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Field rodent population abundance and cocoa crop loss

(Populasi roden di ladang dan kehilangan hasil koko)

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Key words: rodent, population, cocoa, rat, crop loss

Abstrak

Kajian terhadap populasi roden di kawasan koko pedalaman yang berhampiran dengan hutan menunjukkan bahawa spesies tupai *Callosciurus notatus, C. nigrovittatus, C. prevostii, C. caniceps, Sundasciurus tenuis* dan *S. lowii* ialah perosak sekali-sekala dengan kehadiran yang terhad. Binatang lain yang dijumpai termasuk kencong *(Tupaia glis)*, spesies tikus hutan (*Leopoldamys sabanus, Maxomys whiteheadi* dan *Stenomys bowersii*) yang tidak berupaya merosakkan buah koko. Kesemua binatang ini tidak hadir di kawasan tanaman koko di tepi pantai kecuali *C. notatus* yang didapati dengan bilangan terhad. Bagi murida, bilangan spesies *Chiropodomys gliroides, Rattus rattus diardii, R. exulans* dan *R. argentiventer* terhad di kedua-dua kawasan tanaman koko. Bilangan *R. tiomanicus* bukan sahaja setanding dengan bilangan tupai, bahkan bertambah dengan peningkatan umur tanaman koko di kawasan pedalaman yang berhampiran dengan hutan. Di kawasan koko di pinggir pantai, *R. tiomanicus* spesies dominan dan satu-satunya spesies tikus yang dijumpai dengan banyaknya. Aras kerosakan buah yang lebih tinggi berserta perubahan populasi yang lebih besar di kawasan koko yang berhampiran dengan hutan adalah disebabkan oleh tupai. Corak perubahan populasi yang perlahan dengan bilangan tikus pembiak yang besar serta kadar rekruitmen yang rendah menunjukkan bahawa kelahiran lebih penting daripada imigrasi. Korelasi berat badan dengan ukuran badan dan kepala serta ukuran ekor mempunyai variasi yang lebih kecil dan lebih tepat berbanding dengan korelasi berat badan dengan ukuran tapak kaki belakang dan ukuran telinga tikus.

Abstract

Field rodent population studies in inland cocoa areas adjacent to forest show that the squirrel species *Callosciurus notatus, C. nigrovittatus, C. prevostii, C. caniceps, Sundasciurus tenuis* and *S. lowii* are occasional pests and their presence may be limited. Others present were treeshrew *(Tupaia glis)* and rat species (*Leopoldamys sabanus, Maxomys whiteheadi* and *Stenomys bowersii*), forest species that are unable to damage cocoa pods. These animals were absent in cocoa plantings established on the coastal plains except for *C. notatus* which was noted in limited numbers. For the murids, limited numbers of *Chiropodomys gliroides, Rattus rattus diardii, R. exulans* and *R. argentiventer* were noted in both areas. The abundance of *R. tiomanicus* is comparable to that of squirrels and increases with the age of cocoa plantings in inland areas adjacent to the forest. In coastal cocoa plantings, it is the dominant and sole rat species present in

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abundance. A higher level of pod damage with a wider fluctuation in animal population noted in cocoa areas close to forest is attributed to squirrels. The slow and gradual population fluctuation pattern with large numbers of potential breeding rats and low rates of recruitment indicated that birth was more important than immigration. Correlation of body weight to head and body length, and to tail length of the rat had less variation with better accuracy as compared to hind foot and ear length.

Introduction

Population dynamics to monitor population trends, gather demographic data on survival rates, recruitment and reproduction are matters related to animal densities that contribute to species attaining pest status. The population of a species may be measured as the number of animals per unit area or as the density of one population relative to that of another (Krebs 1989). Most studies on rodents in cocoa plantings in Peninsular Malaysia have been on coastal areas (Han and Bose 1980; Kamarudin 1982; Lee 1982; Kamarudin and Lee 1989) and *Rattus tiomanicus* is found to be the predominant and abundant species. Most rat control programmes in estates were undertaken based on severe cocoa pod damage (indirect assessment of high rat infestation) to circumvent losses. Where studies were undertaken to determine the effectiveness of control programmes (Lee and Arikiah 1984; Lee and Kamarudin 1986), limited samplings of rats with marking and recapture were undertaken to estimate the initial rat population using Peterson's and Bailey's methods; and continuous rat removal was undertaken at post-poisoning to estimate the remaining rat population using Hayne's method. Rats noted were of different sizes, ages and body weights ranging from 38 g to over 160 g.

Attempts to understand the population dynamics of rats in cocoa have been made by animal capture-mark-recapture studies in a cocoa-coconut (dwarf variety) planting. Kamarudin (1992) undertook the study for 18 months sampling a 0.74 ha field plot at intervals of 17–19 days and analysed the data with the Jolly-Seber method. His studies were affected after 12 months by a rat baiting programme in surrounding cocoa fields as the population declined suddenly due to animal emigration into the depopulated surrounding areas. The rat population in his study area did not recover.

In the light of the above, the paucity of information and the increase cocoa plantings in inland areas, the need is not only for information on population dynamics of animal pest species in coastal cocoa plantings but also that in inland areas. This paper presents findings on the population dynamics of rodent species in inland and coastal cocoa plantings in relation to the extent of damage and crop loss encountered. The population structure would contribute towards understanding the pest problem and the species encountered in different surroundings, thereby facilitating, planning research, management and control strategies.

Materials and methods

Trappings of animals were undertaken monthly for 36 months at a plot in MARDI Hilir Perak (representing a Western Peninsular coastal area) and another plot in Jerangau (representing an inland area adjacent to the jungle). Both plots were about 5 ha and had 9-year-old cocoa trees (planting distances of 3.0 m x 3.0 m) that were fruiting and 3–5 m tall. The former plot had cocoa interplanted with coconuts (Malayan Tall variety at 18 m x 18 m) while the latter was monoculture cocoa.

Live traps were placed in a square grid system covering 10 x 10 co-ordinates spaced at six-tree intervals with fresh coconut meat (2 cm x 2 cm) as baits. A plot size of 1.82 ha was covered by the trapping grid. Two traps were placed at each co-ordinate; one within the tree canopy on a branch or jorquette while the other was at ground level within the tree base. The procedure was similar to that described by Lee (1995). Traps were left in position, undisturbed until inspected daily in the early morning. Each trapping period was 3 consecutive nights.

Animals caught were weighed to the nearest gram using a Pesola scale, sexed and identified to the species level according to the characteristics described by Harrison (1965). Trap location and position of trapped animals (on the ground or on tree top), reproductive condition (male: testis scrotal or abdominal; female: vagina perforated or unperforated, visibly pregnant or lactating) and the number of births in trap (if any) were recorded.

All new *R. tiomanicus* caught had the following measurements made:

- tail length: from the anus to the tip of the true tail, held in line with the body laid on its back;
- hind foot length: from the posterior margin of the heel in a straight line to the tip of the longest toe (middle digit), excluding the claw;
- head and body length: from the tip of the nose to the anus, with the body laid on its back, fully extended but not stretched, and
- ear length: from the inside of the notch of the base to the tip of the ear.

They were then ear-tagged with numbered Monel-metal No.1 fingerling tags, and subsequently recaptured animals had the above parameters taken. Tagging was also undertaken for all rodent species. All marked animals were released at the point of capture and precautions were taken to ensure that the released animals did not immediately run into the traps.

