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THE ECOLOGY, PEST STATUS AND CONTROL OF THE MALAYSIAN WOOD RAT *(RATTUS TIOMANICUS* MILLER) IN A COCOA-COCONUT PLANTATION

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Geo A Petrides

Major professor

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THE ECOLOGY, PEST STATUS AND CONTROL OF THE MALAYSIAN WOOD RAT (RATTUS TIOMANICUS MILLER) IN A COCOA-COCONUT PLANTATION

By

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ABSTRACT

THE ECOLOGY, PEST STATUS AND CONTROL
OF THE MALAYSIAN WOOD RAT
(RATTUS TIOMANICUS MILLER)
IN A COCOA-COCONUT PLANTATION

By

Kamal Adzham Kamarudin

In an effort to provide baseline data on rodent problems facing the cocoa industry in Malaysia, a 20-months study was conducted at Kuala Bernam Estate, Telok Anson, West Malaysia. Pest species were subjected to multiple release and recapture on marked grids. The extent of cocoa-pod damage to the number of ripe pods, and harvesting intervals were also appraised.

The wood rat (*Rattus tiomanicus* Miller) was the dominant species (95.2%) and serious depredator of cocoa pods. The red-bellied squirrel (*Callosciurus notatus* Boddaert) (3.1%) was a potential threat, while the pencil-tailed mouse (*Chiropodemys gliroides* Blyth) (1.4%) and Polynesian rat (*R. exulans* Peale) (0.4%) were only secondary feeders.

The estimated rat density of 151 to 216 rats/ha were believed to be low since animals were trap-prone. Survival rates between trappings were high (0.5 - 1.0). Potential breeders were large (65 - 100%) with pregnant and lactating females abundant (5 - 57%) in the population. Movements by adults were farthest (males: 14.54 m, females: 10.13 m), and subadults (males:

8.78 m, females: 8.69 m) moved longer distances than juveniles (males: 7.35 m, females: 6.41 m). Home range sizes varied with age but were significantly different only among males.

The wood rats were active between dusk and dawn. They exhibited three activity peaks during the night (at 1800 - 2000, 2200 - 2400 and 0200 - 0400 hours). Rainfall seemed to reduce and delay rat activity. Bright moonlight caused animal activity to decline.

Damage to cocoa pods was not highly correlated with rat population density, total number of ripe pods or harvesting intervals. Together, these factors accounted for 42 percent of the variability in total damage.

Decisions to control rats with rodenticides must be based on their cost-effectiveness. Chemical and labor cost, efficacy of the poison and market-price of the cocoa product together must be considered.

Two decimated rat populations from Bromethalin poisoning partly recovered in six and nine months. Even by then, they achieved only 79.5 and 88.4 percent of their original numbers.

Rat management strategies must incorporate ecological knowledge of the pest species. Natural predation is encouraged and pesticides too, may be desirable and economical. Continual habitat destruction, however, is highly recommended.

Dedicated to my late mother

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

INTRODUCTION

The cocoa plant (*Theobroma cacao* L.) is a member of the Sterculiaceae family. The word "cacao" is often used to name the tree while "cocoa" is applied to the beverage powder manufactured from the beans. In this text, however, the word "cocoa" is used throughout both for the tree and its products.

The plant is native to the rainforest regions of tropical America. Its original range is believed to have been on the lower equatorial slopes of the Andes (Cheeseman, 1948). As a tropical plant of the humid tropics, cocoa is grown commercially between 15°N and 15°S of the equator. There are other small localized areas in the subtropical latitutdes, such as the lowlands of Sao Paulo, Brazil, however, where cocoa is also grown (Alvim, 1975).

In Malaysia, the Amelonado cocoa variety was the first to be introduced in 1778 (Koening, 1894). The crop was a failure, however, and was completely abandoned in 1886 (Mainstone, 1976). Later attempts by the Malaysian Department of Agriculture to cultivate cocoa also were unsuccessful. The variety used proved to be highly susceptible to cocoa-dieback (Haddon, 1961), a disease widespread in West Malaysia (Keane and Turner, 1972; Chan and Lee, 1973).

The present intense interest in cocoa as a plantation crop in Malaysia arose only after the Second World War. The declining and unpredictable yields in the leading production areas of West Africa encouraged its establishment elsewhere. Intensive research, particularly in breeding and selection (Rosenquist, 1950; Anon, 1969; Toxopeus, 1972), further enhanced the impetus to grow cocoa on a commercial basis. New varieties also were found which exhibited a reduced susceptibility to the disease and showed better growth, bean quality, and yield (Chee, 1972; Edwards, 1972; Arasu and Phang, 1972).

The first of the renewed Malaysian commercial cocoa plantings began in Jeranggau in 1950. From then on, this product has risen to become the most important agricultural export next to rubber and oil palm. The cultivation of cocoa is in accord with the Malaysian government diversification policy to cushion any setbacks in world prices of the other agricultural products (Third Malaysia Plan, 1976-1980).

The growing interest in the crop is clearly demonstrated by the increase in acreage under cocoa especially in West Malaysia. Currently, this acreage is estimated at 40,000 acres monocropped and 89,000 acres intercropped. The general projected concensus, provided that prices remain favorable, is that in the next 20 years there will be an additional 160,000 acres of monocropping and 120,000 acres of intercropping. Furthermore, in Sabah, East Malaysia, an existing 30,000 acres is expected to increase to 150,000 acres (Ramadasan, 1980). The importance of cocoa is also reflected by the raw production figures which increased from 2000 metric tons in 1968/69 to 22,000 in 1979/80 (Gill and Dufus, 1981 Cocoa Market Report).

The rapid expansion of the cocoa industry especially from 1978 until early 1980 is attributed mainly to favorable prices. Further, an economic comparison between rubber, oil palm, and cocoa cultivation clearly favors the latter (Lim and Chai, 1978; Yaakob and George, 1979). The availability of better planting materials and the adoption of a cocoa-coconut intercropping system also have contributed to the substantial increase in participation by small holders who comprise nearly 50 percent of the Malaysian cocoa industry.

Concomitant with the rapid rate of expansion in cocoa cultivation, disease and pest outbreaks became of great significance. The mammals, a major pest group which includes rats, squirrels, civet cats, monkeys, and occasionally wild pigs (Conway, 1971) have continually harassed farmers. Among these animals, rats were believed to be the group most responsible for inflicting substantial losses on cocoa pods (Kamarudin and Lee, 1981).

Large-scale rat control had been attempted through the use of chemical rodenticides. These materials are quick-acting, economical, and fit conveniently into most farmers' management schedules. Rodenticidal usage also found wide acceptance by both government agencies and private plantation-operators. Nevertheless, rats have continued to cause heavy losses. Continuous, heavy and often indiscriminate pesticide applications evidently further aggravated the situation by inducing widespread resistance to the chemicals among rodents (Lam, 1980). These conditions could jeopardize the future of this mode of control.

PURPOSE OF THE STUDY

Modern pest management must rely on sound ecological principles (Luckman and Metcalf, 1975). A thorough understanding of the biology of the target species must form the basis for proper control strategies. As has been pointed out by Welch (1977), the goals in biological investigations are 1) to provide input for a detailed analysis of management needs, 2) to elucidate the bionomics of the pest under local conditions, 3) to arrange for statistical, logistical, and economic analyses of potential monitoring protocols, and 4) to facilitate the construction of decision-making rules. Since very little was known about rats and other rodent pests of cocoa, this study was undertaken.

The biology, ecology and population dynamics of the Malaysian wood rat (Rattus tiomanicus Miller), a common rat species in cocoa, were investigated. The damage inflicted by the pest also was examined. A technique for monitoring losses and for making control decisions was developed. Pest population build-ups as a result of applying rodenticides were appraised as related to population composition, recruitment and rat movements. Management recommendations and the considerations of cocoa rat control with rodenticides were evaluated in relation to current technology and the economic and environmental criteria of today.

STUDY AREA

The study was carried out at Kuala Bernam Estate, a 850 ha (2065 ac) cocoa plantation situated about 192 km north of Kuala Lumpur, the capital city of Malaysia. It is located in the coastal area in one of the prime cocoa-growing regions of Malaysia.

On the estate, cocoa plants were intercropped with coconut palms and planted at 3.0 x 3.0 m (10 x 10 ft) intervals. Each two rows of cocoa were flanked by coconut palms planted 9.0 m (30 ft) apart. Sabah-hybrid cocoa and semi-dwarf MAWA (Malaysian dwarf x West African Tall) coconuts were the varieties utilized. The palms were planted not only for shade but also for the value of their copra.

The field plots selected (Fields 1, 27, 35 and 36, Figure 1) for the study were chosen on the basis of reportedly high pod losses. The cocoa shrubs in these plots were about 7-10 years old and of bearing age. Cocoa plants measured 3.0 - 5.0 m tall while coconuts were 6.5 - 10.0 m in height. The cocoa crowns formed a closed canopy with palm fronds forming a still-higher layer.

The climate of the area shows little monthly variation in temperature and rarely is any month without rain (Figure 2). Throughout the year, daily temperatures vary but little, usually between 26°C to 28°C. The average monthly rainfall ranged between 5 mm and 300 mm. Humidity remains high for most of the year. Relative humidity rarely falls below 65% during the day and is around 95% for the majority of nights. True daylength varies only by about 20 minutes during the year (Ooi and Chia, 1974). Effective daylength may be shortened by heavy cloud cover, however, during the wetter months (Wycherly, 1973).

The study was conducted between January 1980 - December 1981, with field experiments extending from March 1980.

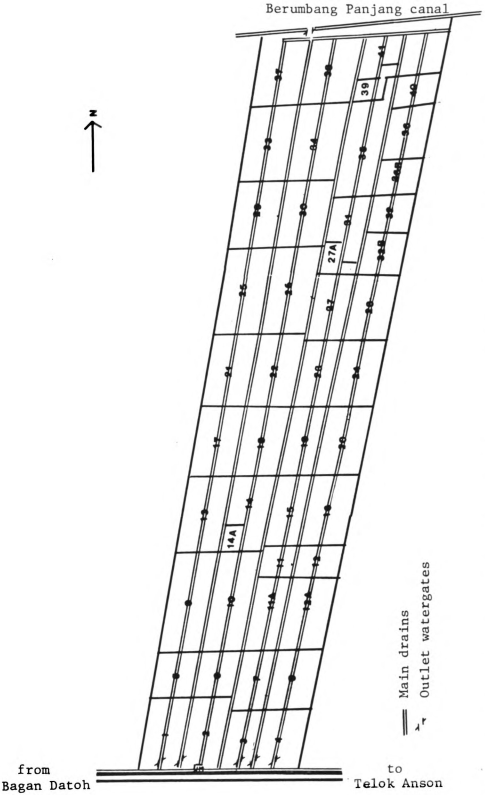


Figure 1. Fields layout at Kuala Bernam Estate, Telok Anson, West Malaysia. Experimental plots in Field 1 (44 ac), 27 (50 ac), 35 (101 ac) and 36 (60 ac).

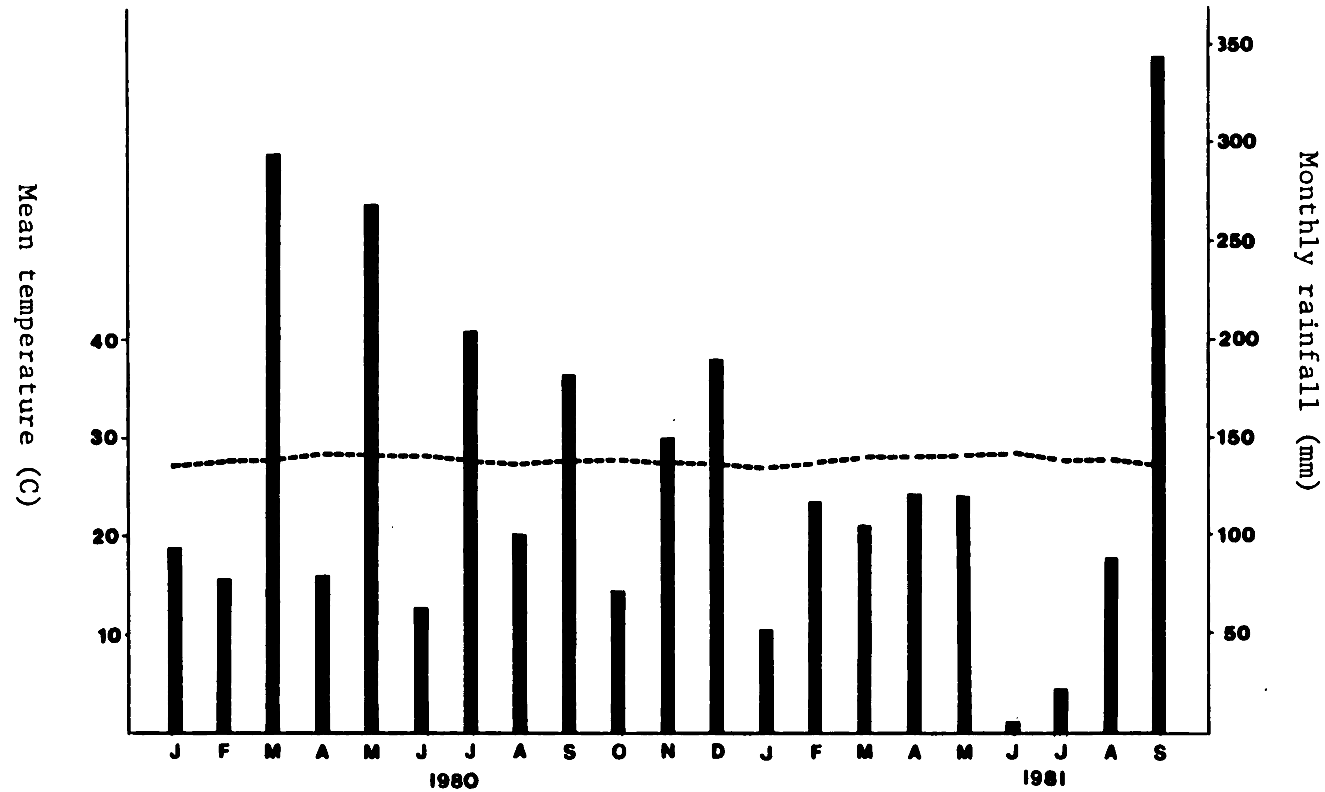


Figure 2. Monthly mean daytime temperature (----) and monthly rainfall (bar) at MARDI Hilir Perak research station, Telok Anson, West Malaysia from January 1980-September 1981.

1.0 IDENTIFYING MAMMALIAN PESTS OF COCOA

Over 60 vertebrate species, mainly rats and squirrels, have been listed by Thorold (1975) as potential depredators on cocoa. These rodents, belonging mostly to the Sciuridae and Muridae families, occur in cocoa-growing areas of the world. They have been reported as pests in West Africa by Everard (1964), in the Solomon Islands by Friend (1971), throughout the Pacific islands by Strecker and Jackson (1962), across the West Indies by Urich (1911), and in South India by Bhat (1980).

In West Malaysia, Han and Bose (1980) identified the pests to be *Rattus tiomanicus* (Miller), *R. argentiventer* (Robinson and Klaus), *Callosciurus notatus* (Boddaert), and *Arctogalidia trivargata* (Gray). Kamarudin and Lee (1981) also found a civet cat (*Paradoxurus hermaphroditus* Pallas) to be causing damage. In East Malaysia, Conway (1971) added monkeys and wild pigs to the rodent list of mammalian cocoa depredators there.

Since a number of species have been reported damaging cocoa and coexisting in the cocoa ecosystem, identifying and quantifying them is essential to the selection of appropriate management choices and control efforts. The habits of these animals also must be appraised.

MATERIALS AND METHODS

Animals trapped from Fields 1, 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia were utilized to tabulate and analyze data on the numbers, sex, and location of trapped animals. The experimental procedure used has been described (Kamarudin, 1982c,f). At the same time, a small trapping exercise was carried out in Field 27 to capture animals for laboratory studies. Six individuals of each species known to occur in the area were autopsied in the laboratory, and their stomach contents were examined for the presence of cocoa mucilage. The amount of cocoa products in their stomach were compared to the other food materials present and recorded subjectively as trace, moderate or high.

RESULTS

In order of relative abundance, rodent species captured were R. tiomanicus, C. notatus, Chiropodemys gliroides (Blyth) and R. exulans (Peale). Equal numbers of males and females were captured for the minority species (Table 1.1). More males were caught in R. tiomanicus ($p<0.05$). For C. notatus, C. gliroides, and R. tiomanicus, 79 - 83 percent of the animals were trapped in the trees, and as for R. exulans only 11 percent. Examinations of the stomach contents of sampled animals revealed the presence of trace and moderate amounts of cocoa mucilage in R. tiomanicus and C. notatus, respectively, but none in the stomachs of the other two species (Table 1.1).

Although three of the four rodent species captured had been recognized earlier as pests of cocoa, the pencil-tailed mouse (C. gliroides) had not been so reported. The three specimens of each sex of this species averaged 95 mm head and body length (range 90 - 105 mm), tail 131 mm (range 126 - 133 mm), hind foot 20 mm (range

Table 1.1 A summary of species composition, sex ratios, position of trapped animals, and stomach contents. Animals were tallied from Fields 1, 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia from March 1980 - November 1981.

Species	Percentage abundance (N)	Sex-ratios (M per F)	Percentage of animals trapped in cocoa tree tops	Cocoa mucilage in stomach contents
R. tiomanicus	95.2 (1041)	1.26*	78.6	+
C. notatus	3.1 (34)	1.27	90.0	++
C. gliroides	1.4 (15)	1.50	93.3	nil
R. exulans	0.4 (4)	1.00	11.1	nil

* X^2 test significant at $p < 0.05$

+ trace of cocoa mucilage

++ moderate cocoa mucilage

N number of animals trapped

19 - 21 mm), and weight 23 g (range 22 - 24 g).

DISCUSSION

Rattus tiomanicus is the dominant species in the area. The other species were trapped only occasionally. With the exception of R. exulans, the Polynesian rat, an evident ground-dweller, they tended to be arboreal. Harrison (1957) and Medway (1969) also described R. exulans as a ground rat. Harrison (1957) trapped R. tiomanicus chiefly on the ground, yet only 21 percent of this species was trapped beneath the trees in this study.

