1570.

HINCKLEY, A D (1973). Ecology of the coconut rhinoceros beetle *Oryctes rhinoceros* (L). *Biotropica, 5*: 11-16.

HO, C T (1996). The integrated management of *Oryctes rhinoceros* (L) populations in the zero burning environment. *Proc. of the 1996 PORIM International Palm Oil Congress - Agriculture Conference* (Ariffin, D; Mohd Basri, W; Rajanaidu, N; Mohd Tayeb, D; Paranjothy, K; Cheah, S C; Chang, K C and Ravigadevi, S eds.). PORIM, Bangi. p. 336-368.

HURPIN, B and FRESNEAU, M (1973). Laboratory studies on fecundity factors in *Oryctes monoceros* Ol. and *O. rhinoceros* L. (Col. Scarabaeidae). *Annales de la Societe Entomologique de France, 9(1)*: 89-117

JANOUSEK, T E and OLSON, J K (1994). Effect of a lunar eclipse on the flight activity of mosquitoes in the upper Gulf Coast of Texas. *Journal of American Mosquito Control Association Lake Charles, 10* (2): 222-224.

LIAU, S S and AHMAD, A (1991). The control of *Oryctes rhinoceros* by clean clearing and its effect on early yield in palm to palm replants. *Proc. of the 1991 PORIM International Palm Oil Development Conference - Agriculture Conference* (Yusof Basiron; Jalani Sukaimi; Chang, K C; Cheah, S C; Henson, I E; Norman Kamarudin; Paranjothy, K; Rajanaidu, N and Mohd Tayeb Dolmat eds.). p. 396-406.

MARIAU, D (1999). Knowledge of oil palm pests and population management. *Proc. of the 1999 PORIM International Palm Oil Congress – Agriculture Conference*. p. 409-415.

MONTY, J (1974). Teratological effects of the virus Rhabdionvirus Oryctes on *Oryctes rhinoceros* (L.) (Coleoptera, Dynastidae). *Bulletin of Entomological Research, 64*: 633-636.

NIRULA, K K (1955). Investigations on the pests of the coconut palm II. *Oryctes rhinoceros* L. *Indian Coconut Journal, 8*: 161-180.

NORMAN, H K and MOHD BASRI, W (1997). Status of rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) as a pest of young oil palm in Malaysia. *The Planter, 73(850)*: 5-21.

NORMAN, K; ZAIDI M I; MAIMON, A and BASRI, M W (2001). Factors affecting development of *Oryctes rhinoceros* in some substrates commonly found in the oil palm environment. *J. Oil Palm Research Vol. 13 No. 1*: 64-74.

SOUTHWOOD, T R E (1962). Migration of terrestrial arthropods in relation to habitat. *Biological Review*, 37: 171-214.

SOUTHWOOD, T R E (1971). *Ecological Methods with Particular Reference to the Study of Insect Populations*. Second edition. Chapman and Hall, London. 524 pp.

SRINIVASA N; VIRAKTAMATH, C A and THONTADARYA, T S (1990). Influence of moon phase and weather on the light trap catches of insect pests of rice. *Oryza., 27*(2): 183-190.

TAYLOR, L R (1963). Analysis of the effect of temperature on insects in flight. *Journal of Animal Ecology, 32*: 99-112.

TURNER, P D (1973). An effective trap for *Oryctes*-beetle in oil palm? *The Planter, 49(573)*: 488-490

ZELAZNY, B and ALFILER, A R (1987). Ecological methods for adult populations of *Oryctes rhinoceros* (Coleoptera, Scarabaeidae). *Ecological Entomology, 12*: 227-238.