Analysis of data collected was undertaken with computer programmes developed by Krebs (1988) to determine population estimates and demographic information. In the analysis, animals were grouped into age-weight classes of adults, sub-adults and juveniles (inclusive of young) as described by Lee (1995). The programme computes the population estimate from mark and recapture data using Jolly's stochastic model (Jolly 1965). This model is an improvement over other census and population models (Caughley 1977) by defining the probabilities for which certain events occur.

Results

Animal species

A total of 484 animals comprising 11 rodent and one treeshrew species were recorded and released in the Jerangau plot *(Table 1)* throughout the 36-month study period. The squirrel species caught were *Callosciurus notatus*, *C. nigrovittatus*, *C. caniceps*, *C. prevostii*, *Sundasciurus tenuis* and *S. lowii*. The murid species caught were *R. tiomanicus*, *Leopoldamys sabanus*, *Maxomys whiteheadi*, *Stenomys bowersii* and *Chiropodomys gliroides*. The treeshrew species was *Tupaia glis*. About 25% of all the animals caught were squirrels while 60% were the wood rat *R. tiomanicus*. For all species (except *C. gliroides* with 3 caught), almost equal number of males and females were caught (ratio of male to female ranged from 0.8 to 1).

The majority of the squirrels were trapped within the tree canopy (for *C. notatus and C. nigrovittatus*; χ^2 = 25 and 24.4, D.F. = 1, both p <0.001; *for S. tenuis, S. lowii, C. caniceps and C. prevostii*; χ^2 = 6.4, 7.0, 5.34 and 4.0, D.F. = 1, p = 0.009, 0.120, 0.020 and 0.046), with very few being caught on the ground. For the murids, a large number of *L. sabanus* (χ^2 = 21.56, D.F. = 1, p <0.001) and all *M. whiteheadi* were trapped at ground level. In contrast, all *C. gliroides* were caught within the tree canopy. A large number of *R. tiomanicus* (119 animals) were caught within the tree canopy. However, significantly more animals (173) were trapped on the ground (χ^2 = 9.99, D.F. = 1, p = 0.003). Small numbers of *S. bowersii* and *T. glis* were caught within the tree canopy and on the ground.

Table 1. Animal species, sex, body weight and location trapped in Jerangau and Hilir Perak cocoa plantings from Jan. 1991 to Dec. 1993

Animal species	Sex		No. of animals trapped			Body weight (g)
	M	F	Total	Top*	Ground*	
Jerangau						
Callosciurus notatus	23	26	49	42	7	100.0–300.0
Callosciurus nigrovittatus	22	20	42	37	5	102.0–280.0
Callosciurus caniceps	6	6	12	10	2	229.0–280.0
Callosciurus prevostii	2	2	4	4	0	250.0–350.0
Sundasciurus tenuis	4	6	10	9	1	50.0–91.0
Sundasciurus lowii	3	4	7	7	0	60.0–87.0
Rattus tiomanicus	160	132	292	119	173	37.0–151.0
Leopoldamys sabanus	14	15	29	2	27	53.0–417.0
Maxomys whiteheadi	7	6	13	0	13	33.0–78.0
Stenomys bowersii	5	6	11	4	7	46.0–175.0
Chiropodomys gliroides	1	2	3	3	0	23.0–30.5
Tupaia glis	8	10	18	9	9	112.0–159.0
Total			484			
Hilir Perak						
Callosciurus notatus	3	4	7	5	2	150.0–300.0
Rattus tiomanicus	241	304	545	260	285	37.0–165.0
Rattus exulans	2	3	5	2	3	30.0–65.0
Total			557			

*site of trap

The squirrels ranged in body weight from 100 g for sub-adults of *C. notatus* to 350 g for *C. prevostii* adults. *S. tenuis* and *S. lowii* had body weights ranging from 50 g to 91 g while *R. tiomanicus* weighed 37–151 g. The heaviest rat species was *L. sabanus* (417 g).

In Hilir Perak, over the same time interval, a total of 557 animals comprising three rodent species were trapped in the cocoa planting study plot *(Table 1).* About 98% of the animals caught were the wood rats *(R. tiomanicus)* and squirrels (*C. notatus* accounted for 1.25%). A large number of *R. tiomanicus* (260 animals) were caught within the tree canopy but this was not significantly (x^2 = 1.146, D.F. = 1, p = 0.25) less than that (285 animals) caught on the ground. The rats weighed 37–165 g. Five squirrels were trapped on the ground and they weighed 150–300 g. *R. exulans* weighed 30–65 g.

Monthly animal abundance

The number of animals caught varied on each trapping occasion *(Table 2)*. The mean monthly number of animals caught in Jerangau was 25 ± 12 (range 6–49) while in Hilir Perak it was 43 ± 15 (range 12–76). The number of marked animals noted on each trapping occasion could be as low as one to a high of 27 (mean 12 ± 8) in Jerangau, and 4–156 (mean 28 ± 14) in Hilir Perak. The number of new animals caught, marked and released ranged from 4 to 31 (mean 14 ± 7) in Jerangau and 7 to 27 (mean 16 ± 6) in Hilir Perak.

The number and incidence of squirrels caught were rather low and erratic. There were occasions when no squirrels were caught and the largest number of new squirrels caught at a sampling period was 13 for Jerangau (mean 4 ± 4). The number of squirrels recaptured ranged from none to 15 (mean 4 ± 4). In Hilir Perak, squirrels were occasionally caught and in all instances it

Table 2. Mean ± SD monthly number of rodents trapped and released in the study plot from Jan. 1991 to Dec. 1993

Parameter	Jerangau	Hilir Perak
Total animals	25 ± 12 (6–49)	43 ± 15 (12–76)
Marked animals	12 ± 8 (1–27)	28 ± 14 (4–56)
New animals	14 ± 7 (4–31)	16 ± 6 (7–27)
Marked *R. tiomanicus*	9 ± 6 (2–24)	28 ± 14 (4–56)
New *R. tiomanicus*	9 ± 5 (1–20)	16 ± 6 (7–26)
Marked squirrels	4 ± 4 (0–15)	Nil
New squirrels	4 ± 4 (0–13)	0.2 ± 0.4 (0–1)

Values in brackets indicate range

was only one animal (mean 0.2 ± 0.4). Out of a total of seven squirrels marked and released in the study plot, none were ever recaptured. An occasional *C. gliroides* was caught in Jerangau (three animals throughout the 36 months) and none were ever recaptured.

The animal population estimated by Jolly's method for the 1.82 ha trapping grid in Jerangau *(Figure 1)* fluctuated between 53 and 430 (29–236 animals/ha) while in MARDI Hilir Perak *(Figure 1)* it was from 73 to 311 (40–171 animals/ha). Squirrels made up about 27% (range 0–65%, *Figure 2*) of the animal population estimated in Jerangau, whereas in MARDI Hilir Perak, with the exception of an occasional squirrel and *R. exulans* caught, the estimated animal population represents that of the wood rat. In Jerangau, the number of new squirrels recruited averaged 4 ± 4 (range 0–13, *Figure 2*) while that of rats averaged 9 ± 5 (range 1–20) in contrast to 16 ± 6 (range 7–27) for Hilir Perak *(Table 2).* The rat (excluding the occasional *C. gliroides*) population estimated in Jerangau was 24–180 (14–100 animals/ha).