Kamarudin and Lee (1981) earlier reported on the extent and damage potential of R. tiomanicus and C. notatus. Based on their stomach contents, these species apparently could be serious pests of cocoa. Although R. exulans and C. gliroides were trapped in and among cocoa plants, they probably do not pose a serious threat to the crop. Based on the lack of cocoa mucilage in their stomach contents and the amount of energy required by these small animals to gnaw through 5 - 10 mm of shell thickness to reach the beans, they are believed to feed mainly on pods that are leftover after damage by the other rodents.

Although Han and Bose (1980) pointed out that cocoa mucilage is easily digestible and thus probably difficult to detect in the stomach contents of some animals, the substance was found in some abundance in R. tiomanicus and C. notatus. Even though Williams (1973) had suggested that the mucilage probably represents a "luxury" item in the diet of the rat, it was found to be a common item in the diet of R. tiomanicus. As for the Polynesian rat (R. exulans), which has been reported as a pest of cocoa in the Pacific islands, Strecker and Jackson (1962) believed that they had to "learn" to consume cocoa plant-parts.

On the study area, it seemed that R. tiomanicus and C. notatus were responsible for most cocoa pod losses. In terms of seriousness to inflict heavy pod losses, R. tiomanicus in its great abundance certainly is the most serious pest there and deserves the primary attention of cocoa-growers.

2.0 GROWTH AND REPRODUCTION OF LABORATORY-BRED *RATTUS TIOMANICUS* (Miller)

Accurate age estimation is vital in population studies. Eye-lens weights have been considered accurate to estimate age for some immature mammals but not for the smaller vertebrates because of the relative magnitude of measuring errors (Dapson and Irland, 1972). Age and body-weight relationships have been frequently used because of their ease and convenience. Although bias is inherent in comparisons of this sort, Harrison (1956a) thought that variation would be negligible in areas where climate is uniform and breeding is continuous throughout the year. He postulated that Malaysian rat populations were stable, having a constant age structure and with members having similar growth rates.

The age-weight relationship of *R. tiomanicus* had been studied earlier by Harrison (1956a) but in forest and oil palm habitats. Although the same rat species was found in cocoa, it was thought that due to differences in food types, habitat, and cover their growth rates probably would differ. A study was made to examine the age-weight relationship for a cocoa inhabiting *R. tiomanicus* population. In addition, the rat's rate of reproduction was investigated.

MATERIALS AND METHODS

Twelve pregnant female *R. tiomanicus* were live-trapped from cocoa fields 10 and 36B Kuala Bernam Estate near Telok Anson, West

Malaysia, and placed singly in laboratory cages measuring 45 x 45 x 30 cm. Rats were fed with laboratory chow, coconut meat, cocoa, bones, and water _ad lbitum_. Birth dates and numbers of young were recorded.

The young were weighed at birth and weekly thereafter. At weaning, they were separated from their mothers. Female rats were then paired to males of slightly heavier weights. Males that died during the pairing process were replaced by males of equivalent weights. Care was taken to prevent mating brothers and sisters. The times of first and subsequent births were noted. Young from these births were subjected to treatments similar to their mothers.

Body weights were recorded up to death or 60 weeks whichever came first. Weights of pregnant females were excluded beginning three weeks prior to birth. This was done to avoid false reporting of weight to age. The relationship of age and weight were compared statistically using the Statistical Package for Social Sciences (SPSS) computer programs (Nie _et al_., 1975).

RESULTS

1. Age-weight relationship

Growth curves for males and females were plotted on scattergrams (Figures 2.1 and 2.2). Both sexes exhibited steady growth rates up to 20 weeks, and tended to level off thereafter. Weight gains declined as the animals proceeded towards old age. Males weighed more than females in each age-class.

Because of the curvilinear nature of the growth pattern, a

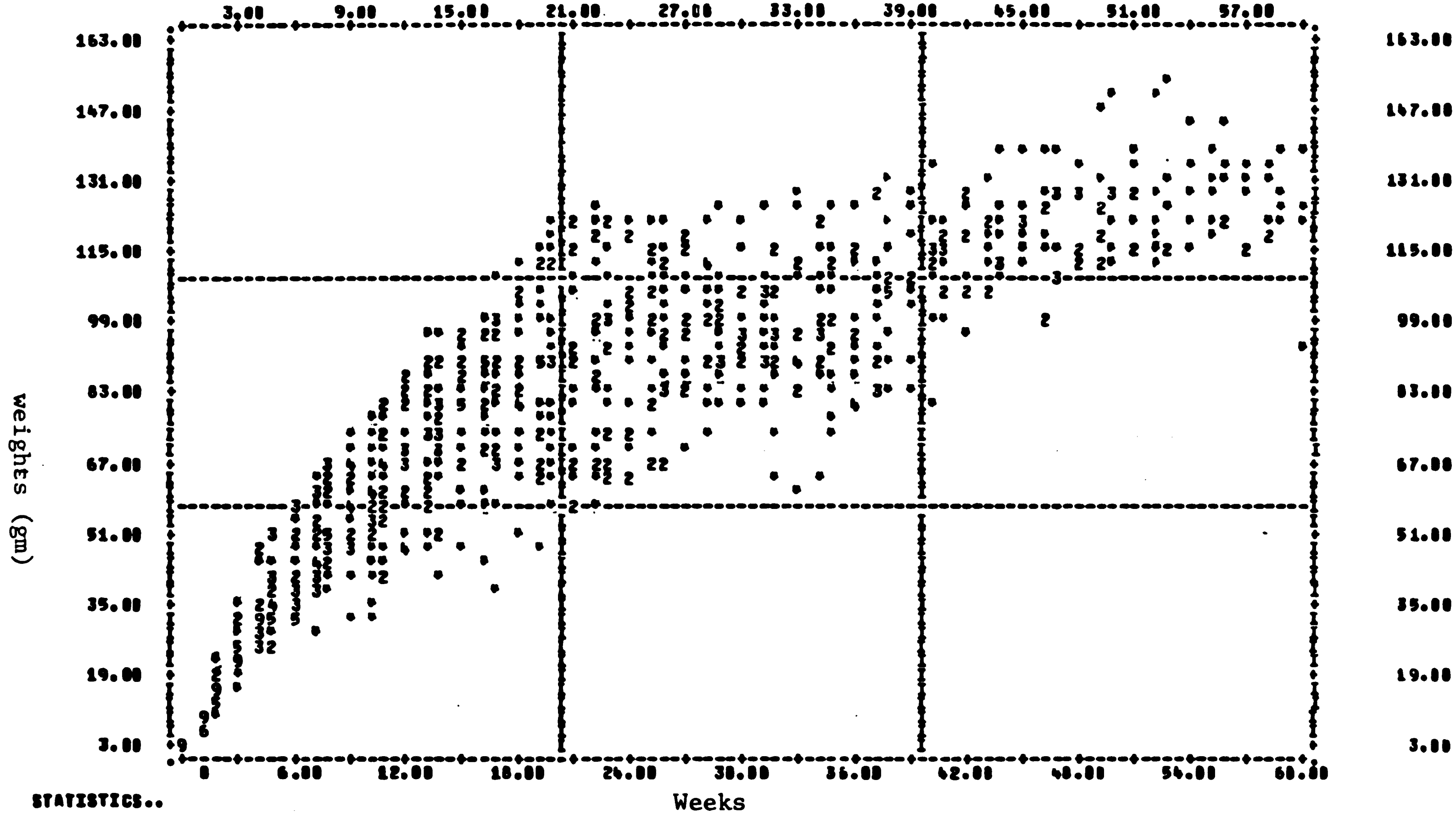
Figure 2.1. A scattergram of the age-weight relationship for male *Rattus tiomanicus* (Miller) from Kuala Bernam Estate, Telok Anson, West Malasia bred in the laboratory, 1980-1981. Linear regression relationship from birth up to the 20th week was computed as:

$$Y_{wt} = 14.3119 + 4.2082\ X_{wks}$$

AGE - WEIGHT RELATIONSHIP FOR MALES 07/06/82 SPSS V8.0 .10.27.04. PAGE 2

FILE NONAME (CREATION DATE = 07/06/82)

SCATTERGRAM OF (DOWN) WEIGHT
(ACROSS) WEEKS



STATISTICS..

CORRELATION (R)-	.86026	R SQUARED -	.74004	SIGNIFICANCE R -	.00001
STD ERR OF EST -	17.09210	INTERCEPT (A) -	36.94083	STD ERROR OF A -	1.08093
SIGNIFICANCE A -	.00001	SLOPE (B) -	1.93295	STD ERROR OF B -	.03927
SIGNIFICANCE B -	.00001				

PLOTTED VALUES - 853 EXCLUDED VALUES - 0 MISSING VALUES - 0

******** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

Figure 2.1

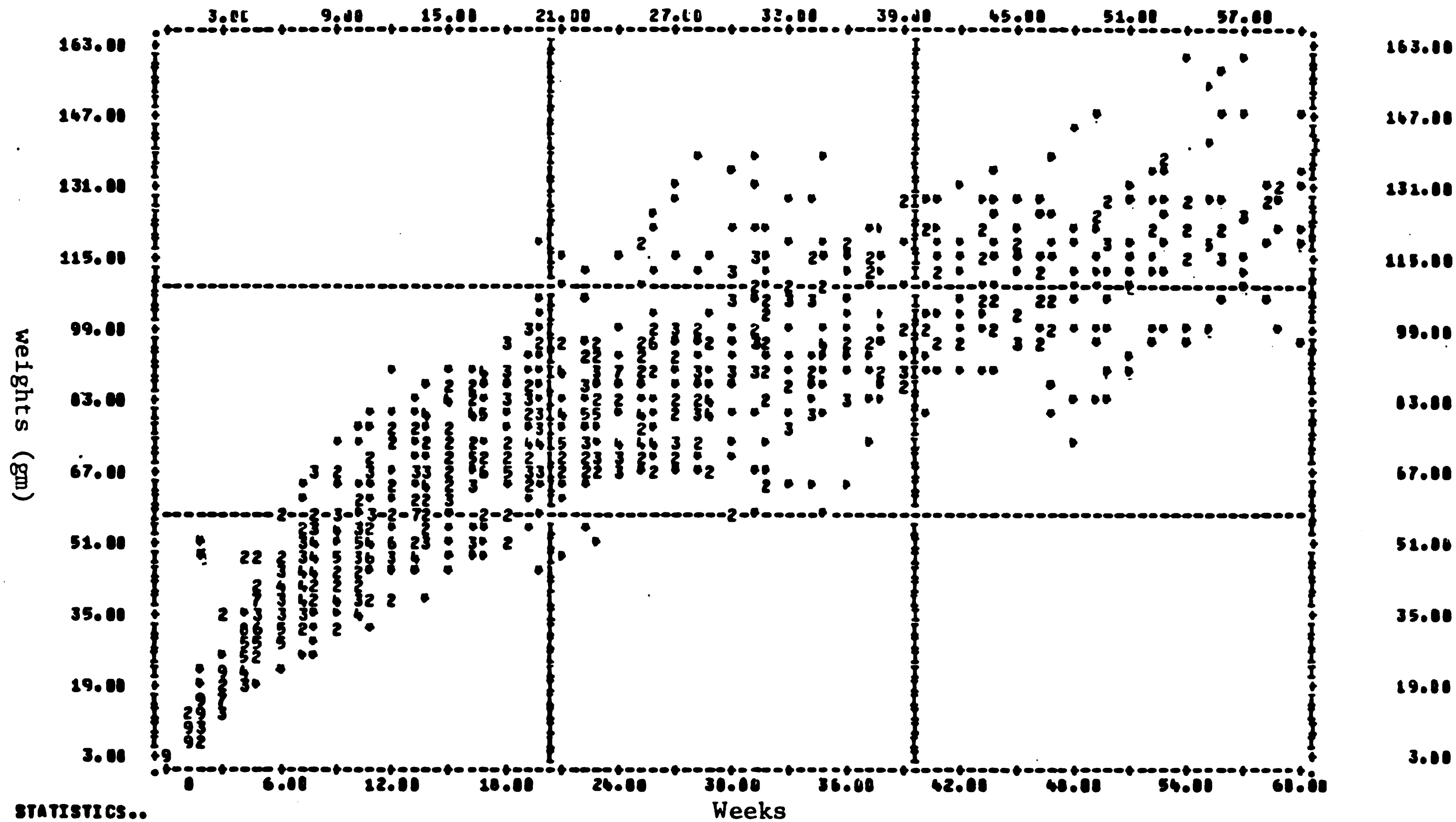
Figure 2.2 A scattergram on the age-weight relationship for female Rattus tiomanicus (Miller) from Kuala Bernam Estate, Telok Anson, West Malaysia bred in the laboratory, 1980-1981. Weights three weeks prior to giving birth were excluded. Linear regression relationship from birth up to the 20th week was computed as:

$$Y_{wt} = 13.0219 + 3.7275\ X_{wks}$$

AGE - WEIGHT RELATIONSHIP FOR FEMALES 07/06/82 SPSS V8.0 .10.30.41. PAGE 2

FILE NONAME (CREATION DATE = 07/06/82)

SCATTERGRAM OF (DOWN) WEIGHT 3 WEEKS PRIOR TO BIRTH EXCLUDED
(ACROSS) WEEKS



STATISTICS..

CORRELATION (R)-	.87626	R SQUARED -	.75784	SIGNIFICANCE R -	.00001
STD ERR OF EST -	16.40649	INTERCEPT (A) -	31.43108	STD ERROR OF A -	.85762
SIGNIFICANCE A -	.00001	SLOPE (B) -	1.09582	STD ERROR OF B -	.03138
SIGNIFICANCE B -	.00001				

PLOTTED VALUES - 1111 EXCLUDED VALUES - 0 MISSING VALUES - 0

******** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

Figure 2.2

linear relationship between age and weights was evident only up to 20 weeks. There were strong correlations between weights to ages in both males and females (r = 0.8952 and r = 0.8974 respectively). A linear regression equation for both sexes was fitted up to 20 weeks (Figures 2.1 and 2.2).

2. Reproduction

The mean number of young born to 12 adult females was 4.4 and their sex-ratio was 0.75 males per female. The mean birth weights for 21 males and 26 females were 4.0 and 3.8 g, respectively. Average weights were 34.0 g for males and 30.0 g for females when weaned 28 days after birth. Fifty percent of the males were scrotal and half the females had perforated vaginal membranes by the seventh week after birth. Their mean weights then were 59.2 and 56.2 g, respectively (Table 2.1).

On the average, 50 percent of females were visibly pregnant for the first time by 24 weeks after birth when they weighed 88.6 g. Half of adult mortality occurred by the mean ages of 34 weeks for males at mean weight 114.0 g, and by 40 weeks at mean weight of 106.4 g for females. The mean number of placental scars was 6.6 (range 4 - 10).

Mean days to first birth was estimated to be 202.6 days (about 29 weeks), ranging from 121 to 265 days. The mean number of young varied from 3.6 at first birth to a maximum of 5.8 young at litter number four. The days between litter varied from 22 to 155 days. Mean litter size was 5.7 and ranged from 2 - 9 litters throughout a female's lifespan (Table 2.2).

Table 2.1. A summary of reproductive data for males and females *Rattus tiomanicus* (Miller) from Kuala Bernam Estate, Telok Anson, West Malaysia, 1980-1981 bred in the laboratory.

	Mean values (+ SE or ranges)	
	Males (N=21)	Females (N=26)
Birth weight (g)	4.0±0.2	3.8±0.1
Weight at weaning (g)	34.0±1.4	30.0±1.3
Age at weaning (days)	28 (26-35)	28 (26-35)
Weight when 50% testes scrotal/vaginas perforated (g)	59.2±2.4	52.6±3.5
Age when 50% testes scrotal/ vaginas perforated (weeks)	7 (5-9)	7 (5-9)
Weight when 50% pregnant (g)	-	88.6±4.5
Age when 50% pregnant (weeks)	-	24 (17-29)
Placental scars[1]	-	6.6±1.2
Weight when 50% adult mortality (g)	114.0±5.7	106.0±7.4
Age when 50% adult mortality (weeks)	34 (19-43)	40 (24-54)

[1]May represent more than 1 litter

Table 2.2 Reproductive data on litter size and interval between littering for female laboratory-bred *Rattus tiomanicus* (Miller) from Kuala Bernam Estate, Telok Anson, West Malaysia, 1980-1981 with varying number of litters.

Litter size	Number of females sampled	Mean number of young (range)	Mean interval between litters in days (range)
1	11	3.6 (3 - 5)	
			62.6 (26 - 155)
2	11	3.9 (3 - 6)	
			42.4 (25 - 68)
3	9	3.8 (3 - 5)	
			33.0 (22 - 54)
4	7	5.8 (4 - 7)	
			72.4 (24 - 127)
5	6	4.3 (3 - 6)	
			33.6 (24 - 87)
6	6	3.8 (3 - 5)	
			56.2 (54 - 57)
7	4	4.0 (3 - 5)	
			32.4 (24 - 64)
8	2	2.0 (1 - 3)	
			32.0 (30 - 34)
9	2	4.0 (3 - 5)	

DISCUSSION

The existence of a linear relationship between body weights and growth in rats and mice (Harrison, 1951; Krebs et al., 1969; Hirata and Nass, 1974) enabled a regression of age and body weight to be used frequently for estimating the animals' age. Harrison (1956a) pointed out that the growth of a rat appears to occur at a fairly regular rate up to a certain size with weight then fluctuating about that size. Up to a certain weight then, body weight could be an acceptable indicator of age. Hirata and Nass (1974) utilized age-weight curves up to 20 weeks for Norway, black and Polynesian rats. Similarly, with R. tiomanicus body weight also was approximately linear up to 20 weeks and then tended to level off.

Reproductive data for laboratory-bred R. tiomanicus from cocoa areas were within the ranges of those obtained by Harrison (1951, 1956a) for wood rats from oil palm and forest habitats. Slight differences were detected, however, in the mean number of young and in fertility age and pregnancy rate. Differences between rats of the same species but in different habitats have been attributed by Jackson and Barbehenn (1962) to nutritional or environmental factors rather than to genetic variation. This study yielded no evidence to the contrary.

The gestation period of R. tiomanicus is unknown, although Harrison (1951) estimated it to be 21 days from data for related species. It was found in these laboratory studies that females of this species were capable of producing another litter after 22 days. Harrison's estimate, therefore, was not excessive.

3.0 POPULATION DYNAMICS AND DEMOGRAPHY OF THE MALAYSIAN WOOD RAT, RATTUS TIOMANICUS (MILLER) IN A COCOA PLANTATION

The Malaysian wood rat, Rattus tiomanicus (Miller), is the dominant rodent species found in cocoa plantings (Han and Bose, 1980; Kamarudin and Lee, 1981), and causes substantial damage to cocoa pods. Although the same rat species also is detrimental to oil palms and has been studied there (Wood, 1969, 1971), its activities in cocoa have not been much investigated. With the recent upsurge in cocoa acreage (Ramadasan, 1980), however, more effort must be allocated to study the pest.

The present study investigated the rat population dynamics in a cocoa plantation with main objectives to monitor population trends, gather demographic data on survival rates, recruitment, reproduction, movements and home ranges. These are matters which relate to animal densities and which contribute to the species attaining pest status.

MATERIALS AND METHODS

The study was carried out on Field 1, Kuala Bernam Estate, Telok Anson, West Malaysia, an area of 18 ha (about 44 ac) of cocoa interplanted with coconut palms. The cocoa trees were about seven years old, bearing and 3 - 5 m tall. Their canopies were dense and touched each other. The coconut palms measure 5 - 8 m in height with loose fronds touching the tops of cocoa plants. Ground vegetation was absent except for some grasses around the irrigation drains. Dead leaves, coconut fronds and piles of coconut husks littered the floor of the study area (Figure 3.1).

A 10 x 20 points trapping grid was marked based on the cocoa planting density of 10 x 10 ft. Each trap point was a cocoa tree 20 ft (6.1 m) from its neighbour. The trapping area thus covered an area of 80,000 sq ft (about 0.74 ha). Four hundred live-traps were utilized. Each trap measures 30 x 15 x 12 cm, and were made locally from 2 x 1 cm netting material. Two traps were placed at each trap point. One was set at the base of the cocoa tree and the other tied to a branch between 1 - 2 m above ground. Fresh coconut meat was used as baits.

Trapping was carried out from February 1980 until November 1981. Each trapping period was for three nights with an inspection daily in the morning. The interval between trappings was 17 - 19 days and was chosen to enable trappings to be rotated for all weeks of a month. On three occasions, however, the trapping interval was prolonged to 26 days.

All animals captured were ear-tagged with numbered Monel-metal No. 1 fingerling tags. Each specimen was identified to species, weighed to the nearest gram using a Pesola scale, and sexed. Trap location and position of trapped animals (on the ground or tree-top), reproductive condition (male: testis scrotal or abdominal; female: vagina perforated or unperforated, visibly pregnant or lactating), and the number of births in traps were recorded. Animals were released at points of capture and precautions were

Figure 3.1. Field conditions of the study plot in Field 1 Kuala Bernam Estate, Telok Anson, West Malaysia.

taken to prevent released animals from running immediately into traps.

Nest counts also were carried out after each trapping sequence. Ladders were used to reach coconut crowns and these were inspected for presence or absence of nests. All coconut palms within the trapping grid were examined.

Data were punched on IBM cards and the analysis was performed on the Michigan State University Cyber 170/750 computer. Computer programs developed by Krebs (1972) to analyze population estimates and demographic information gathered on small mammals populations were used to interpret the data collected in the field. The first program computed the population estimate from mark and recapture data using Jolly's stochastic model (Jolly, 1965). This model is a considerable improvement over other census models (Caughley, 1977) by defining the probabilities for which certain events occur. The multiple mark and recapture procedure also has the advantage of accumulating other information about the population.

Survival rates, the minimum number of animals known to be alive, and the proportion of marked animals during each trapping sequence were also computed. The minimum number of animals known to be alive is the sum of the number of animals actually caught in week t plus the number of previously-marked animals trapped subsequent to week t, but not in week t. The estimated population was also tested for equal-catchability following the example shown in Caughley (1977) for the first marked sample and their subsequent captures.

The second program tallied information on the absolute number of trapped animals, body-weight distributions, fates of animals, positions of trapped animals, reproductive information and movements within the three trap-nights periods. Movement was measured by the average length between two consecutive capture points the animal was trapped during a 3 trap-nights. Maximum range measures the farthest distance moved by a rat in any two consecutive captures during the trapping period. Mean body weight and all information were analyzed by this program according to sex and age. Though it was not possible to determine the exact ages, animals were grouped in three classes based on weights: adults ≥90 g, subadults 60 - 89 g, and juveniles ≤59 g. These weights were assigned based on laboratory studies (Kamarudin, 1982b).

Home ranges estimates were based on a computer program written by Dunsworth (1976) and based on a model by Koeppl et al. (1975). The program computes from a bivariate normal model an elliptical home range as well as calculating the center of activity. Results were based on 10 or more captures using the format outlined by Krebs (1972). The A1 formula proposed by Jennrich and Turner (1969) and Mazurkiewicz (1969) was adopted in this study when making comparisons on the animal's home range sizes. This technique estimates the minimum area of an ellipse that is expected to contain some arbitrarily chosen proportion 1-α (such as 95%) of the animal's activity. This method is more preferable and has been discussed by Madden and Marcus (1978).

Statistical analyses were done according to the SPSS program

(Nie et al., 1975).

RESULTS

Four rodent species were trapped in the area as described earlier (Kamarudin, 1982a). Since the other three species were relatively uncommon, attention was focused on the R. tiomanicus population, the dominant species trapped. The population level and trend of the wood rat in the 0.74 ha trapping grid between March 1980 and November 1981 tended to fluctuate between 102 ± 6 and 160 ± 9 animals (138 to 216 animals/ha). While there appeared to be more males than females in the population, the difference was not significant according to Chi-square analyses (Figure 3.2).

The rates of survival to the following trapping period (17 - 19 days later) were relatively high throughout the study, varying between 0.5 and 1.0. Both male and female rats exhibited similar survival patterns (Figure 3.2).

The proportions of marked animals in the population varied between 62 and 93 percent of the minimum number of animals known to be alive (Table 3.1). Tests on equal catchability in both males and females indicated that the animals caught tended to be trap prone. Censuses may have been confined only to the trappable population and not reflect the total numbers present.

New additions to the population per trapping period ranged from zero to 50 animals and constituted about 5 to 35 percent of the total population (Figure 3.3). The number of new juveniles joining the population seemed to exhibit small cyclical trends every

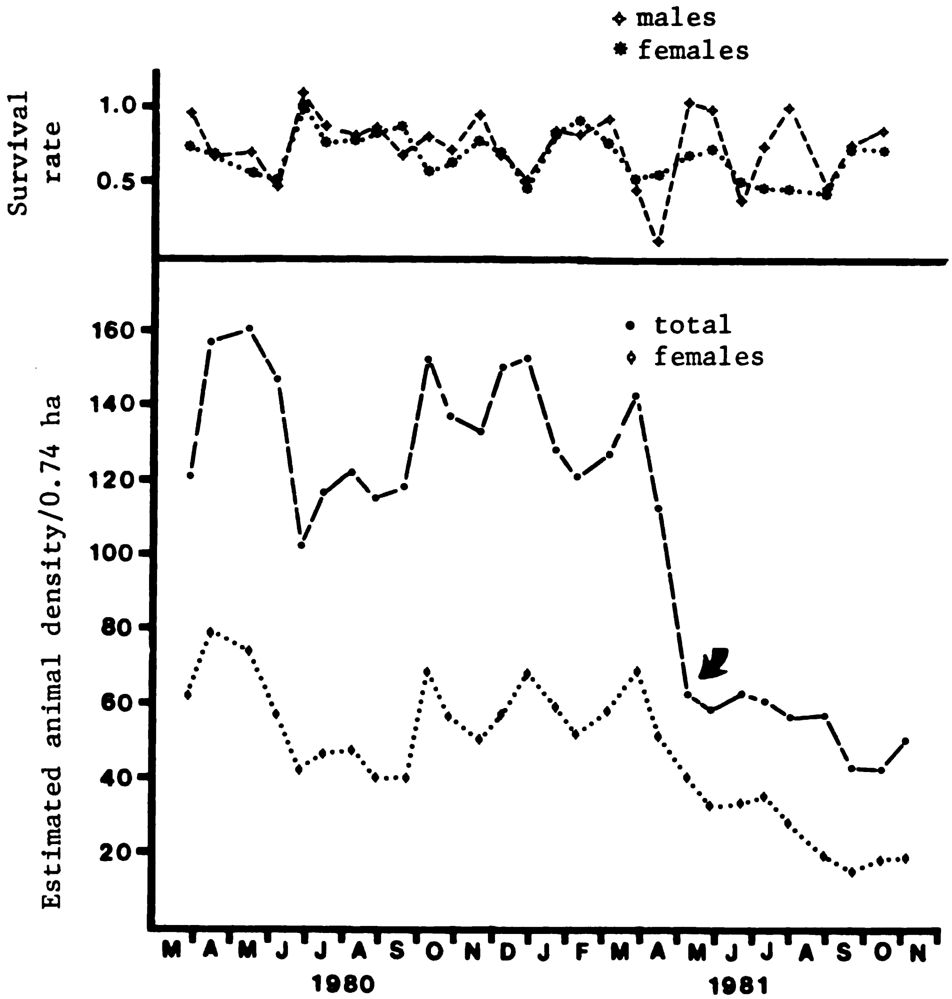


Figure 3.2. Survival rates and estimated animal densities for Plot 1 Kuala Bernam Estate, Telok Anson, West Malaysia between March 1980-November 1981 in 0.74 ha trapping grid. The area between the dashed and dotted lines represent the male population and under the dotted lines are females. The arrow indicates the time of accidental poisoning.

Table 3.1 Proportions of marked animals in traps and minimum number known to be alive in Plot 1 at each trapping sequence between March 1980 - November 1981, Kuala Bernam Estate, Telok Anson, West Malaysia.

Week	Proportion of marked animals	Number known to be alive
1	0.0	64
5	0.48	103
8	0.62	128
12	0.69	135
15	0.81	112
18	0.90	96
21	0.87	105
24	0.82	104
27	0.87	102
30	0.85	102
33	0.62	137
36	0.87	120
39	0.82	120
42	0.79	124
45	0.75	126
48	0.78	107
51	0.85	114
54	0.85	111
57	0.77	114
60	0.81	98
63[1]	0.93	58
66	0.93	55
69	0.82	59
72	0.68	50
75	0.74	46
79	0.75	43
82	0.80	34
86	0.77	34
89	0.67	41
92	0.71	34

[1]Accidental poisoning with one round of Brodifacoum baits.

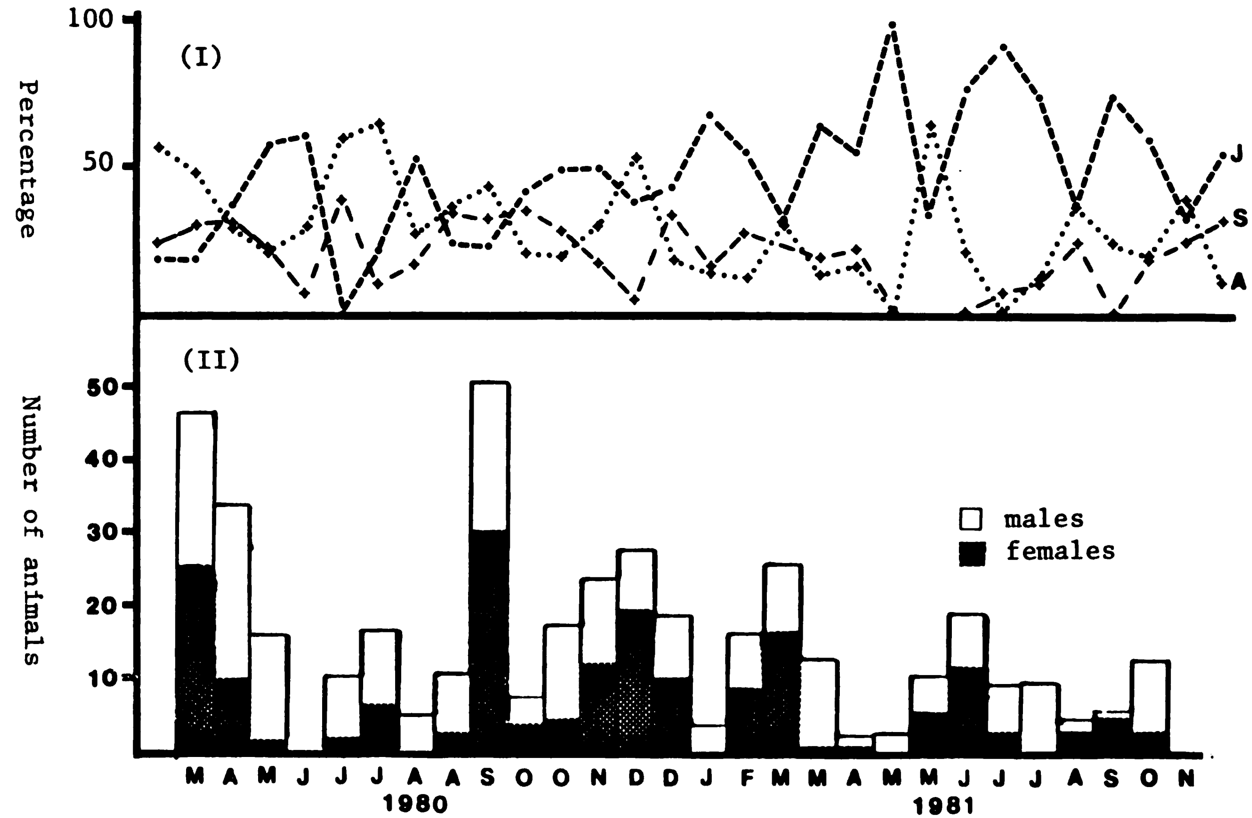


Figure 3.3. Recruitment at varying trapping periods between March 1980-November 1981 by age-weight classes (I) and sexes (II) for Plot 1, Kuala Bernam Estate, Telok Anson, West Malaysia. Recruitments are expressed as percentages for age-weight classes, and by absolute numbers for sexes, J = juveniles, S = subadults and A = adults.

three or four trapping periods. Visual comparison made between rainfall pattern (Figure 2) and the recruitment cycle (Figure 3.3) apparently did not show trends to relate the two. Recruitments into the population did not favor one sex, except for the May 1980 sampling when more males joined the population ($p<0.05$) and in September 1981 when more females were recruited ($p<0.05$). The age-weight composition of these new recruits were also examined. The proportions of new animals by age-weight classes did not show trends of any one class to dominate, although intermittently adults and juveniles appeared to predominate. This was true prior to December 1980, but in later trappings, juveniles were heavily recruited (Figure 3.3).

Though trapped rats weighing 16 to 178 g had been captured throughout the entire study, a large proportion of the animals were adults (males: 64.5% and females: 53.9%). The rest comprised sub-adults which consisted of 20.4 percent males and 28.3 percent females. Juveniles were made up of 15.1 percent males and 17.8 percent females. The total males and females sampled were 1086 and 741, respectively. Pregnant females were excluded from the analyses to avoid false reporting in the age-weight classes.

There was a high percentage of potential breeders in the population (Figure 3.4). The proportion of males with scrotal testes ranged from 65 to 95 percent, and the proportion of females with perforated vaginas was 80 to 100 percent. The percentage of visibly pregnant and lactating females varied between 5 and 57 percent of the total female population. Four females gave birth while in

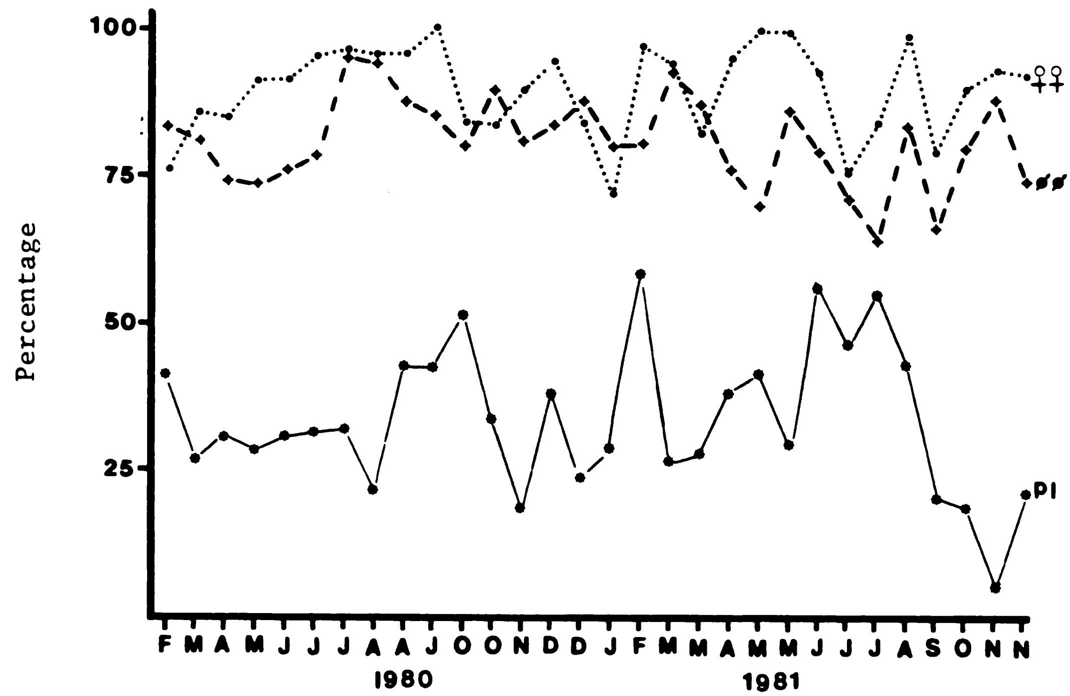


Figure 3.4. Proportions of scrotal males, females with perforated vaginas, and visibly pregnant and lactating females (Pl) between February 1980-November 1981 for Field 1 Kuala Bernam Estate, Telok Anson, West Malaysia.

traps, and the mean number of young at birth was 4.5 (range 3 - 6).

Movements within a three trap-night trapping period were computed separately for rats captured between March 1980 and April 1981, and between May and November 1981. This was done to avoid any effect of differential population densities on the rats' degree of movements during the two time periods, since the field was accidently poisoned by the Estate management staff in April 1981. Animals trapped during March 1980 - April 1981 showed significant differences ($p<0.05$) in the distances moved between all three age-weight classes. Adults travelled farthest (males: 14.54 m, females: 10.13 m). Subadults (males: 8.78 m, females: 8.59 m) in turn, moved further than juveniles (males: 7.35 m, females: 6.41 m). The movement patterns by rats captured during May - November 1981 indicated similar trends. Mean distances then, however, were comparatively greater in females of subadults and juveniles age-weight classes (Table 3.2).