Crop loss and animal abundance

Monthly pod losses noted at each animal population sampling and marking period ranged from 91 to 480 pods for Jerangau and 95 to 375 pods for Hilir Perak *(Figure 1).* The damaged pods at Jerangau were characteristic of that due to rats and squirrels as described by Kamarudin and Lee (1981). Similarly, the pods in Hilir Perak were all damaged by rats except a few with symptoms of squirrel attack. Fluctuation in crop loss for both the fields corresponded to the estimated animal population except for a few occasions. Regressional analysis of pod loss *(x)* to the animal population estimate *(y)* for the two fields *(Figure 3)* gave the equations as :

$y_{\text{rod popn}} = 8.39\ (\pm\ 33.64) + 0.93x_{\text{pod loss}}$ ($r^2 = 0.54$; $r = 0.73$) for Jerangau rodent population and

$y_{\text{rat popn}} = 22.88\ (\pm\ 16.45) + 0.31x_{\text{pod loss}}$ ($r^2 = 0.35$; $r = 0.59$) for Jerangau rat population.

For MARDI Hilir Perak, the equation was:

$y_{\text{rat popn}} = -0.21\ (\pm\ 16.43) + 0.77x_{\text{pod loss}}$ ($r^2 = 0.74$; $r = 0.86$)

The correlations were highly significant ($r = 0.73, 0.59, 0.86$, $n = 35$, $p < 0.001$). In the analysis, the Jerangau rodent population accounted for 0.93 pod damage/animal (for rats and squirrels) which was three times higher than that of the rat population which had 0.31 pod damage/animal. In Hilir Perak, the rat population accounted for 0.77 pod damage/animal since no squirrel population estimate could be made from only one new animal caught on several occasions.

Other population parameters

New additions to the Jerangau field population per trapping period ranged from 4 to 34 animals *(Figure 4)* and constituted about 2.3–25.0% of the total population. Recruitment into the population did not favour any particular sex. Age-weight class analysis showed variations in the

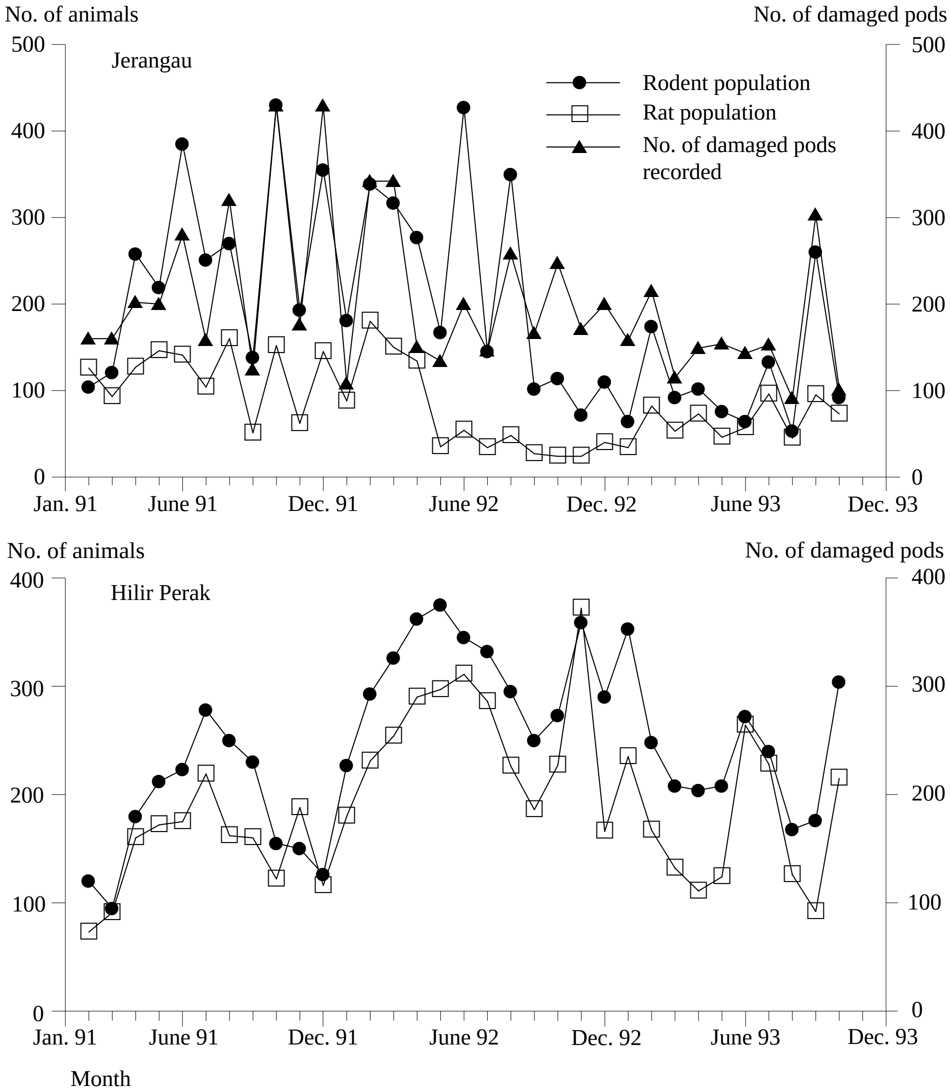


Figure 1. Estimated animal population for Jerangau and Hilir Perak for 36 months in the 1.82 ha trapping grid

recruitment of juveniles, adults and sub-adults. More juveniles and sub-adults were recruited than adults. The number of new juveniles joining the population exhibited small cyclical trends. There were occasions when no new adults were noted.

In Hilir Perak, new additions to the population at each trapping period ranged from 4 to 25 *(Figure 5)* and constituted about 2–28% of the estimated animal population. On all sampling occasions, both males and females were recruited with instances of more males and more females. Age-weight composition of new recruits showed variations in the proportion of adults, sub-adults and juveniles. There were more adults in most of the trapping periods and almost similar numbers of sub-adults and juveniles. Small cyclical trends were noted in the number of juveniles joining the population.

In both areas, there were a large percentage of potential breeders in the population *(Figure 6).* The proportion of