The furthest distance travelled was 79.5 m recorded for adult and subadult males for the March 1980 - April 1981 population. For the May - November 1981 population, the furthest recorded movement was only 61 m by an adult male. A comparison between the two rat densities showed that although the latter population had a longer mean length of movements, it was not a statistically significant difference (Table 3.2).

The extent of movements during the entire three trap-nights by the three age-weight classes showed that 38 and 48 percent adult males and females, respectively, travelled less than 6.1 m. While

Table 3.2. Movements of *Rattus tiomanicus* (Miller) in Plot 1 Kuala Bernam Estate, Telok Anson, West Malaysia during a three trap-nights.

	TRAPPING PERIODS			
	March '80 - April '81		May - November '81	
	Mean distance (m ± SE)	Maximum range (m)	Mean distance (m ± SE)	Maximum range (m)
ADULTS				
- males (N=366)	14.54 ± 3.30	79.51	19.07 ± 5.91	61.28
- females (N=326)	10.13 ± 2.17	60.06	12.23 ± 2.77	60.98
SUBADULTS				
- males (N=100)	8.78 ± 2.83	79.51	8.61 ± 3.69	19.27
- females (N=104)	8.69 ± 2.73	54.54	9.05 ± 3.01	32.84
JUVENILES				
- males (N=46)	7.35 ± 3.18	32.84	6.98 ± 2.94	13.64
- females (N=50)	6.41 ± 3.19	14.30	14.30 ± 4.57	32.84

subadults, 55 percent of males and 51 percent of females moved within this distance. For juveniles, 63 percent of males and 78 percent of females exhibited a similar length of movements among rats trapped during the March 1980 - April 1981 period. As for May - November 1981, there were lower proportions, only 21 and 33 percent adults, 50 and 41 percent subadults, and 44 and 43 percent juveniles, male and female which move this distance. The number of animals involved became fewer in both populations as the length of movements increased (Table 3.3).

Home range size was calculated for rats with ten or more captures (Table 3.4). The results mainly, therefore, were from data collected over an extended length of time, so that individuals often matured from one age class to another. To allow for changes in age, home ranges were computed and grouped under adults, subadults-adults, juveniles-subadults, and juveniles-adults depending on their weights at first and last capture. There were significant differences in the mean home range areas for males for the various groups (F-test, $p<0.01$). Least significant difference (LSD) tests showed only the adults and the juveniles-subadults to differ significantly ($p<0.05$) in their mean home range areas. For females, there were no significant differences in home range areas among the various groups. Neither did male and female home ranges differ significantly when the two sexes of the juveniles-adults groups were compared statistically.

The rats build their nests in the coconut fronds from loose frond sheaths and from leaf blades with the midribs removed.

Table 3.3. Numbers and percentage distributions of rats for various lengths of movements during one 3-nights trap period in Plot 1 Kuala Bernam Estate, Telok Anson, West Malaysia.

Distance moved (m)	Adults		Subadults		Juveniles	
	males	females	males	females	males	females
Animals Trapped Between March 1980 - April 1981						
0 - 6.1	139 (37.6)	157 (48.2)	55 (55.0)	52 (50.5)	29 (63.0)	39 (78.0)
6.2-12.2	64 (17.3)	81 (24.8)	25 (25.0)	30 (29.1)	9 (19.6)	6 (12.0)
12.3-18.3	45 (12.2)	48 (14.7)	13 (13.0)	9 (8.7)	6 (13.0)	3 (6.0)
18.4-30.5	52 (14.1)	26 (8.0)	4 (4.0)	9 (8.7)	1 (2.2)	1 (2.0)
30.6-48.8	50 (13.5)	12 (3.7)	1 (1.0)	2 (1.9)	1 (2.2)	1 (2.0)
48.9-73.2	18 (4.9)	2 (0.6)	0	1 (1.0)	0	0
73.3-109.8	2 (0.5)	0	2 (2.0)	0	0	0
Animals Trapped Between May - November 1981						
0 - 6.1	11 (21.2)	36 (33.3)	9 (50.0)	11 (40.7)	10 (43.5)	6 (42.9)
6.2-12.2	10 (19.2)	38 (35.2)	5 (27.8)	10 (37.0)	9 (39.1)	4 (28.6)
12.3-18.3	7 (13.5)	16 (14.8)	3 (16.7)	3 (11.1)	4 (17.4)	1 (7.1)
18.4-30.5	7 (13.5)	13 (12.0)	1 (0.6)	2 (7.4)	0	1 (7.1)
30.6-48.8	12 (23.1)	4 (3.7)	0	1 (3.7)	0	2 (14.3)
48.9-73.2	5 (9.6)	1 (9.6)	0	0	0	0

Table 3.4 Mean home range sizes based on the bivariate home range model in hectares ($\pm$ SE) for Rattus tiomanicus (Miller) in Plot 1 Kuala Bernam Estate, Telok Anson, West Malaysia between March 1980-November 1981.

Adults	
- males (N=22)	0.43$\pm$0.06
- females (N=13)	0.12$\pm$0.02
Subadults-Adults	
- males (N=10)	0.17$\pm$0.05
- females (N=18)	0.13$\pm$0.02
Juveniles-Subadults	
- males (N=5)	0.07$\pm$0.02
- females (N=4)	0.18$\pm$0.09
Juveniles-Adults	
- males (N=18)	0.20$\pm$0.04
- females (N=15)	0.11$\pm$0.02

N = number of sample size

Occasionally, fresh cocoa leaves were included among the nesting materials. In most nest counts, it was noted that one palm only housed one nest. Pairs of rats with their young were observed running out of some nests during inspections. There was a good correlation between the number of nests and the rat estimated population in the trapping grid ($r = 0.67.7$, $r^2 = 0.4512$, $n = .24$, $p<0.01$, see Figure 3.5).

DISCUSSION

The population of R. tiomanicus in the experimental area was estimated variously between 138 and 216 animals/ha. The decline in the population from April 1981 onwards was attributed to an accidental single round of baiting by the Estate management staff during one of their routine field-poisoning programs. As a result, the population in the study plot was reduced and did not recover thereafter probably the results of migration out of the study area into the surrounding depopulated fields. Han and Bose (1980) from their field studies on animal pests of cocoa at three estates estimated that their rats numbered 100 - 300 rats/ha. Although these two estimates tended to agree, it was believed that the calculation of 138 - 216 rats per ha in the present study was an underestimation. This conclusion is based on the observation that a relatively high proportion of the same marked animals in the study area were being caught repeatedly. A test of equal probability of capture confirmed that some individuals were trap-prone. Hence, it follows that others were relatively trap-shy and that population estimates based on

Figure 3.5. A scattergram on the relationship between nests and *Rattus tiomanicus* (Miller) populations in Plot 1 Kuala Bernam Estate, Telok Anson, West Malaysia, March 1980-November 1981.

NEST AND POPULATION RELATIONSHIP 05/27/82 SPSS V8.0 .14.52.41. PAGE 4

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SCATTERGRAM OF (DOWN) Y ESTIMATED POPULATION
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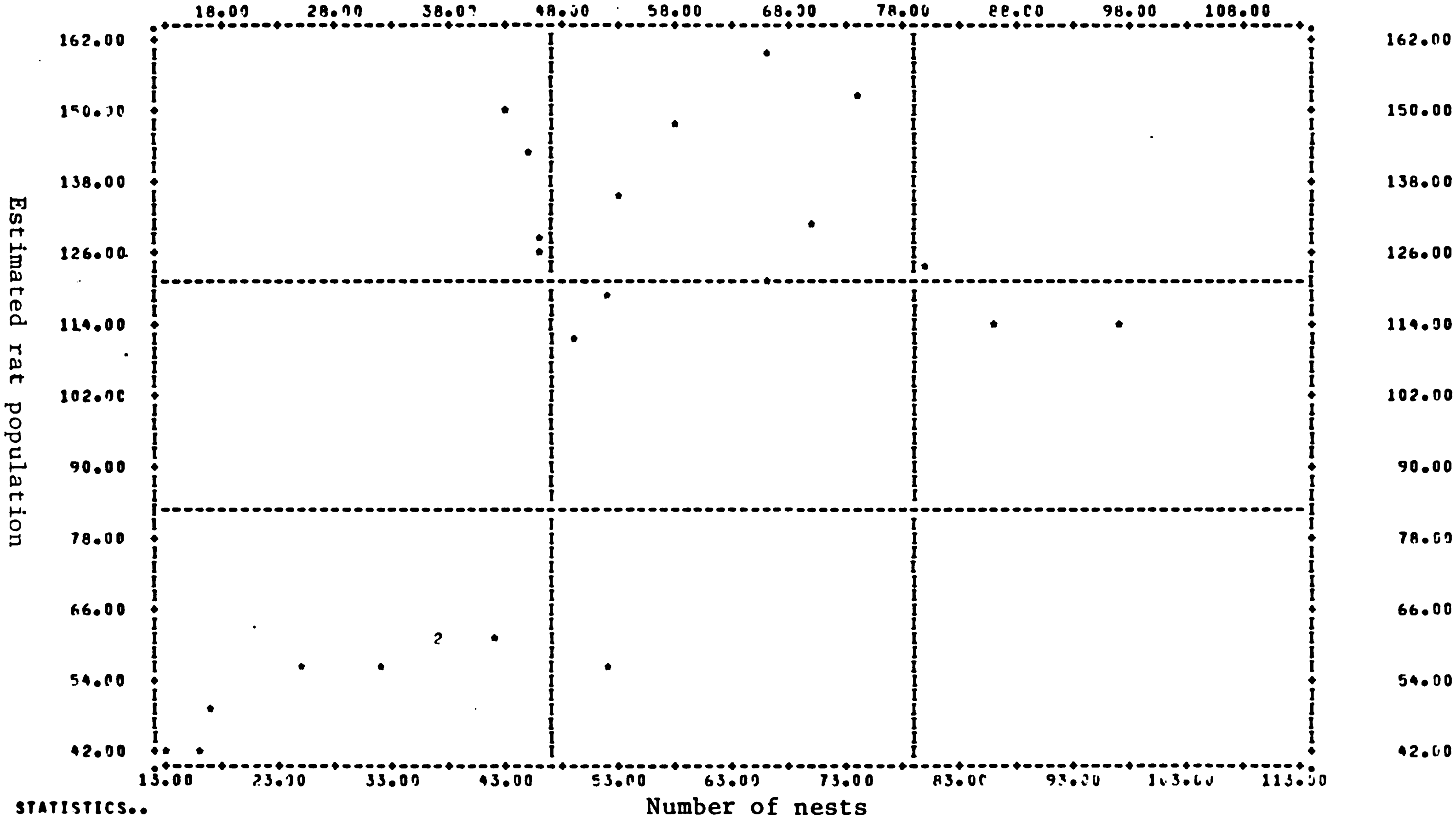

STATISTICS..

CORRELATION (R)-	.67172	R SQUARED -	.45121	SIGNIFICANCE R -	.00016
STD ERR OF EST -	30.92997	INTERCEPT (A) -	41.14941	STD ERROR OF A -	16.03448
SIGNIFICANCE A -	.00876	SLOPE (B) -	1.25143	STD ERROR OF B -	.29429
SIGNIFICANCE B -	.00016				

PLOTTED VALUES - 24 EXCLUDED VALUES - 0 MISSING VALUES - 0

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Figure 3.5

retrapping tended to be low, measuring only a portion of the population.

The tendency of *R. tiomanicus* to be highly trap-prone has been mentioned by Wood and Liau (1978). Eberhardt (1965) and Cormack (1966) suggested that reasons for this phenomenon could include that it is 1) a property inherent to the individual (expressed in its behavior in the immediate vicinity of a capturing device), 2) the result of learning (animals become more prone to capture), and 3) a property depending on the relative opportunity of capture (an animal cannot be captured if no traps are placed within its home range). Caughley (1977) proposed changes in the trapping design to make the chances of capture less dependent on a decision made by the animal, a devised census model to cope with capture-proneness (e.g. Jolly [1965]; Seber [1965] models) or a trapping plan that reduces the time of recapturing occasions could be made so that no animals have time to learn much about getting caught. He also suggested that traps be rotated randomly during each trap night. The latter proposal, however, was not followed in this study, since fixed trap points were required for the estimations of movements and home ranges.

Since there was a good correlation between nest counts and rat density, the former could be used as an index to estimate the rat's density for a particular area. It must be cautioned though, that unless the true estimates of the rats' populations have been derived, nest counts in this study only explained 45 percent of the variability of the estimated populations.

The survival rates of the cocoa wood rats for the periods between trappings were similar to those reported by Wood (1978) between 0.7 - 0.9 for the same rat species in oil palms. Harrison (1956a) also noted similar rates in his studies for the same species. There were instances, however, during the study when the estimates of survival rate exceeded 1.0. This could have occurred from a combination of the true survival rate value, which may indeed be close to 1.0, and a positive error term (Begon, 1979). The low survival rate value for April 1981 was attributed to the accidental poisoning, and more males were being accidentally killed than females during that time. In subsequent census, however, the probability of survival returned to the normal high rate.

Harrison (1956a) believed that in Malaysia where the climate is uniform, breeding is continuous throughout the year. In an earlier study, however, he reported (Harrison, 1952) that a weak correlation existed between rainfall and pregnancy. In this study apparently, such pattern (through visual comparison) was not observed.

Recruitment into the population varied from 5 to 35 percent. Wood (1978) estimated that new rats in oil palm constituted about 10 - 30 percent of the population. Birth probably plays a more important role in recruitment than does immigration. Evidences for this are the high proportions of juveniles (≤59 g) and of breeding females in the population. Though studies of dispersal (Anderson, 1970; Michener and Michener, 1977; Dunford, 1977; Hansen and Batzli, 1978) have indicated that most young individuals disperse at about the time of sexual maturation and the immigration of young born outside the population is a possibility, it is believed that most of the juveniles observed were born in the area. The high proportion of pregnant and lactating females preceeding every new addition by juveniles observed earlier (see beyond) evidently suggested this hypothesis.

As in many species, male rats tended to be more mobile than females and older males moved further than younger ones. This was not so among the various age-groups in the females. The mean distance traversed by adult males on the cocoa study was 15 m and the maximum was 80 m. Harrison (1958) using the standard diameter method, estimated that *R. tiomanicus* moved 90 m in scrub and 102 in grassland habitats. In his study, he observed no sexual differences in the distance moved.

The mean home range areas of the rat was larger in the males than in all females but the juveniles-subadults group. This was attributed probably due to the small sample sizes in the latter. The differences between males and females mean home range areas, however, were not significant. Stroud (1982) also reported that males exhibited larger mean home range sizes than females for *R. rattus* and *R. norvegicus* but statistically they were also insignificant.

In conclusion, the rat density on the study area seems certain to be larger than that estimated. Survial rates were high and recuitment into the population mainly was via birth.

4.0 ACTIVITY PATTERNS OF RATTUS TIOMANICUS (MILLER) IN A COCOA PLANTATION

Knowledge of pest activity patterns is essential in pest management to the formulation of suitable control measures (Mease and Cheeseman, 1969). Despite this need, little is known about rats that are pests of cocoa.

This study was undertaken to investigate the activity pattern of Rattus tiomanicus (Miller), the most common and principal depredator of cocoa in West Malaysia. Sex, weight, animal distribution and reproductive status were examined as related to the activity pattern and trapping response of the species.

MATERIALS AND METHODS

The study was carried out in Field 27, Kuala Bernam Estate near Telok Anson, West Malaysia on a 10 x 20 trapping grid covering 0.74 ha of cocoa interplanted with coconut. The experimental layout and trapping techniques were similar to that previously described (Kamarudin, 1982c).

Three 96-hour periods of continuous day and night trapping were carried out during October 6 - 10, 1980, February 9 - 13, 1981 and June 5 - 19, 1981. Traps were first set just before 1000 hours, with the first inspection at noon on the first day. After inspection, fresh coconut-meat baits were added and the traps immediately reset. Thereafter, they were checked regularly at two-hour intervals. Trapped animals were identified to species, weight, sex, location and position of trap and reproductive status (male: testis scrotal or abdominal, female: vagina perforated or unperforated, pregnant or lactating) were recorded. Trapped animals were released at the point of capture, and precautions were taken to prevent rats that had just been released from running immediately back into the same trap. Observations at night were carried out using dry-cell battery-operated searchlights. Throughout the trapping periods rain and the presence/absence of moonlight were noted.

The activity pattern of R. tiomanicus was measured by the numbers of captures during specific time intervals, a procedure similar to those of Brown (1956) and Blaustein and Fugle (1981). The trapping response of the rats was tested by their equal probability of capture using the binomial expansion method. Population estimates made for the three sampling periods were also based on this technique.

During the three sampling periods, the sun set at approximately 1830 and rose at 0630 hours. A light drizzle was recorded between 1700 and 2000 hours for three evenings during the February trapping. A full moon prevailed throughout the trapping in June 1981.

RESULTS

1) Activity pattern

In all sampling periods, nearly all rats (99%) were captured between dusk and dawn (1800 - 0600 hours). Three peak activity periods at 1800 - 2000 hours, 2200 - 2400 hours, and 0200 - 0400 hours were evident during most 24-hour periods. During February 1981, however, only two peaks of activity at 2000 - 2200 hours and 0200 - 0400 hours occurred. The percentage of February captures between 0400 - 0600 hours were considerably higher, too, as compared to the other periods (Figure 4.1).

There was significant difference in the number of animals captured between the three sampling periods (F-test, $p<0.01$, Table 4.1). But even though there was a daily decline during all three trapping periods, these declines were not statistically significant. Equal proportions of male and female rats were caught during each trapping interval. The percentage of new captures ranged between 5.4 and 11.2, with most new animals being caught between midnight and dawn (Table 4.2).

2. Animal size distribution in relation to trapping interval

Weights of trapped animals during the entire sampling periods varied between 18 and 178 g. They were then placed into eight weight classes at 20 g intervals (Figure 4.2). A large proportion of the males captured at each time interval weighed between 80 and 139 g. Rats weighing less than 39 g and more than 160 g were found active only during the early part of the night (1800 - 2200 hours) and in the morning hours (0200 - 0600 hours). With females, a majority weighed between 80 - 119 g. Their representation in the 40 - 79 g weight class also was relatively large. Young females (≦39 g) showed an activity pattern similar to that of the males, but the heaviest females (≧160 g) were trapped only between 2000 and 2200 hours. Weight classes of 120 - 139 g for

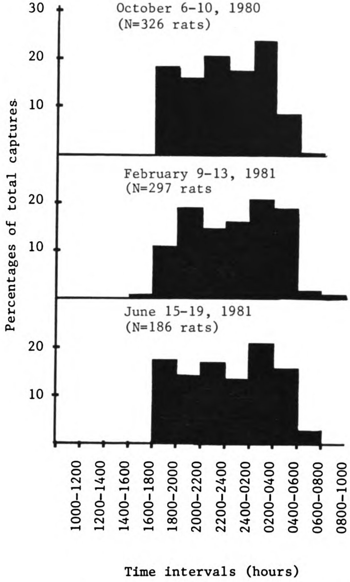

Figure 4.1. Relative amounts of Rattus tiomanicus (Miller) activity measured by the number of captures during two-hour periods at three sampling periods (October 1980, February 1981 and June 1981) at Kuala Bernam Estate, Telok Anson, West Malaysia.