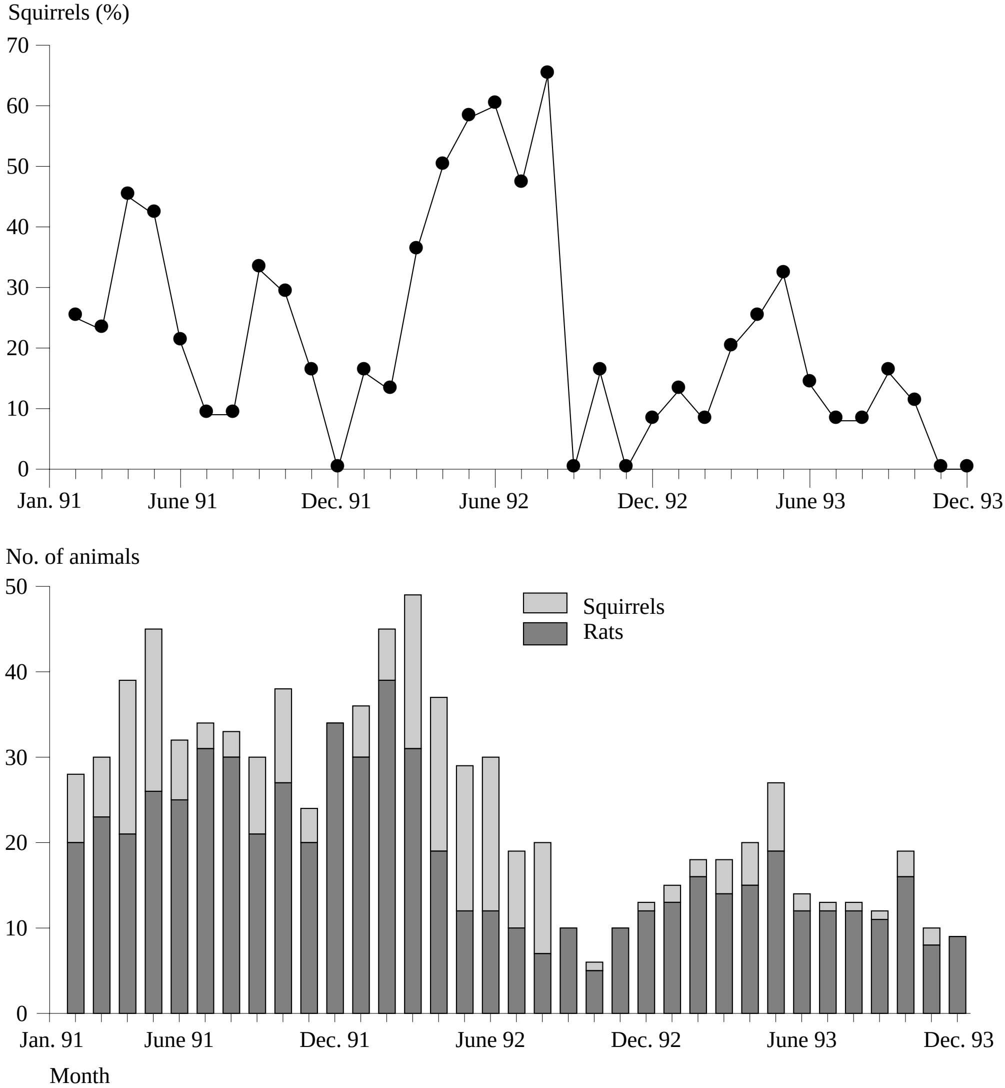


Figure 2. Monthly proportion of squirrel in the estimated animal population and recruitment of rats and squirrels in Jerangau for 36 months

males with scrotal testis was 33–90% in Jerangau and 52–91% in Hilir Perak. The females with perforated vagina ranged from 47% to 90% for Jerangau and 57% to 95% for Hilir Perak. The visibly pregnant and lactating females formed 5–60% of the total female population in Jerangau and 29–68% in Hilir Perak.

Measurements of tail, hind foot, head and body length, and ear in relation to body weight of all the new-caught rats (both males and females had similar values) showed continuous distribution and overlapping in values (*Figure 7).* There was a trend of increasing length measurement with an increase in body weight. The relationship between the parameters and body weight of the rats appeared to be more quadratic than linear. Regressional analysis gave equations as:

for tail,

$y_{mm} = 80.27 \pm 2.69 + 0.93x - 0.003x^2$

($r^2 = 0.65$, C.V. = 7.30)

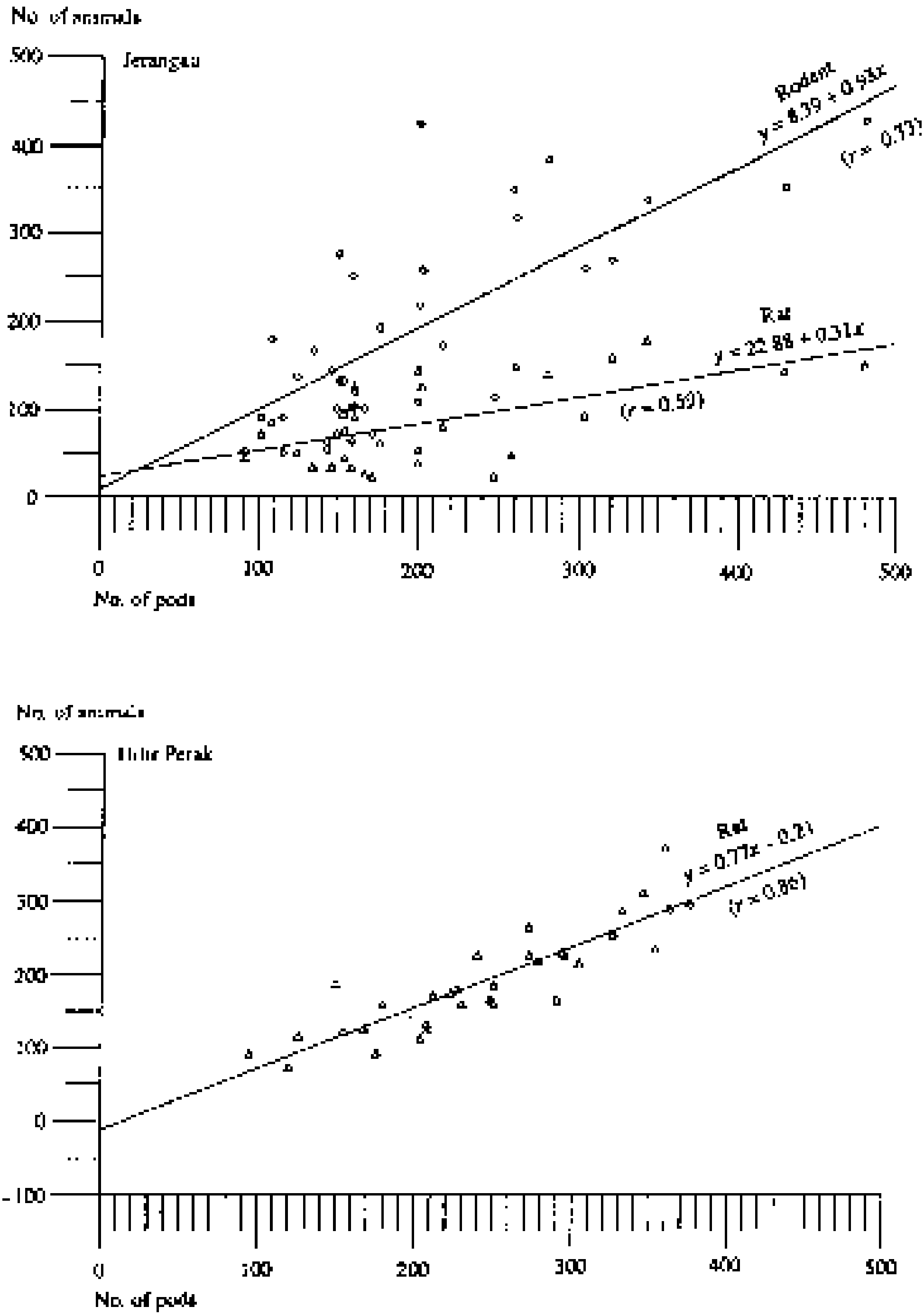


Figure 3. Realationship of pod loss to animal population estimate for Jerangau and Hilir Perak over 36 months