Table 4.1. Total live-captures of Rattus tiomanicus (Miller) in Field 27 Kuala Bernam Estate, Telok Anson, West Malaysia during three sampling periods.

	Sampling Periods*			
Trapping days	October 1980	February 1981	June 1981	Total
1	90	82	59	231
2	85	90	47	221
3	77	61	48	186
4	74	64	32	170
Total	326	297	186	809

*Significantly different at $p < 0.01$, F-test.

Table 4.2. Distribution of new and recaptured *Rattus tiomanicus* (Miller) of each sex by two-hour trapping intervals cumulative of October 1980, February 1981 and June 1981 sampling periods at Kuala Bernam Estate, Telok Anson, West Malaysia.

Time intervals (hours)	Percentages of new captures		Percentages of recaptures	
	Males (N)	Females (N)	Males (N)	Females (N)
1600-1800	0	0	50.0 (1)	50.0 (1)
1800-2000	1.6 (2)	4.6 (6)	44.6 (58)	49.2 (64)
2000-2200	2.3 (3)	3.1 (4)	48.5 (63)	46.1 (60)
2200-2400	2.2 (3)	5.9 (8)	44.4 (59)	48.5 (66)
2400-0200	4.0 (5)	7.1 (9)	42.9 (54)	46.0 (58)
0200-0400	6.5 (11)	4.7 (8)	45.6 (77)	43.2 (73)
0400-0600	6.4 (7)	4.6 (5)	43.1 (47)	45.9 (50)
0600-0800	0	0	25.0 (1)	75.0 (3)
0800-1000	0	0	50.0 (1)	50.0 (1)

N = numbers of rats caught

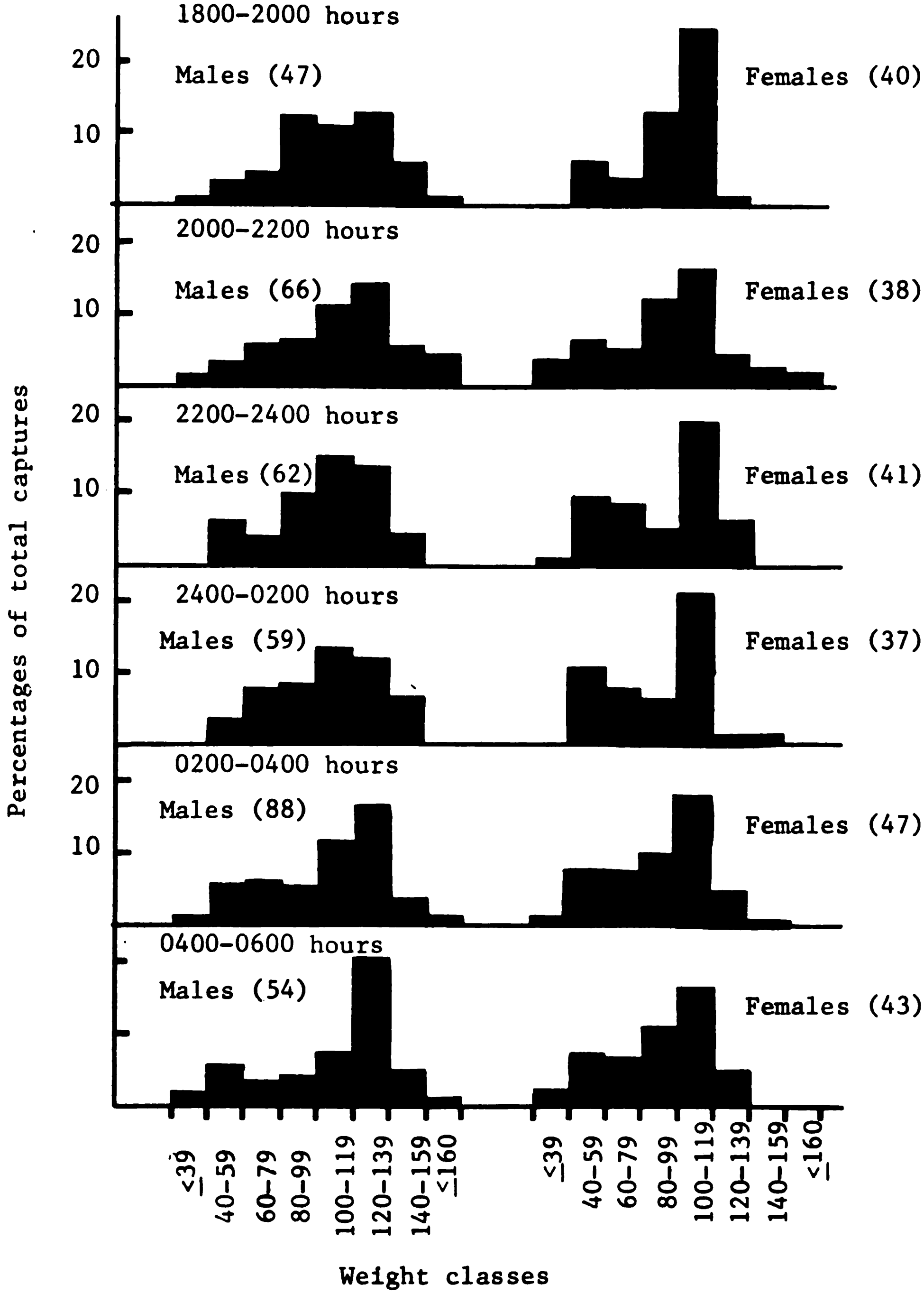

Figure 4.2. Weight distributions of <u>Rattus tiomanicus</u> (Miller) at different time of capture intervals at Kuala Bernam Estate, Telok Anson, West Malaysia. One animal captured between 1600-2000 hours and five between 0600-0800 hours were not graphed due to small size of sample.

males and 100 - 119 g for females were the largest single class throughout each time interval.

3. Reproduction

The distributions of males with scrotal testes and of females with perforated vaginas during each time interval were not significantly different. In the male population, the proportion of scrotal males ranged between 83 and 100 percent. As for females, those with perforated vaginas varied between 91 and 100 percent of the total female population, and 22 to 45 percent were visibly pregnant. Pregnant females were captured mostly between 1600 and 0600 hours, and were evenly distributed throughout. None was trapped later (Table 4.3).

4. Trap response

From the cummulative total of all three sampling periods, 73 percent of the animals were caught only once, 22 percent twice, four percent thrice, and less than one percent four times (Table 4.4). A test for equal probability of capture for each sampling period revealed that individual rats were not caught with equal frequency.

Of the total number of rats that were trapped more than once, 36 percent were again captured during the same night if they had been caught for the first time between 1800 and 2000 hours. Animals that were trapped the first time between 2000 and 2200 hours, had 34 percent chance of being recaptured, 2400 and 0200 hours had eight percent chance of being retrapped, and of the those caught for the first time between 0200 and 0400 hours, only three percent

Table 4.3. Reproductive conditions of males and females *Rattus tiomanicus* (Miller) at various trapping intervals within a 24-hour period cummulative of October 1980, February and June 1981 trappings in Field 27 Kuala Bernam Estate, Telok Anson, West Malaysia.

Time[1] interval (hours)	No. of males with scrotal testes (%)	No. of females	
		with perforated vaginas (%)	Pregnant (%)
1600-1800	0	0	1 (100.0)
1800-2000	41 (87.2)	68 (94.4)	32 (44.4)
2000-2200	60 (90.9)	59 (92.2)	26 (40.1)
2200-2400	52 (83.9)	67 (90.5)	33 (44.6)
2400-0200	54 (91.5)	61 (91.0)	29 (43.3)
0200-0400	73 (83.0)	78 (96.3)	34 (42.0)
0400-0600	45 (83.3)	52 (94.5)	12 (21.8)
0600-0800	1 (100.0)	0	0
0800-1000	1 (100.0)	0	0

[1]Other time intervals had no capture

Table 4.4 Frequency of repeated trapping of the same *Rattus tiomanicus* (Miller) individual during a 24-hour period of trapping at Kuala Bernam Estate, Telok Anson, West Malaysia during three different sampling periods.

No. of times captured	Sampling periods			Percent
	October '80	February '81	June '81	
Once	195	151	101	73.3
Twice	54	51	30	22.1
Thrice	5	12	7	3.9
Four times	1	2	1	0.7

Table 4.5. Trap occupancy by different *Rattus tiomanicus* (Miller) individuals during a 24-hour trapping period at Kuala Bernam Estate, Telok Anson, West Malaysia during three sampling periods.

No. of rats	Sampling periods			Percent
	October '80	February '81	June '81	
One	126	170	165	75.2
Two	23	43	56	19.9
Three	3	7	10	3.3
Four	1	5	4	1.6

were recaptured. Animals that were trapped after midnight did not yield three or more recaptures (Table 4.6). And the frequency of trapping the same rat more than once was greatest after a lapse of four to six hours from the time of their last capture (Table 4.7).

Of all traps that had occupants, 75 percent were occupied only once during the 24-hour trap-period. Twenty percent of the traps caught two different rats, three percent of the traps caught three different rats, and only two percent of the trap had four different occupants during a 24-hour trap-period. Test for equal probability of trap occupany during all three sampling periods showed that the traps were not equally occupied (Table 4.5).

Population estimates for the three sampling periods were based on the (unfortunately false) assumption that all rats were equally subject to capture. These censuses, however, indicated that there were 382 rats present in October 1980, 276 rats in February 1981, and 184 rats in June 1981.

DISCUSSION

That the period of greatest activity for *R. tiomanicus* was between dusk and dawn is not surprising. Similar findings have been reported for *Microtus* and *Reithrodontomys* species by Hamilton (1937) and Blaustein and Fugle (1981). Davis (1933) found a two- to four-hour cycle of activity for *Microtus* species associated with feeding peaks at dusk and dawn. In *R. tiomanicus*, three peaks of activity were indicated. But rain during the early evenings of the February 1981 sampling period evidently caused the rats to delay their

Table 4.6. Frequency of additional captures of _Rattus tiomanicus_ (Miller) when the first capture occurred at various times cummulative of the October 1980, February 1981 and June 1981 sampling periods, Kuala Bernam estate, Telok Anson, West Malaysia.

Time at first capture (hours)	Frequency of captures during the same night		
	Twice (%)	Thrice (%)	Four times (%)
1600-1800	0	0	1 (0.6)
1800-2000	47 (28.1)	12 (7.2)	2 (1.2)
2000-2200	48 (28.7)	7 (4.2)	1 (0.6)
2200-2400	26 (15.7)	5 (3.0)	0
2400-0200	13 (7.8)	0	0
0200-0400	5 (3.0)	0	0

Table 4.7. Frequency of _Rattus tiomanicus_ (Miller) recaptures with respect to time laspe from last capture within a 24-hour period, Kuala Bernam Estate, Telok Anson, West Malaysia.

Time lapse from last capture	Numbers of animals			
	October '80	February '81	June '81	Percentages
2 hours	11	19	10	21.5
4 hours	15	25	16	30.1
6 hours	18	22	14	29.0
8 hours	10	13	6	15.6
10 hours	3	3	1	3.8

activities and resulted in only two peak activities. Brown (1956) also found that the above-ground activity of Clethrionomys was influenced by rain. In his case, he found that where rain started before the animals came above ground the animals would postpone their activity and a larger catch would follow. With R. tiomanicus during the February 1981 sampling where activity was delayed, a larger capture occurred later between 0400 and 0600 hours.

In the tropics where daylength does not vary much throughout the year (Ooi and Chia, 1974), the main factors influencing rat activity probably are rainfall and moonlight. Although there was no direct measure of the moon's illumination, the low number of captures of R. tiomanicus during the full moon of June 1981 sampling probably suggested this relationship. Harrison (1952) has reported that in nocturnal forest rats, conceptions were more frequent during periods prior to full moon which probably implies that activity was greatest during this time. He, however, found such activity pattern to a lesser extent in house and oil palm rats. An association between moonlight and animal activities has been established in temperate areas for beach mice (Peromyscus polionatus) by Blair (1951), in Fresno kangaroo rats (Dipodomys nitratoides) by Lockard and Owings (1974), and in D. ordii by Kaufman and Kaufman (1982).

The presence of moonlight has been inferred to cause high predation losses and this has been demonstrated by Kruuk (1964) on the high hunting success of foxes. The relative importance of moonlight on the principal predators of R. tiomanicus, snakes and owls, however, is not known.

The wood rat's response to trapping indicated that only 25 percent were repeaters. These repeaters were again trapped only if they had been captured previously during the early part of the night. Trapping of *R. tiomanicus* at two-hour intervals showed unequal catchability. Such a behavior is understandable, however, since the rats probably would not have had enough time to randomly mix before the next trapping commenced. Similarly with the unequal probability of trap occupancy, random behavior was not achieved.

CONCLUSIONS

Information on the activity pattern of a pest species such as *R. tiomanicus* is useful in formulating control strategies. Control programs using traps and poison baits especially would benefit if implemented in synchrony with the pest's most active period. Problems associated with trap failures and losses of baits as a result of long exposure of traps or baits to non-target species also thus can be minimized. The effects of rainfall and lunar cycle also may be important during control campaigns.

5.0 ECONOMIC LOSSES OF COCOA BY RATS: A CAUSATIVE APPRAISAL

Economic losses of cocoa caused by rats in Malaysia have been reported by Mainstone (1978), Wood and Liau (1978) and Han and Bose (1980). The last authors found field losses of up to 2100 pods/ha/week, which was 92 percent of the crop yield. Kamarudin and Lee (1981) studied the extent and damage potential of three small mammals found damaging cocoa in the laboratory and found the rat Rattus tiomanicus to damage 0.5 pods/day.

Serious damage by rats has also been found in other cocoa-growing regions of the world. Montserin (1937) reported losses in Trinidad to be 2060 pods/ha/year or about 30 percent of the total production. In Ghana, however, Glendinnings (1962) recorded only light to moderate damage (60 - 1061 pods/ha/year) or about 0.7 to 7 percent of the crop. Cocoa damage in Gambia was noted by Everard (1968) at 8.4 percent in 1966. Williams (1973), in Fiji, found 3000 pods damage/ha/year and peaked at 9490 pods. Vernon and Sundaram (1970) found that increasing the interval between harvesting to four weeks in Fiji resulted in a significant increase in damage thus making it advantageous to harvest early. Yet Friend (1971) reported little difference in damage in his trials in the Solomon Islands with various harvesting intervals.

Although it is generally accepted that rat density is the primary causative agent having a direct effect on the total losses experienced, other factors such as the number of harvestable (ripe) pods available at that time, the interval between harvesting rounds, and various cultural practices may also contribute to the risk of damage.

The present study proposed to evaluate 1) the number of harvestable (ripe) pods available, 2) the pest population density, and 3) the harvesting intervals as related to the intensity of damage. The effects of all three factors acting together were also investigated.

MATERIALS AND METHODS

Harvesting records of good and damaged cocoa pods were collected from Kuala Bernam Estate, Telok Anson, West Malaysia during May 1980 to October 1981 fruit-collecting rounds. Field 1 was monitored as the study area and the intervals between each harvest were recorded. At the same time, the densities of animal populations in the field were also estimated (Kamarudin, 1982c). Data were analyzed statistically using the Statistical Package for Social Science (SPSS) computer programs (Nie *et al*., 1975) on correlation analysis and multivariate regression.

RESULTS

The Pearson r correlations between total damage incurred and population densities, total harvestable pods, and harvesting intervals were comparatively weak (r = 0.4408, 0.3004 and 0.3526, respectively). The number of damaged pods did not fluctuate in a manner corresponding to the total harvestable pods. No parallel pattern was obvious either with population density (Figure 5.1). Yet, controlling the effects

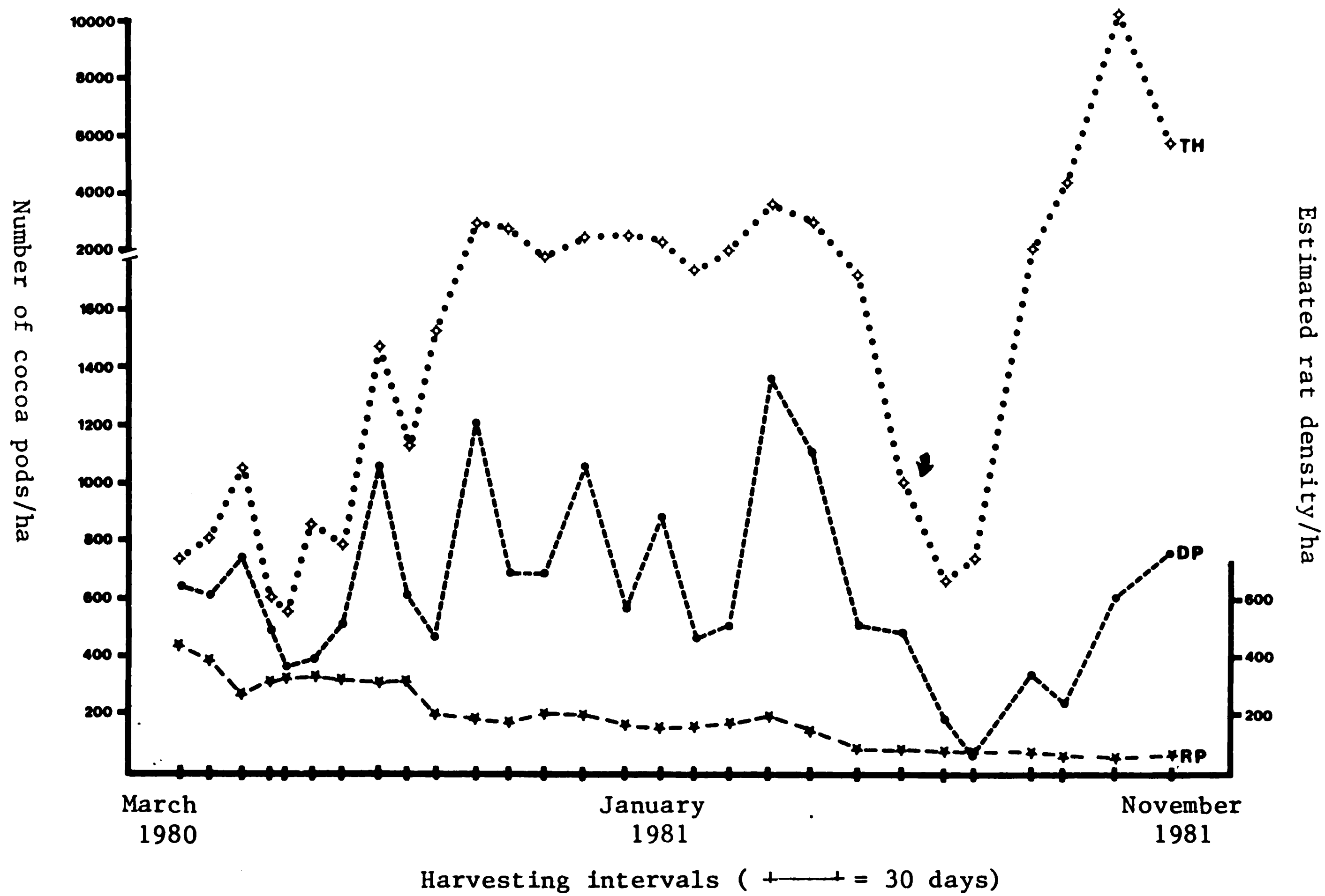

Figure 5.1. The relationships of rat population (RP), damaged pods (DP), and harvestable pods (TH) at different harvesting intervals from March 1980 to November 1981 harvests for Plot 1, Kuala Bernam Estate, Telok Anson, West Malaysia.(➘) indicates time of accidental poisoning.

of the other two contributing variables by partial correlation analyses showed that total damage exhibited the highest association with population densities ($r = 0.5140$), with the number of harvestable pods ($r = 0.4185$) and harvesting intervals ($r = 0.2441$) being of less importance.