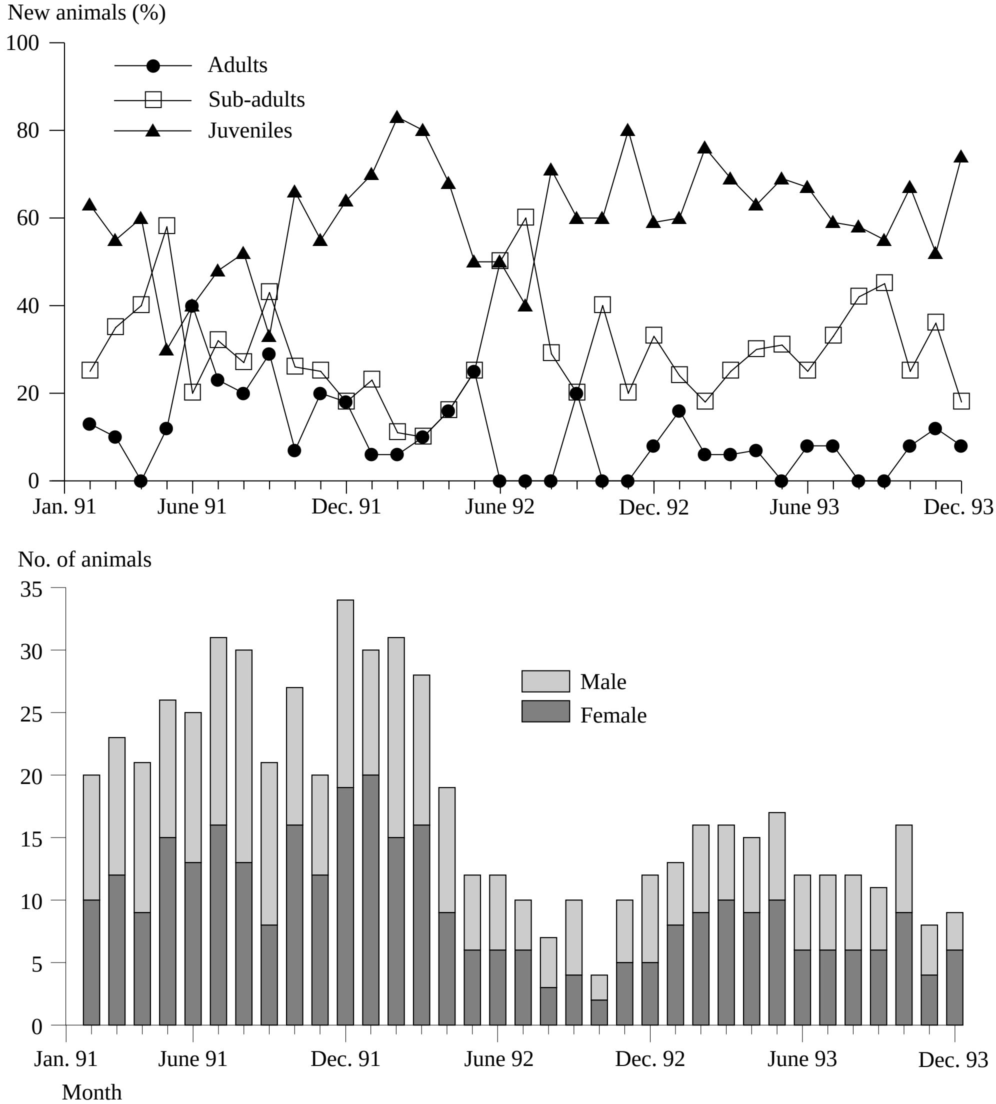


Figure 4. Animal recruitment at each trapping period in Jerangau for 36 months by age-weight class and sex

linearly $y_{mm} = 102.2 \pm 1.23 + 0.44x$
($r^2 = 0.61$, C.V. = 7.63)
for hind foot,
$y_{mm} = 17.67 \pm 0.50 + 0.10x - 0.0003x^2$
($r^2 = 0.31$, C.V. = 8.28)
linearly $y_{mm} = 20.12 \pm 0.22 + 0.03x$
($r^2 = 0.29$, C.V. = 8.41)
for head & body,
$y_{mm} = 68.68 \pm 2.50 + 1.04x - 0.003x^2$
($r^2 = 0.71$, C.V. = 7.03)

linearly $y_{mm} = 94.14 \pm 1.17 + 0.47x$
($r^2 = 0.67$, C.V. = 7.50)
for ear,
$Y_{mm} = 15.86 \pm 0.41 + 0.07x - 0.0002x^2$
($r^2 = 0.21$, C.V. = 7.94)
linearly $y_{mm} = 17.97 \pm 0.18 + 0.02x$
($r^2 = 0.19$, C.V. = 8.07)

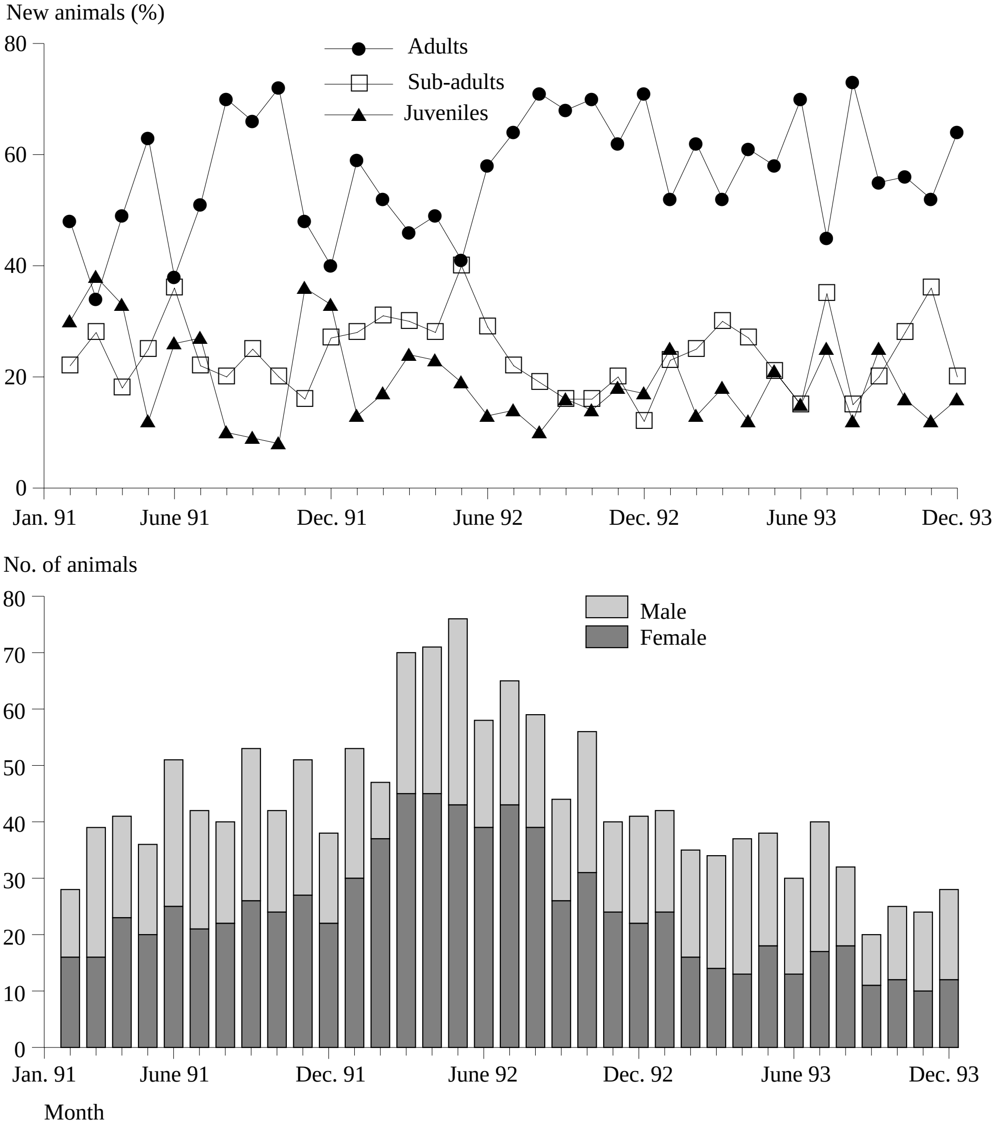


Figure 5. Animal recruitment at each trapping period in Hilir Perak for 36 months by age-weight class and sex

where x is the body weight and y for the respective body measurements.