The impact of each single factor together on the total damage showed a much stronger correlation ($R = 0.6467$, $R^2 = 0.4183$). The beta coefficient (a measure of the impact for each of these factors in their combined state) showed the highest values for population density ($\beta = 0.4797$), followed by the density of harvestable pods ($\beta = 0.4324$) and the length of harvestable intervals ($\beta = 0.2369$).

DISCUSSION

Han and Bose (1980) found total damage to be highly correlated with the number of harvestable pods. Friend (1971) also indicated that some general interrelationship existed between total damage and harvestable pods. In this study, however, the correlation between total damage and harvestable pods was not strong. The association of total damage to animal density was even more moderate. As such, it was postulated that all three factors individually did not impart a great impact on total damage. If considered together, however, a much higher interrelation was evident. Yet the three factors together only managed to explain about 42 percent of the total variation in total damage. In conclusion, since population density and the abundance of harvestable pods showed a moderate interrelation to total damage, other factors, perhaps cultural or physiological in nature, must be involved to account for the remaining 58 percent variability in total damage.

6.0 COMPARATIVE FIELD EFFICACIES AND COST-BENEFITS OF BAITING FOR RODENT CONTROL IN COCOA PLANTATION

Among the rodent species which are pests of cocoa in Malaysia, the wood rat (Rattus tiomanicus Miller) is believed to be most important (Kamarudin and Lee, 1981). The animals gnaw through the husk to reach the mucilage layer enveloping the cocoa beans. In the process, beans are removed and lost. Significant losses by these rats had been reported by Mainstone (1978) and Wood and Liau (1978). Han and Bose (1980) estimated losses to be M$470.00/ha/week.

A variety of management tools are available to farmers to combat the pest but chemical rodenticides are most used. Poison baits give quick and visible results and can be applied conveniently. Due to the ease of application, overzealous farmers sometimes carry out their programs indiscriminately. Baits were being continuously placed and with up to 12 rounds (e.g., every 3-4 days) in one program are frequent.

With today's high cost of agricultural chemicals and environmental demand, farmers should be disciplined to use chemicals more intelligently. With the recent discovery of the new "second-generation" anticoagulants and acute poisons (reviewed by Jackson, 1979), too, the conventional concept of baiting may often be economically unsound. Further, there has been a report of resistance to poisons by rats in cocoa (Lam, 1980).

One other pressing problem confronting the farmers is to decide when control is necessary. As pointed out by Dolbeer (1981), the simple guiding maxim should be that benefits (money saved by reduced damage) must exceed the cost of control. Benefits are derived from the prudent selection of efficient chemicals and awareness of their costs. Unfortunately very little effort has been expended in examining these matters in relation to anticipated or actual losses.

This study proposed to look at some of the basic parameters of decision-making in carrying out chemical control programs against rats in cocoa. It will discuss (1) the efficacies of varying number of rounds of bait application for one "second-generation" acute poison, Bromethalin (EL-614)*, (2) the cost-benefit ratios of baiting, and (3) cocoa bean prices and efficacies of control at different levels of anticipated damage.

MATERIALS AND METHODS

The study was conducted at Kuala Bernam Estate near Telok Anson, West Malaysia. Three fields of cocoa about seven years old and planted under coconuts were selected as the study plots based on reportedly high pod losses. Each treatment field was 10 ac (4.05 ha) in size and comprised of 10 one-acre blocks. All fields were baited with 200 ppm waxbound commercially-prepared Bromethalin baits. Baiting regimes (Table 6.1) of (i) two,

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*<u>N</u>-methyl-2, 4-dinitro-<u>N</u>-(2,4,6-tribromophenyl)-6-(trifluoromethyl) benzenamine.

Table 6.1. Baiting, trapping and harvesting schedules for three 10-acre fields Kuala Bernam Estate, Telok Anson, West Malaysia, 1981.

Treatments	Baiting Dates	Trapping Dates	Baiting Harvests Pre	Baiting Harvests Post
2 rounds	March 21, 24	March 18, 19, 20 April 8, 9, 10 April 28, 29, 30 May 20, 21, 22 June 6, 7, 8	March 3	March 23 April 7, 25 May 20 June 1
4 rounds	March 21, 24, 27, 30	as above	as above	as above
6 rounds	March 21, 24, 27, 30 April 2, 6	as above	as above	as above

(ii) four, and (iii) six baiting rounds (at 3-4 days interval) were tested. One bait cube (of about 8 g each) was placed at the base of every fourth cocoa tree (i.e., three consecutive trees were non-baited for a 25% field saturation) in all tree rows. Only baits that were totally removed by the rats were replaced.

1) Baiting efficacies

Pre- and post-baiting records of total pods harvested and the number of rat-damaged pods were noted. In each field, data were collected only from the six middle blocks to avoid edge effect. The efficacies of the various treatments were judged by the percentage reduction in damaged pods as assessed by pre- and post-baiting harvests.

2) Cost-benefit analyses

The working model used to derive costs and benefits was adopted from Dolbeer (1981). The basic principle is to balance the costs of introducing a control program (Y) with the anticipated benefits (bX) as a result of practising the control. Cost (Y) includes the chemicals and man-hours required to broadcast the baits. Anticipated benefits is the product of the fraction of loss prevented (b) as a result of applying control and the amount of expected dollar loss (X) if no control were instituted. Decision to apply a control program then would only be profitable if the anticipated benefit (bX) exceeded this cost (Y) of control. The fraction of loss prevented (b), in this context, is the efficacy of the control method.

The amount of expected dollar loss (X) when no control was to be instituted can be deduced by dividing total cost (Y) by efficacy (b); $X = Y/b$. The expected loss in dollars then can be converted to the number of pods expected to be lost by dividing (X) with the price (P), the market value of the pods. A graph of profit (benefit minus cost) against the expected loss in terms of pod numbers can be drawn to obtain the cost-effectiveness of various baiting regimes.

3) Minimum control efficacies and various price levels required to match cost of control

Assuming a control program budgeted at M$17.000/ha and cocoa beans at various market price levels, the corresponding control efficacies to break-even with cost can be deduced. Efficacy of control (b) is obtained by dividing cost (Y) by price (P) and the anticipated loss (X) in kg or the unit price is based on.

RESULTS

1) Baiting efficacies

Maximum relief from pod damage was achieved by the various treatments during the April 24th harvest (Table 6.2) after 31, 26 and 19 days of the last placement of baits, respectively. The effects among treatments were significantly different (F-test, $p<0.05$), however, only on the harvests of April 7. Least significant difference (LSD) tests revealed that the efficacy of four baiting rounds differed significantly from that of six baiting rounds ($p<0.05$) at that harvest date. At other harvests, there was no

Table 6.2. Percentage reduction (± SE) in cocoa pod damage for three 10-acre fields at Kuala Bernam Estate, West Malaysia following Bromethalin poisoning (200 ppm) to control damage by rodents, 1981.

Treatments	Date of Harvests				
	March 23[a]	April 7	April 24	May 20	June 1
2 rounds	26.40±5.27 (2)	74.90±4.48 (13)	81.32±4.19 (31)	70.36±2.35 (56)	53.48±4.89 (69)
4 rounds	29.23±8.02 (2)	60.13±6.82* (8)	84.62±1.51 (26)	74.35±8.64 (51)	52.16±3.31 (64)
6 rounds	20.76±7.96 (2)	83.49±3.92 (1)	92.05±2.39 (19)	80.42±5.38 (44)	57.89±10.15 (57)

[a]Harvested after 2 days with only one round of bait application.

*The effect of baiting at 4 rounds was significantly different to 6 rounds ($p < 0.05$) at this harvest date.

( ) Number of days between bait placement and harvest.

significant difference between the efficacies among the three treatments (Table 6.2).

2) Cost-benefit analysis

For two baiting rounds of Bromethalin at a cost of $12.35/ha, the amount of pods that must be saved to break-even with the investment made would be 70.2 (using the conversion factor 8.4 pods to a kg wet bean, and price of wet bean at $1.50/kg). Since control with two baiting rounds was only 81 percent effective, to save 70.2 pods the anticipated damage must be 86.6 pods. Similarly for four and six baiting rounds (at their respective costs of control and efficacies), their anticipated damage levels were estimated at 123 and 190 pods in order to save 105 and 175 pods that will cover the cost incurred implementing each control program, respectively (Table 6.3).

Thus at the various hypothetical anticipated damage levels (Figure 6.1), poison-baiting with two rounds was most cost-effective provided the level of damage did not exceed 77 kg/ha wet bean (645 pods). If damage exceeded this value then four baiting rounds should be selected to control the damage, and if more than 133 kg/ha wet bean (1121 pods) were anticipated to be lost, control program with six baiting rounds would be the most profitable choice.

3) Relationship of control efficacies and anticipated damage to cocoa bean prices

If there is a wet bean price of $1.00/kg and 100 pods is anticipated to be lost if no control is instituted, in order to

Table 6.3. A summary of bait applications and costing analysis for three 10-acre (4.05 ha) fields Kuala Bernam Estate, Telok Anson, West Malaysia, 1981.

Treatment	1 Baits used	2 Cost of baits ($)	3 Labor (Man-days) and cost ($)	4 Total Cost	5 Efficacy	6 Antici-pated damage ($)	7 Wet beans loss (kg/ha)	8 Damaged pods per ha
2 rounds	1660	41.50	1.2 (9.24)	50.74	81%	62.64	10.31	87
4 rounds	2275	56.88	1.6 (12.34)	69.22	85%	81.44	13.41	123
6 rounds	4174	104.35	2.9 (22.33)	126.68	92%	137.70	22.66	190

$: Malaysian ringgit = 44 US cents

1 actual number of baits placed
2 1000 cubes at projected price $25.00
3 1 man can place 1400 cubes @ 7.70 per man day
4 labor + chemical cost
5 percent reduction in percentage pod damaged
6 derived from 4 ÷ 5 assuming that benefits (bX) equals cost (Y)
7 derived from 6 and converted into kg/ha. Used $1.50 kg wet bean weight
8 conversion ratio of 8.4 pods to 1 kg wet bean weight

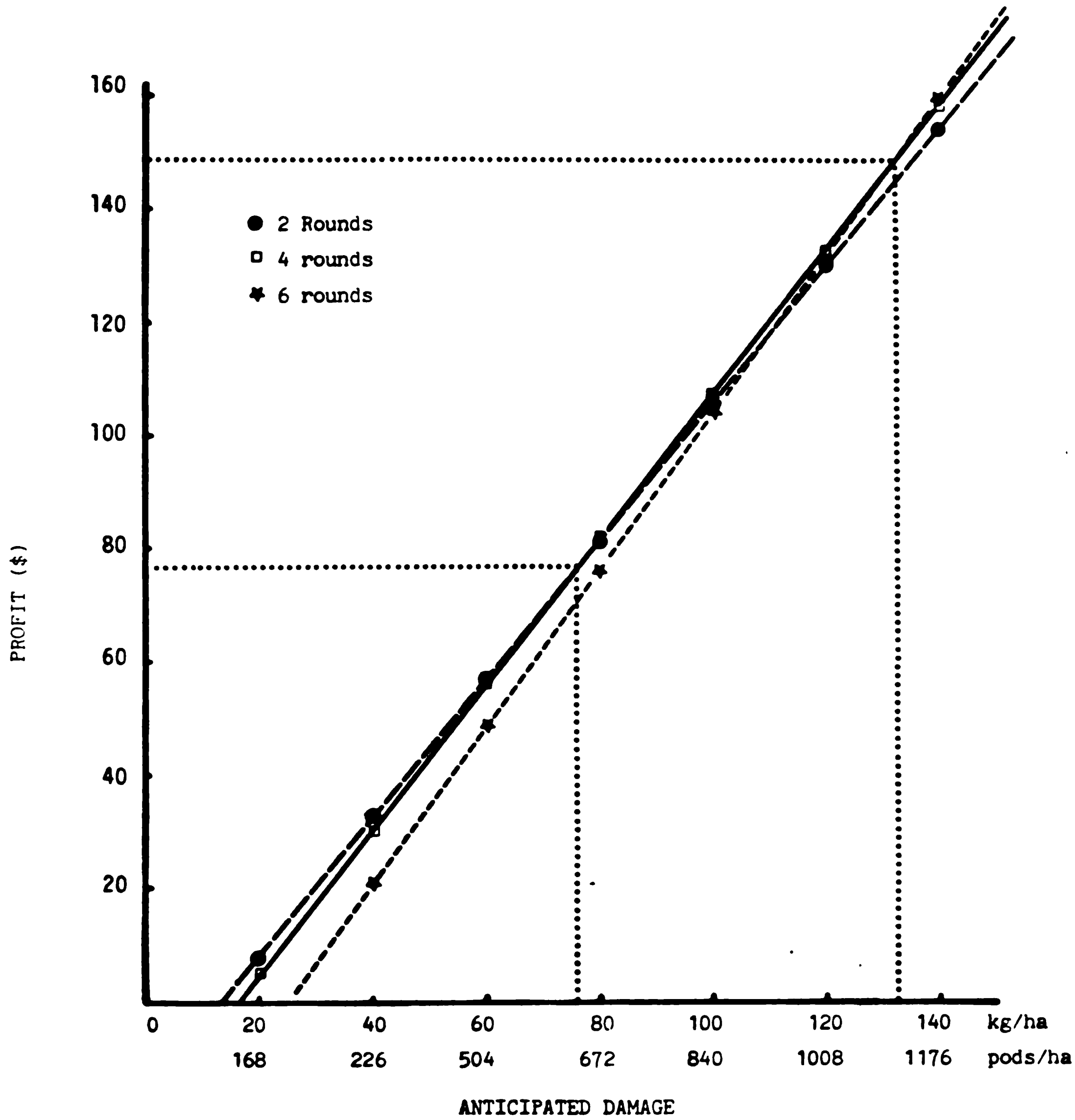

Figure 6.1. A graph of profit against anticipated damage at various baiting frequencies from three 10-acre fields at Kuala Bernam Estate, Telok Anson, West Malaysia, 1981.

break-even a control cost of $17.00 would require a highly effective control program (Table 6.4). When 400 pods are anticipated to be lost at the same price level, however, control need only be 35.7 percent effective in order to break-even with the investment made. Correspondingly, if the price of the cocoa product is at $2.00/kg, the investment made on control need only be 17.9 percent effective at the same level of anticipated damage. It is evident, the efficacy of a control program at break-even point will vary inversely with the market price of the product and the anticipated damage level (Table 6.4).

DISCUSSION

The success of a control program can be measured by 1) the reduction of the pest population or 2) the reduction of loss in yield. The latter was preferred since the outcome will be directly translated in terms of profit a farmer will make. Furthermore, the pest population density in this study (Kamarudin, 1982e) was not strongly correlated with damage.

A comparatively high percentage reduction in damaged pods was achieved with two baiting rounds and increasing the number of rounds only provided marginal increase in the percentage reduction of damaged pods. The fact that the chemical used was a single dose poison (Jackson, 1979; Dreikorn *et al*., 1979; Kamarudin and Maulud, 1981) certainly contributed to the chemical being effective. Thus with larger baiting rounds, although more animals were killed the marginal increase was not proportional to the added cost. With

Table 6.4. Percentage control required to break-even for several cocoa bean price levels and with cost of control at M$17.00.

Price per kg* wet beans (M$)	Anticipated damage			
	100 pods/ha	200 pods/ha	300 pods/ha	400 pods/ha
1.00	142.9	71.4	47.6	35.7
1.50	95.2	47.6	31.7	23.8
2.00	71.4	35.7	23.8	17.9

*1 kg = 8.4 pods

Bromethalin rodenticides, probably there was no need for repeated exposure of baits but rather only to vary the dosage at the start of the program.

Total elimination of the pest problem is difficult if not impossible. The objective of control must be to reduce the pest population to allow for economic production. Many workers have suggested that control only be implemented if the pest population or yield loss exceeds some threshold limit. In cocoa, Williams (1973) proposed a threshold level of 5 percent of total pod production. This idea of using percentage of total pod production is unrealistic, however, since the percentage of damaged pods tends to remain fairly constant even where there is considerable variation in the actual density of pods (Han and Bose, 1980). Kamarudin (1982e) also found only a weak correlation between total damage and harvestable pods. A threshold limit based on the actual numbers of pods lost would seem to be more desirable, however, since the control program would only be implemented if the problem was severe enough to justify the investment to be made.

Using Bromethalin baits where two baiting rounds are carried out, the "anticipated threshold limit" would be more than 87 pods, for four rounds it would be 123 pods and with six baiting rounds more than 190 pods in order to make a profitable investment.