The r^2 values for the ear (0.19–0.21) and hind foot (0.29–0.31) measurements in relation to the body weight were rather low and the C.V. values were high (7.94–8.41), indicating very poor correlation especially when ear and hind foot measurements ranged from 10 mm to 25 mm and 15 mm to 27 mm respectively. In contrast, the r^2 values for head and body (0.67–0.71) as well as tail (0.61–0.65) measurements in relation to body weight, with C.V. values of 7.03–7.30 (similar to that of the ear and hind foot), were low compared to the dimensional measurements (head and body: 70–180 mm, tail: 80–190 mm, ear: 10–25 mm and hind foot: 15–27 mm), indicating a better and more precise relationship.

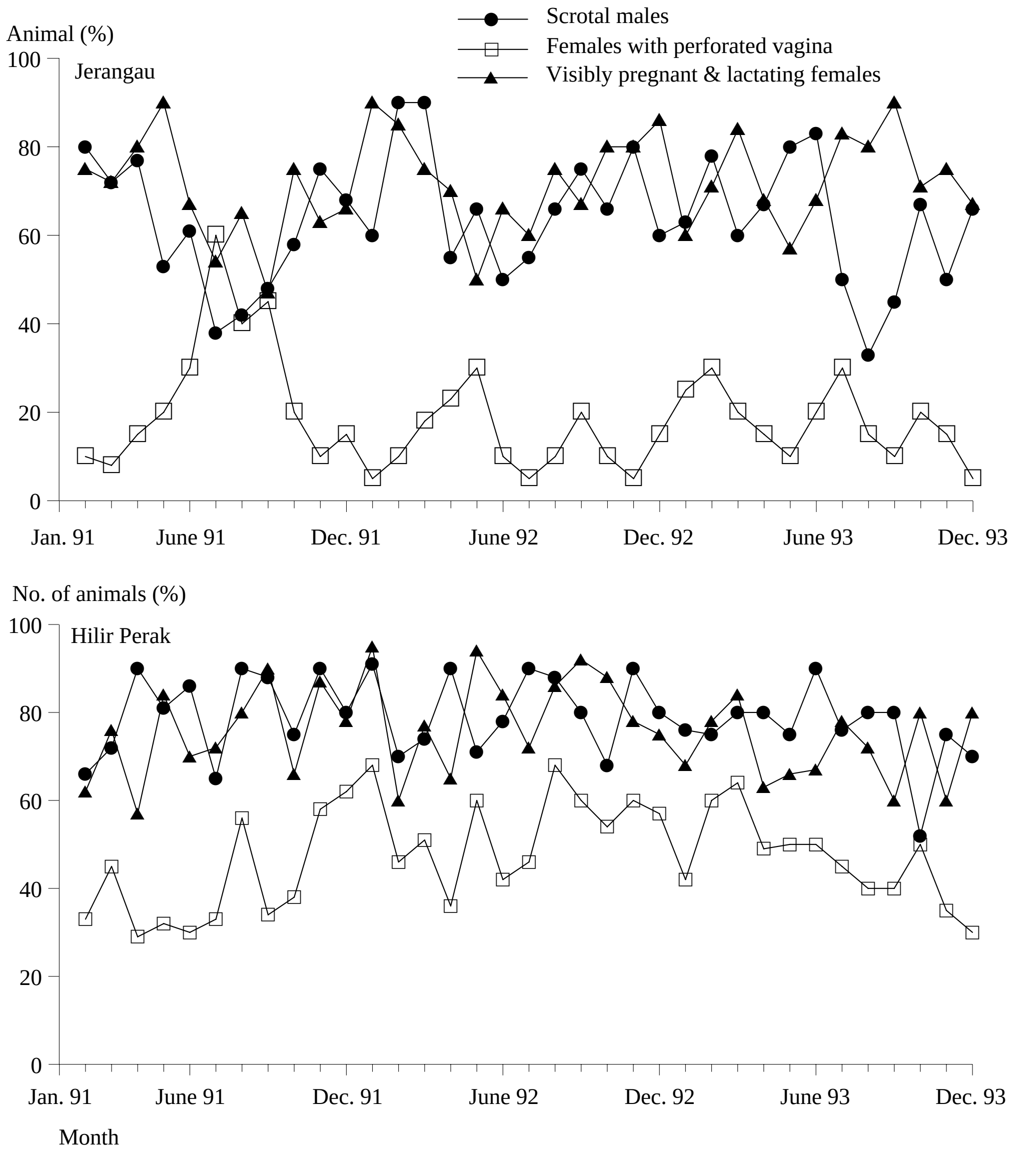


Figure 6. Proportion of scrotal males, females with perforated vagina, and visibly pregnant and lactating females in Jerangau and Hilir Perak fields

Discussion

The method of trapping studies conformed to that described by Flowerdew (1976). He indicated that trapping grid for small mammal population studies should be as compact as possible (square or circular) with at least two traps at each trapping point. Furthermore, the spacing between trapping points should not be greater than 15 m and the trapping or sampling sessions should be undertaken once a month.

Many methods are available for analysing the capture-mark-recapture data, including ‘method A’, Petersen’s method, Bailey‘s Triple Catch, Schnabel’s and Jolly’s method (Southwood 1978). However, Jolly’s method is preferred because the above field studies on open rat populations are more biologically realistic situations where the

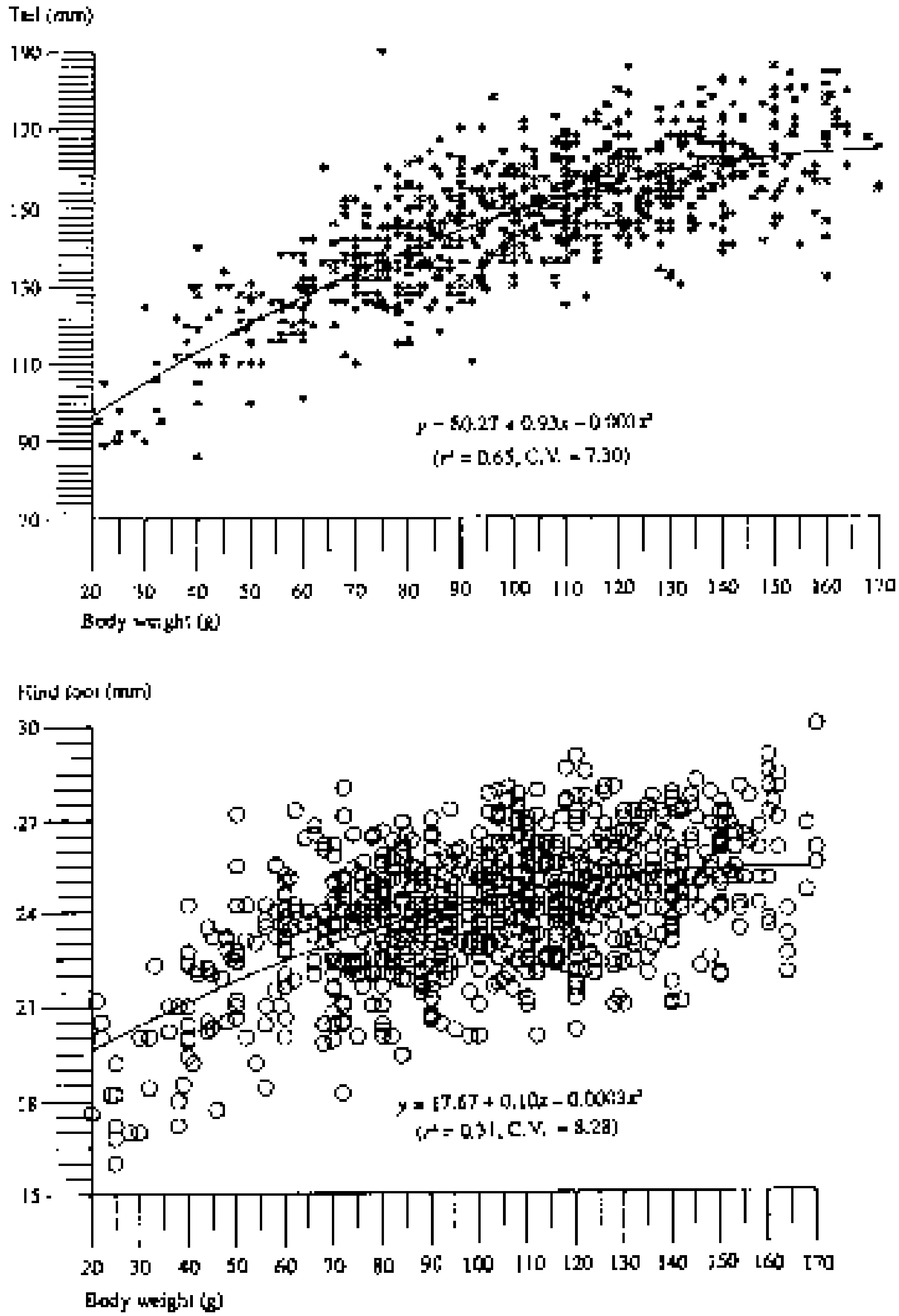
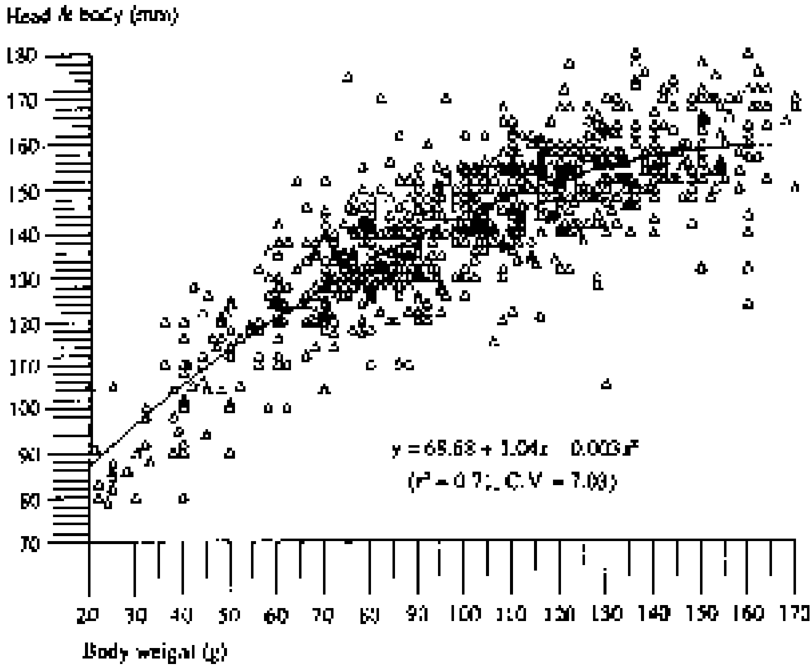
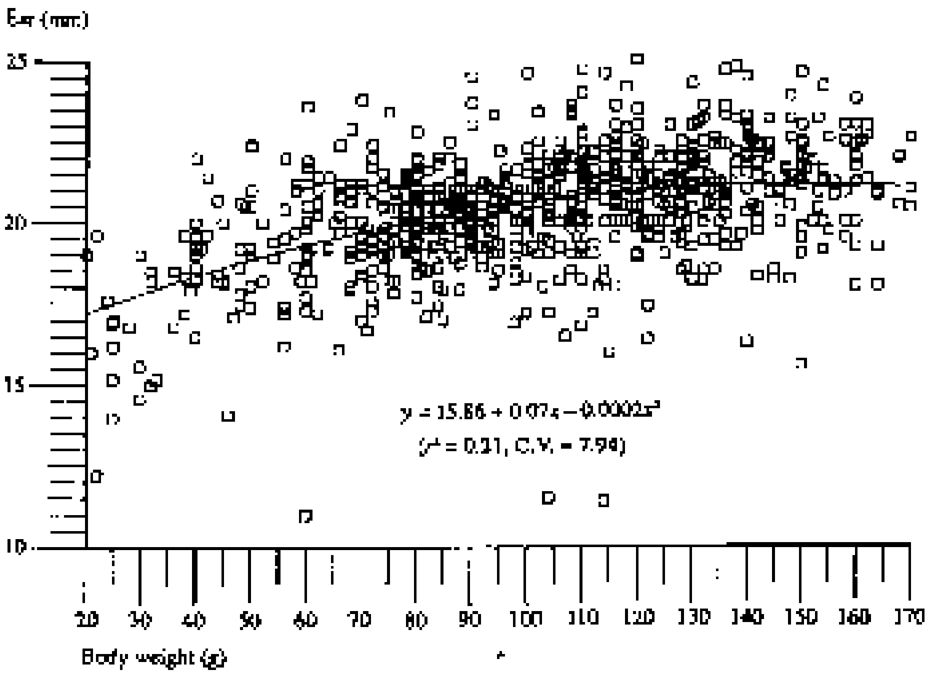


Figure 7. Relationship of body-weight of ***Rattus tiomanicus*** *to tail length, hind foot length, head and body length as well as ear length*



Head & body (mm)
180
170
160
150
140
130
120
110
100
90
80
70
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
Body weight (g)
y = 65.68 + 1.04x 0.003x²



Ear (mm)
25
20
15
10
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
Body weight (g)
y = 15.86 + 0.07x − 0.0002x²
(r² = 0.21, C.V. = 7.94)

populations are constantly changing in age and size with births, deaths, immigration and emigration. The method also estimates variances that are related to the population estimate. It is usually reliable when 9% or more of the population are sampled and the survival rate is not less than half (0.5), which is usually the case for work on mammals with a large number of sampling occasions; thus it remains probably the most useful method (Southwood 1978). Furthermore, the sampling time is negligible in relation to the intervals between sampling.