In conclusion, the damage-threshold limit suitable in cocoa would best be based on factors of chemical and labor costs, the effectiveness of the control (efficacy), the price of the cocoa product and the anticipated damage to the cocoa crop if no control was instituted. An appropriate control campaign can be selected to maintain a profitable return on investment.

7.0 THE RECOVERY OF A WOOD RAT POPULATION, *RATTUS TIOMANICUS* (MILLER), IN A COCOA PLANTATION AFTER FIELD POISONING

The chemical control of rodent pests of cocoa has always been attractive in Malaysia. The method is effective, economical, and fits conveniently into the farmers' field management schedules. But as Howard (1967) has pointed out, destruction of the pests by artificial means such as poisoning or trapping only provides temporary relief. The population usually recovers quickly, he says, to levels equalling or even exceeding the densities recorded prior to control. Such population resurgences have been studied by many ecologists (Stickel, 1946; Emlen *et al*., 1948; Van Vleck, 1968; Batcheler, 1968; Rowley, 1968). The recovery phenomenon often is referred to as Errington's inverse-density law (Errington, 1945), which implies that population restoration mainly results from enhanced reproduction and survival rates.

The present study was undertaken to test this hypothesis in a Malaysian wood rat population. The work was done at Kuala Bernam Estate, near Telok Anson, West Malaysia between February 1980 until November 1981.

MATERIALS AND METHODS

Fields 35 and 36 at the Kuala Bernam Estate were selected as study sites of approximately 24 and 41 ha in area, respectively. These plots supported mature (7 - 10 years old) and bearing cocoa plants interplanted with dwarf coconut palms. The cocoa trees were planted about 3 m apart in rows flanked by coconut palms spaced about 9 m apart after every two cocoa rows. The cocoa foliage was dense with neighbors touching each other to form a continuous canopy. Old coconut fronds hung loosely and often rested on the cocoa canopy. Other field conditions have been described elsewhere (Kamarudin, 1982c).

A trapping grid of 10 x 10 trap-points spaced 6.1 m (20 ft) apart located about the center of each field was marked. A total of 200 live-traps were utilized in each field. Half were placed on the ground at the tree base, and the other half were tied above ground to a branch of the cocoa tree.

The two field areas were poisoned and the animal populations estimated (Table 7.1) by the removal method (Caughley, 1977). Animals were trapped for 3 - 5 trap-nights and animals captured were not returned to the population. The multiple-recapture technique was used later to monitor the recoveries of the populations to their initial levels. The trapping procedures, data recorded, and appraisal of census results were similar to those described earlier (Kamarudin, 1982c).

Rodent populations in the two fields essentially were anihilated by placing waxbound Bromethalin* poison baits at the 100 ppm toxicity level over the entire areas. Three baiting programs were applied before a satisfactorily low animal number was achieved. The rodent population was first poisoned at a 25 percent field saturation

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*N-methyl-2, 4-dinitro-N-(2,4,6-tribromophenyl)-6-(trifluoromethyl) benzenamine.

Table 7.1. Trapping and baiting schedules for Fields 35 and 36, Kuala Bernam Estate, Telok Anson, West Malaysia.

Treatments	Dates
1. Population estimate by CRM	February 6-9, 1980
2. Baiting at 25% field saturation	April 25, 1980
Replacement rounds	April 28, May 2 & 6, 1980
3. Population estimate by CRM	May 19-22, 1980
4. Baiting at 50% field saturation	June 23, 1980
Replacement round	June 27, 1980
5. Population estimate by CRM	July 1-4, 1980
6. Population estimate by CRM	September 23-27, 1980
7. Crown baiting	October 1, 1980
8 Multiple recapture studies	October 14, 1980 - November 29, 1981

CRM = catch and removal method

(one eight gram cube was placed at every fourth cocoa tree in each tree-row) with three replacement rounds after every third or fourth day. Only baits that were totally removed were replaced. For the second baiting, the fields were again poisoned at a 50 percent saturation (one bait every second tree in each tree-row), with one replacement round. In both instances the baits were dropped at the base of the cocoa tree. The final field poisoning was by crown baiting in each coconut tree. Each bait cube was deposited into the coconut crown, resting between the fronds.

The exact age of the trapped animals could not be determined thus they were grouped into three age-weight classes. Animals were adults if their body weight equals or greater than 90 g, subadults, if weighed between 60 and 89 g, and juveniles, if weighed less than 60 g.

RESULTS

The species composition of the recovering rodent population in both fields was 94.5 percent wood rat (*Rattus tiomanicus* Miller), 3.7 percent red-bellied squirrel (*Callosciurus notatus* Boddaert), 1.7 percent pencil-tailed mouse (*Chiropodemys gliroides* Blyth), and 0.1 percent Polynesian rat (*R. exulans* Peale). Because of the very low proportions of the other three species throughout the study periods, only the recovery of *R. tiomanicus* population was appraised in detail.

1. Population dynamics

The population of the wood rat, R. tiomanicus prior to baiting was estimated at 112.8 rats for plot 35 and 138.0 for plot 36 within each 3721 m^2 trapping grid. After the first baiting, the population in plot 35 remained at 114 animals but in plot 36 declined to 98. A further decline to 48 rats was observed after the second baiting in plot 36 and to 38 in plot 35. Estimates made two months later showed that the rat populations had increased to 68 and 79 rats respectively, in the two study plots. Poisoning by crown baiting later succeeded in reducing the rat density to 38 rats for plot 35 and to 18 rats for plot 36. These survivors then formed the nucleus of the R. tiomanicus population whose recovery to their initial levels was to be monitored.

The decimated R. tiomanicus population recovered rapidly. Plot 36 peaked at 122 rats (88.4% of the initial level) after about nine months. The pattern of recovery for the rat population in plot 35 was similar but peaked much earlier at six months and at a lower density of 89 animals (79.5% of the initial level). From then on both populations tended to decrease and fluctuate about a constant range. Neither returned permanently to their original density during the study (Figure 7.1).

2. Recruitment

Males were recruited into the population to a significantly greater extent than females ($p<0.01$) as seen on six trapping occasions in plot 35. Only one trapping favored females there. Similarly, more males were added to the population on four occasions ($p<0.01$)

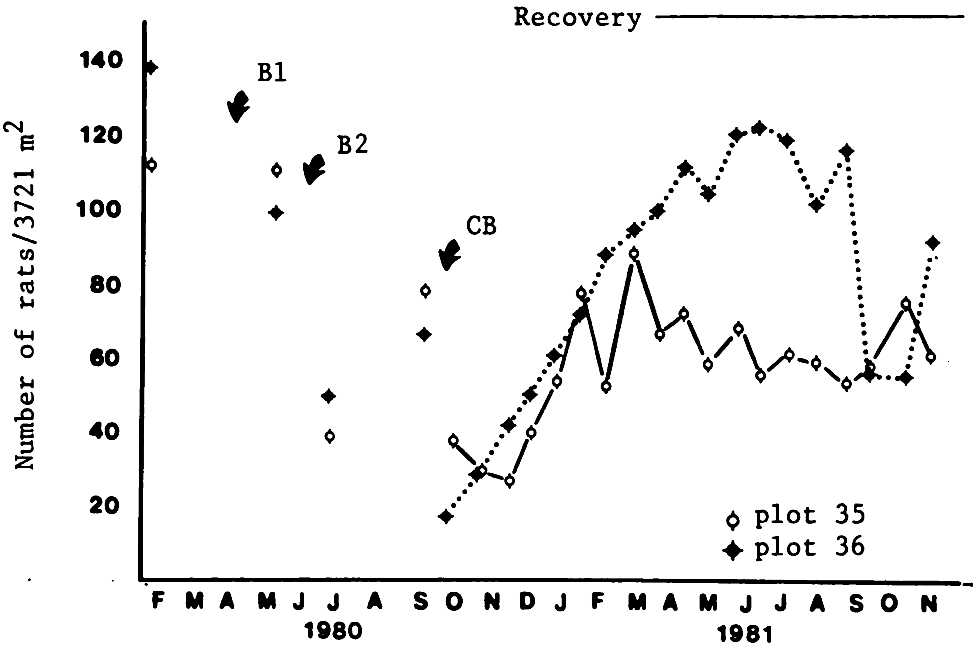

Figure 7.1. Population recovery trends of <u>Rattus tiomanicus</u> (Miller) after three field-poisonings with Bromethalin (100 ppm) for Plots 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia. (0) represents the initial population prior to baiting, (B1) the population after baiting at 25% field saturation, (B2) the population after baiting at 50% saturation, and (CB) after crown baiting (see text).

as compared to three ($p<0.05$) in favor of females for plot 36. For 10 other trapping-efforts in plot 35 and nine on plot 36, there was no significant difference (Figure 7.2).

The proportions of new (untagged) captures during each of the trapping periods according to age-weight class in the recovering R. tiomanicus population were also compared (Figure 7.3). During the early stages of the population recovery, a large proportion of adults (72 - 100%) were being caught on both plots. The addition of adults decreased in later trappings, as more juveniles and sub-adults became more prominent.

3. Reproduction

The proportion of potential breeders in R. tiomanicus population (males with scrotal testes and females with perforated vaginas) were relatively large and constant throughout the study (70 - 100%). The proportion of visibly-pregnant and lactating females varied between 25 and 59 percent of the total female population (Figure 7.4). In the original population (February 1980 census) in plot 35 and 36, 52.1 and 24.7 percent of the females were pregnant and lactating, respectively. During the trappings, five females littered in the traps, and the mean number of those young was 3.0 (range 1 - 6) rats.

4. Movements and home ranges

There were significant differences in the mean lengths of movements within a trapping period (3 trap-nights) for several age-weight classes in both study plots. In plots 35, male and female

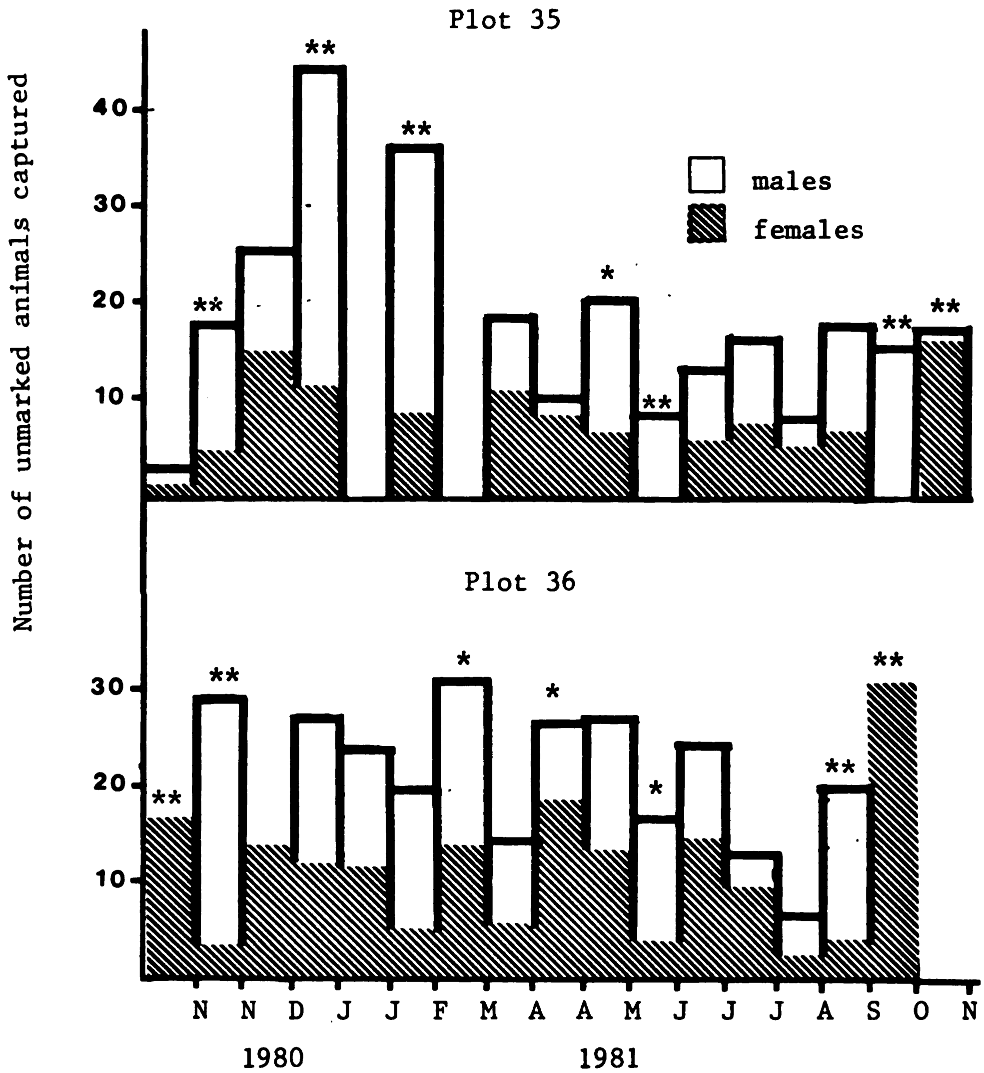

Figure 7.2. Recruitments of <u>Rattus tiomanicus</u> (Miller) into Plots 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia according to sex between November 1980 to November 1981 trapping occasions. X^2 test significant at $p < 0.01$ = **, $p < 0.05$ = *.

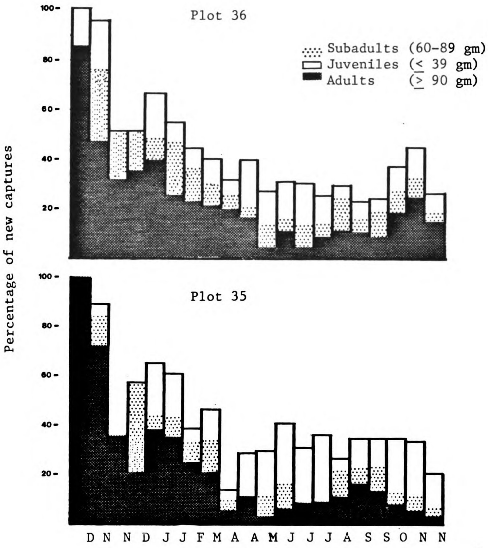

Figure 7.3. Age-weight compositions of newly captured <u>Rattus tiomanicus</u> (Miller) for Plots 35 and 36, Kuala Bernam Estate, Telok Anson, West Malaysia on consecutive trapping occasions (October 1980-November 1981).

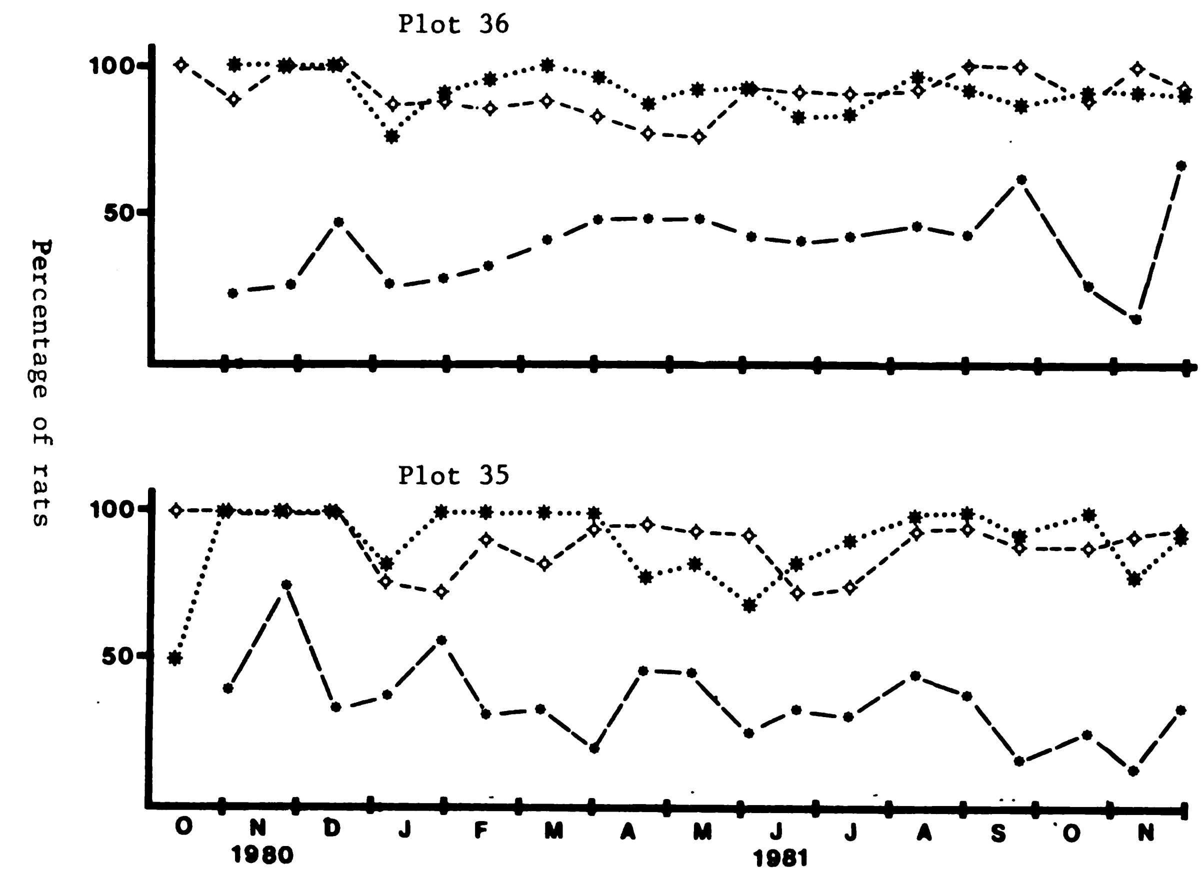

Figure 7.4. Percentages of scrotal males and females with perforated vaginas in a recovering population of Rattus tiomanicus (Miller) after field poisoning for Plots 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia between October 1980 to November 1981. (◆ = males, ✱ = females, and ● = pregnant and lactating females).

adults travelled on the average 16.33 and 11.39 m as compared to 8.92 and 16.89 m by subadult males and females, respectively. For plot 36, mean distances travelled by adult males was 10.84 m and 7.96 m by females, and subadult males moved 8.73 m and the females 9.19 m on the average. But juveniles travelled much shorter distances ($p<0.05$). Males also travelled significantly further than females ($p<0.05$). Movements by rats for all age-weight classes (males and females distances combined) in the two plots were compared, and found them to be significantly different ($p<0.05$). The maximum distance travelled by adults and subadults male and female to range between 24.34 and 43.10 m, and juvenile to range maximally between 6.10 and 12.19 m (Table 7.2).

As has been discussed elsewhere (Kamarudin, 1982c), due to the prolonged capture period, measurements of home ranges were grouped by age-weight class upon first and last capture. Home ranges computation using the A1 formula (Jennrich and Turner, 1969; Mazurkiewicz, 1969) yielded mean areas for adults as 0.38 ha for males and 0.14 ha females in plot 35, and 0.11 ha and 0.05 ha for males and females respectively, in plot 36. Rats captured first as subadults and monitored until adults yielded 0.03 ha in males, and 0.04 ha in females for plot 35 and 0.08 ha and 0.03 ha for plot 36, respectively. Animals first captured as juveniles and home range area monitored until their adult stages, showed 0.06 ha for males (no data for females) for plot 35 and 0.01 ha for males and 0.04 ha for females in plot 36 (Table 7.2).

The home ranges for both sexes were combined and compared

Table 7.2 Summary of movements within a trapping period (3 trap-nights) and home ranges data of *Rattus tiomanicus* (Miller) for Plots 35 and 36 Kuala Bernam Estate, Telok Anson, West Malaysia during October 1980-November 1981.

	Adults		Subadults		Juveniles	
	Male	Female	Male	Female	Male	Female
Mean distance ($m \pm SD$)						
- Plot 35	16.33 ± 1.39 (18)	11.39 ± 1.05 (16)	8.92 ± 1.57 (11)	16.89 ± 2.77 (11)	10.34 ± 1.72 (9)	5.77 ± 1.09 (5)
- Plot 36	10.84 ± 1.02 (18)	7.92 ± 0.52 (16)	8.73 ± 1.38 (14)	9.19 ± 1.89 (14)	5.76 ± 0.94 (7)	3.76 ± 0.36 (6)
Maximum distance travelled (m)						
- Plot 35	36.58	36.58	31.09	42.67	8.63	12.19
- Plot 36	43.10	36.58	24.34	27.25	6.10	6.10
	Adults		**Subadults**		**Juvenile-adult**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
Mean area ($ma \pm SD$)						
- Plot 35	0.38 ± 0.09 (2)	0.14 ± 0.11 (3)	0.03 (1)	0.04 (1)	0.06 (1)	?
- Plot 36	0.11 ± 0.10 (8)	0.05 ± 0.02 (8)	0.08 ± 0.07 (3)	0.03 ± 0.02 (5)	0.01 (1)	0.04 ± 0.02 (2)

( ) = sample size

between the two plots but only for adults due to the low sample size in the others. Rats in plot 35 indicated larger home ranges than those in plot 36, but they were not statistically different. A comparison between the sexes in each plot also gave non-significant results (Table 7.2).

DISCUSSION

Reinfestation by the Malaysian wood rat, R. tiomanicus after a field poisoning has been studied by Wood (1971) for oil palm plantations. He attributed the cause of reoccupation to be partly the result of reproduction and immigration from surrounding areas and vegetation. In this study, immigration evidently contributed most to the rapid recovery of the cocoa rat populations in both plots. As evidence for these conclusions, large proportions of adults were captured during the early stages of population recovery as compared to juveniles. The steep initial rate of increase in both fields also supported this notion, since mating and reproduction would involve a lag in the recovery rate. The mean distance travelled and home ranges were longer and larger in adults, too, so that their movements probably were favored. Furthermore, more males than females were being recruited indicating that any addition to the population via birth could not have taken place soon enough to support this reproduction hypothesis.

Stickel (1946) in her studies of movements of the white-footed mice (Peromyscus leucopus) into a depopulated area, reported that male and female adults and juveniles took part in the movements but that males outnumbered females two to one. Townsend (1935) also recorded trapping more males than females and attributed the tendency for large numbers of males to reinvade a depopulated area to the greater wandering ability of the males. Van Vleck (1963) reported similar findings.

After three poison treatments, the animal populations in plot 35 and 36 were reduced from 113 to 38 rats, and 138 to 18 rats respectively. The rat population in the latter area, however, recovered 88.4 percent of its initial level nine months later. Plot 35 not only peaked much earlier (six months) but attained only 79.5 percent of its initial density. Both rodent populations exhibited similar rate of recovery in the two plots and seemed to fit the logistic growth curve of Verhulst (1838) and Pearl and Reed (1920).

More accelerated rate of population recovery had been reported by Blair (1940). He noted that deer mice repopulate the area to 50 percent its original level within two weeks.

There are studies that favor reproduction as a major contributing factor to population recovery after poison-baiting. Bull (1956) reported that a large number of female rabbits survived arsenic poisoning, and suggested that animals that were lost will be compensated by these females. Gibb (1967) noted that when rabbits were held at low density they usually are in good condition and have long breeding season. He then postulated that the high reproductive potential in such an artificially-suppressed population "explain why we find it difficult to reduce the number of rabbits, the lower we get them." Rowley (1968) also indicated that breeding *in situ* causes the increase in rabbit populations after field poisoning with sodium fluoroacetate (1080).

Reproduction although important probably played a secondary role in the recovery of the rat population in this study. If birth was to be the major contributing factor, then large proportions of pregnant and lactating females should be expected in the recovering populations. This has not been shown in the two plots, and the proportions of these females were within the range of that observed prior to baiting (February 1980 census). Further, in an earlier study of a stable rat population (Kamarudin, 1982c), the proportions of the pregnant and lactating females there were comparable to this study.

Since immigration has resulted in the recovery of the rat populations in both cocoa plots, these animals must have migrated from areas of high densities bordering the fields which was not baited. As such Wood (1971) postulated that if these animals could be halted or restrained, the build up of a new population could be substantially delayed. He then suggested that field poisoning should be carried out on a larger scale.

In most rat control campaigns, measurements of success by pest-control operators had always been towards achieving rat-free areas. In cocoa, such an approach probably needs evaluation in light of the findings in this study. Perhaps some low rat density that would inflict damage well below the economic threshold level be allowed to survive after a field poisoning program. This token population then hopefully will provide pressure on immigration leading towards recovery of pest to their high initial levels. Selective rather than general reduction of the pest during baiting should be advocated to reduce only those pests that had outbalanced the economies of scale.

8.0 MANAGEMENT RECOMMENDATIONS FOR RAT CONTROL IN COCOA

Modern concepts of pest management must rely on sound ecological principles (Luckman and Metcalf, 1975) and a thorough understanding of pest species' biology. Lack of information often leads to misunderstanding the goals and tactics of a control program.

Information on the biology and ecology of the Malaysian wood rat (Rattus tiomanicus Miller), the major mammalian pest infesting cocoa has not been readily available. As a result, information on the pest and its control has been borrowed from studies of Harrison (1951, 1956a, 1957) and Wood (1969, 1971) on similar rat species inhabiting forest, grassland and oil palm habitats. Such wholesale transfer of management practices may or may not be successful.

The present findings have been gathered for the Malaysian wood rat in cocoa and management strategies have been formulated in line with the aspiration of modern control. Whether the recommendations which follow are area-specific (confined to Kuala Bernam Estate) or not is uncertain. It is hoped that they can be applied generally to the other cocoa growing areas but caution is advocated until local evaluations have been made.

Level of damage

Light to heavy damage by wood rat to cocoa in Malaysia have been reported by Wood and Liau (1978), Mainstone (1978) and Han and Bose (1980). A number of other species apart from this rat also have been recorded as pests (Conway, 1971). Kamarudin and Lee (1981) identified and differentiated the modes of cocoa pod depredation by rats, squirrels and a civet cat. Although the damage potential of the other species may sometimes be high, it is believed that wood rats are often the most important pests due to their abundance.

Han and Bose (1980) found a strong correlation between the availability of harvestable pods and the level of damage, while Vernon and Sundaram (1970) reported an interrelationship between harvesting intervals and damage to pods. In this study, though, only a weak correlation was found between these factors (Kamarudin, 1982e). In possible explanation, Strecker and Jackson (1962) and Williams (1973) found that cocoa constituted a "luxury" item in rat diets. They felt that the rodents had to "learn" to depredate on the cocoa mucilage layer. If this is true, population density may be a less-important factor in assessing the degree of damage than the percentage of "learned" individuals in the population. While this may also be the reason of the weak relationships observed between total damage and either available pods or harvesting intervals, the "learning" concept may be best considered as a plausible hypothesis awaiting further study.

Poison baiting

Managing rats so as to achieve satisfactory quality and crop production levels probably will continue to depend on chemicals even though if other approaches are more suitable. This is because chemicals are readily available and killing pests give a sense of achievement. The indiscriminate use of poison, however, can be detrimental to crop production where rats acquire a resistance to chemicals (Lam, 1980). Like any other crop, chemicals should be used in cocoa only when pests reach a threshold level of economic damage. In this context, the threshold should take into account such factors as the cost of control (chemicals and labor), the efficacy of the chemical in use, the market-price of the cocoa product, and the expected loss if no control is instituted. It was determined in the present study (Kamarudin, 1982e), that at a total control cost of M$12.53/ha, a bait efficacy of 81 percent, and a cocoa product marketed at M$1.50/kg wet bean the anticipated threshold for the area was a rodent-loss level of 87 pods/ha. If damage pods increased above this level, then poisoning was warranted.

In an earlier study (Kamarudin, 1982f), it seemed evident that immigration contributed most to the reinfestation of depopulated areas following field rat-poisoning campaigns. The relocated animals must have migrated from areas of highest density surrounding the decimated area. To counter such occurrences in oil palms, Wood (1971) recommended that larger field areas be poisoned during the baiting program. By doing so, he was able to achieve a prolonged period of low rat numbers. A similar strategy is suggested for rat control in cocoa where chemicals are used on an extensive basis.

An alternative approach would be to advocate selective field poisoning. In the present studies of R. tiomanicus, a rather complete removal (87%) on one area nevertheless allowed a rapid recovery of the pest population to its initial level (Plot 36). On another area, though, a somewhat larger percentage (34%) was allowed to survive (Plot 35), the population increase tended to level off at a much lower density than prevailed originally. It was hypothesized that the small surviving population was sufficient to establish territoriality or to exert some other behavioral pressures which thereby prevented excessive immigration into the areas. Whether some other factor (such as habitat change), also was involved to limit population restoration, however, is uncertain. Further studies on the minimum allowable density of survivors that not only will retard immigration but also sustained low damage must first be determined if this recommendation is to be adopted.

Proper bait placement is critical to ensure its maximum exposure to the pest species. Normally, baits are placed at the base of a cocoa tree. Having determined, however, that 75 percent of the R. tiomanicus population was arboreal (Kamarudin, 1982a), it is suggested that exposure would be improved where the baits are placed in the trees themselves. Bait uptake undoubtedly would be further enhanced if they were dropped into the nest sites. This easily could be achieved on the study area, since rat nests were located in the coconut crowns and were easily accessible. Placing baits directly in coconut crowns was done successfully by Valencia (1980) in Colombia for black rats.

The timing of baiting (and trapping) also could be executed in synchrony to times of greatest activity of the target pests. Since the rats are nocturnal, placement of baits in the late afternoon hours would reduce bait losses from uptake by non-target species. It would also reduce the chances of premature trap release by other organisms or by falling twigs/leaves during long exposures prior to rat activity.

Because of the importance of the oil palm industry in Malaysia, most baits available on the market today were prepared primarily for use on oil palm rats. These materials incorporate palm oil products to enhance their uptake. Such ingredients could be a deterrent to bait acceptance by cocoa rats. For them, poison baits should be compounded from ingredients which are familiar and acceptable such as coconut meat (in areas where cocoa is interplanted with coconut) and cocoa fat. Further, in manufactured bait wax frequently is used as a binding material and protection against the hot and wet weather of Malaysia. Since bait uptake and efficiency is reduced with waxbound baits (Kamarudin and Maulud, 1981), a more suitable protective material should be found.

Selection of the poison for use in rat control should take into account the bait efficacy and toxicity levels. Soh _et al_. (1982) working with a varied active ingredient levels of

Bromethalin baits reported that the effectiveness of the bait depended both on the active ingredient in the bait and the size (weight class) of the pest that needed to be reduced.

Cultural practices

Sanitary measures in cultivating cocoa have been neglected by most growers. The concept behind good sanitation is to shrink the carrying capacity of the area for rats. These practices should include the destruction of rat nests by periodic harassment. Cocoa crowns also should be periodically pruned to minimize the overlapping of limbs and limit the arboreal movements of rats. The frequent removal of loose coconut fronds which rest on cocoa canopies also would help reduce rat movements directly from their nests to the cocoa-pod food supply. In areas where coconut trees are tall (over 25 m), rats have been observed to build their nests in the canopies of the underlying cocoa trees. There the proper shaping of cocoa crowns also would minimize nest building.

Predation

Predation as a rat control method has not been fully explored for rats in cocoa. In oil palms, their potential in limiting pest populations have been reported by Lenton (1980) and Duckett (1981) for owls, and Harrison (1956b) and Lim (1974) for snakes.

Harrison (1956b) and Lenton (1980) state that some numbers of rats may be destroyed annually by snakes and owls respectively. Possible benefits from these predators should not be overlooked and indeed, Lenton's (1980) suggestion to build owl nest-boxes often should be followed. Yet, most predator-prey studies indicate that carnivores are usually ineffective in controlling their prey populations (Wodzicki, 1973; Stone and Hood, 1979).

Integrated Pest Management

Effective rat control requires measures continually to destroy rat-habitat components. Rat control should involve:

1. Periodic pruning of cocoa canopies and the removal of old coconut fronds.
2. Regular rounds of nest-site destruction.
3. Dispensing poison baits in nest-sites during poison campaigns and the synchronization of bait dispersals with periods of high pest activity.
4. Selecting baits that contain ingredients favored by the pest species and active ingredients which will insure an efficient kill rate for all pest weight classes.
5. The encouragement of owls and other non-poisonous predators (those not hazardous to field workers).

SUMMARY

Rodent pest problems in the cocoa industry are relatively new in Malaysia. This is because large-scale planting of the crop gained momentum only after the Second World War. As a result very little is known about these pests, and consequently control programs have been ineffective and sometimes non-existent. Since a knowledge of the pests' ecology is basic to sound management strategies, a study of this aspect was undertaken. Also the extent and causes of damage were appraised. A technique for making decisions regarding chemical control was developed. Population build-up as a result of field poisoning with a rodenticide was examined as related to population composition, recruitment and animal movements.

The study was conducted at Kuala Bernam Estate, a 804 ha cocoa-coconut plantation, near Telok Anson on the west coast of Peninsular Malaysia. Live-trappings were carried out for three trap-nights on marked grids at intervals of 17 - 19 days from March 1980 to November 1981. Animals trapped were ear-tagged, identified to species, weighed, sexed, the location and trapped position of animals, and reproductive status were determined before release. Population estimates and home range sizes were computed. The extent of fresh cocoa pod damage were correlated to harvested pods, harvesting intervals and pest numbers.

1. Four rodent species were tapped on the study sites which

contained 95.2 percent wood rat (Rattus tiomanicus), 3.1 percent red-bellied squirrel (Callosciurus notatus), 1.4 percent pencil-tailed mouse (Chiropodemys gliroides) and 0.4 percent Polynesian rat (Rattus exulans). Of these R. tiomanicus and C. notatus were serious depredators of cocoa, however, the latter were too few in numbers to be regarded detrimental. While C. gliroides and R. exulans were considered secondary feeders of cocoa pods.

2. Laboratory studies on R. tiomanicus indicated that linear relationship between weights and ages up to the 20th week existed. At birth males weighed 4.0 g and females weighted 3.8 g and were weaned about 28 days later at 34.0 and 30.0 g, respectively. Fifty percent of males were scrotal and half of the females had perforated vaginas by the seventh week after birth at mean weights 59.2 and 56.2 g, respectively. Fifty percent of the females became pregnant for the first time by the 24th week and weighed 88.6 g. Fifty percent adult mortality occurred at mean ages of 34 weeks for males, and 40 weeks for females with mean weights of 114.0 and 106.4 g, respectively. Mean days to first birth ranged from 121 to 265 days (mean 202.6 days about the 29th week after birth). Their mean number of young varied from 3.6 to maximum 5.8, and litter sizes ranged from 2 to 9 throughout the lifespan of the females. The days between litters varied between 22 and 155 days.

3. The estimated population of R. tiomanicus from a presumably stable population was between 151 and 216 animals/ha. The rats, however, were trap-prone and thus these densities probably were

underestimated. Survival rates between trapping periods were high (0.5 - 1.0). Recruitments were mostly via birth and equal sexes were added to the population. The proportion of potential breeders were comparatively high (65 - 100%) as was the proportion of pregnant and lactating females (5 - 57%). Mean length of movements within three trap-nights was 14.54 m for male and 10.13 m for female adults. Subadult males moved 8.78 m and females 8.69 m while juveniles ranged much shorter distances at 7.35 m and 6.41 m respectively. Home range sizes were significantly different among age classes of males but not in females. Nests were built in the coconut fronds and there was correlation between the number of nests and population densities ($r = 0.6717$, $p<0.01$).

4. Rattus tiomanicus were active between dusk and dawn, and exhibited three peak activity periods during the night (1800 - 2000, 2200 - 2400 and 0200 - 0400 hours). Adults (≥90 g) were captured most during the night. Rainfall and bright moonlight seemed to affect their activities.

5. Total damage to cocoa pods were not highly correlated to animal number, the amount of harvestable pods or harvesting intervals. If these factors, however, were to be combined, they then explained only 42 percent of the variability in total damage.

6. The principal guiding maxim for control should be that benefits must exceed or equal cost. For chemical control then, it would involve computing the cost of control (chemical and labor), the control efficacies, and the market-price of the cocoa products.

Combinations of these factors that resulted in anticipated benefits which equalled or exceeded cost should be chosen.

7. Rat population recovered rapidly after poison baiting. They reached peak levels by six and nine months. If the anihilated population were greatly reduced (to 18 rats, Plot 35), they recovered to about 88.4 percent (i.e., 122 rats) of their initial density. If a substantial number were allowed to survive (38 rats, Plot 35), however, the rate of recovery was the same, but they peaked at only 79.5 percent (i.e., 89 rats) of their initial density. Recruitments into the depopulated areas were mostly via immigration.

8. Ecological information of the target pest species must be incorporated when formulating control strategies. Other practices such as good cultural techniques and natural predation should also be integrated.

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