The difference in animal species noted in Jerangau and Hilir Perak cocoa plantings is apparently due to their surroundings. In Jerangau, the squirrel species *(C. caniceps, C. prevostii, C. nigrovittatus, S. lowii and S. tenuis)*, treeshrew *(T. glis)* and rat species *(L. sabanus, M. whiteheadi and S. bowersii)* are forest-associated animals (Medway 1983). In contrast, *R. tiomanicus* and *R. exulans*, both also known as field rats (Harrison and Quah 1962), are found in agricultural settlements. *C. notatus* was present in both areas. Other studies (Han and Bose 1980; Soh et al. 1983; Ho 1986) also showed no presence of *C. caniceps* in the Peninsular coastal cocoa areas. Over a decade of studies (1969–1979) in oil palm fields of Central Johore, only a few *C. notatus* were noted to be present (Wood 1984). Large numbers of animal species in cocoa areas near jungle and small numbers in cocoa areas within established agricultural settlements in Sabah have also been noted (Conway 1971; Evison and Evison 1980). Similar differences in species composition between oil palm plantings and the jungle have also been noted (Wood and Liau 1978).

Temporal distribution in activity among the species was noted. Most of the squirrel species and *C. gliroides* were trapped within the tree canopy although they can be caught on the ground. Within the cocoa-coconut fields, these animals occupy the upper storey of the coconut crown and feed upon the food resource within the lower cocoa canopy (Lee 1982; Kamarudin 1984). Similarly, most of the *R. tiomanicus* were caught on the ground although a large number can be caught within the tree canopy. This species has also been recorded nesting within the tree canopy (Kamarudin 1984), causing fruit damage and sheltering in the crown of tall oil palms (Wood 1984). The rat species *L. sabanus, M. whiteheadi* and *S. bowersii* are ground dwellers (Medway 1983).

The animal population in Hilir Perak (73–311 animals/ha) showed less variation than that in Jerangau (53–430 animals/ha). Excluding the squirrels, the rat population estimate for Jerangau varied between 24 and 160 indicating that the larger and wider variation in the population estimate is attributable to squirrels. In oil palms, the population of *R. tiomanicus* varied from 183 to 537 animals/ha over a decade study period (Wood 1984). Others (Wood and Liau 1978; Lee and Arikiah 1984) have also obtained different population estimates in cocoa and oil palm areas inferring differences may be attributable to their field carrying capacities.

The population estimate for both fields had slow and gradual fluctuations with cyclical patterns. In both areas, there was no evidence of a population trend where a large increase was followed by a decline (trough). This was similarly observed by Kamarudin (1982) despite his studies were interrupted by an accidental rat poisoning campaign of the estate. In oil palm areas, small cyclical pattern every 4–6 months has been reported by Wood (1984), and within this fluctuating pattern the population estimate can increase from a low (183/ha) to plateau (537/ha) some 3–4 years later (Wood 1984). He reported population troughs could occur after 6–7 years but yet felt that there was still no evidence of a cycle of regular length nor any predictive value to the observed pattern.

The slow and gradual population pattern observed in both plots is attributable to the highly uniform climate without any marked seasonal factors for the perennial nature of the cocoa crop. This is similarly the case for oil palms (Wood 1984). This environment would facilitate continuous breeding throughout the year (Harrison 1956) and is substantiated by the addition of juveniles throughout the study duration in both plots. In contrast, Lam (1983) noted that *R. argentiventer* could breed all year round in the laboratory but in rice fields breeding was markedly seasonal in tandem with the annual rice cropping pattern. Seasonal factors have been identified to affect the reproduction and abundance of the Californian vole (Krebs 1966; Lidicker 1973) and neotropical small mammals in Venezuela (O'Connell 1989). All these differences point to the adaptation of species to successfully exploit its environment to its advantage.

The population showed a slight 'buffering' effect of competing species for Jerangau plantings due to its close proximity to forests and this effect is reduced, culminating with an abundance and dominance of the wood rat in Hilir Perak plantings. The extreme case of minimum 'buffering' effect is seen in oil palms where higher population estimates were recorded (Wood 1984). The other extreme is the maximum 'buffering' effect of competing species with none of dominance noted in tropical rain forests (Harrison 1955).

The species distribution and density in relation to the cocoa plantings in Jerangau and Hilir Perak are in apparent support of the resource-concentration response. Root (1973) stated that herbivores would be differentially attracted to and remain within areas of high resource availability. The factor of 'remain within' would lead to animals being caught very often over long trapping durations. The vegetation pattern and canopy of cocoa plantings could be similar to that of a secondary jungle, a habitat of the wood rats. The availability of plentiful and easily accessible food resource would attract the rats to remain within the area as is seen in Hilir Perak. The diverse species with competitive effects is seen in Jerangau plantings close to forest, with the wood rats slowly gaining a stronger foothold. As the cocoa plantings become more established and extensively cultivated, the near complete predominance of *R. tiomanicus* would occur. This is reflected in the population studies at MARDI Hilir Perak. Such a situation has been seen in oil palms (Wood 1984).

The rat population tends to be in agreement with that of other studies where the rat numbers in cocoa-coconut fields were 100–300 animals/ha (Han and Bose 1980; Kamarudin 1982; Lee and Arikiah 1984). Notwithstanding this, the rat population could be an underestimate in view of a relatively high proportion of the same marked animals being caught repeatedly. A test of equal probability of capture confirmed that some individuals were trap-prone while others were trap-shy. The spatial distribution analysis showed that about 25% of the rats were trapped on four or more occasions. Similarly, in a 20-month trapping-occasion study, Kamarudin and Lee (1989) reported that 25% of the rat population would be caught on four or more trapping occasions. Suggestions to overcome this problem of trap-prone and trap-shy included changes in trapping design and random rotation of traps (Caughley 1977), or a second collection of animals by other means (Wood and Liau 1978). However, these proposals were not followed for fixed trap points were required for population studies and trends. Furthermore, Wood and Liau (1978) mentioned that this problem was not insolvable as *R. tiomanicus* displayed only limited movement in the short term.

The body weights of *R. tiomanicus* caught ranging from 37 g to 165 g were within the juvenile, sub-adult and adult categories. Rats of body weight <37 g were unlikely to be mobile as they would still be under weaning (Lee 1995) although Kamarudin (1982) mentioned trapped rats with body weight as low as 16 g. Similarly, he reported that four females gave birth within the traps although none were encountered in this study. In oil palms, rats of lower body weight (25 g < body weight >10 g) were trapped from fields earmarked for destructive capture and nothing was mentioned from studies in fields that had a saturated rat population (Wood 1984). Similarly, there was no mention of births within traps.

Recruitment into the population varied from 2.3% to 25% with instances of small numbers in Jerangau plantings close to forests. These levels were less than the 10–30% estimated for rat population in oil palms (Wood 1984). Kamarudin (1982) noted a higher level of recruitment with instances of as high as 35% for cocoa fields in an estate near to oil palm plantings. The low recruitment (2–25%) indicated that probably birth played a more important role than immigration in the rat population. This is supported by the large percentage of potential breeders (males with scrotal sac and females with perforated vagina). A relatively large number of lactating females were noted at times. In addition, there were cyclical trends of juveniles joining the population.

In Jerangau, the relation to pod loss of the rodent population (0.93) which is thrice higher than that (0.31) of the rat population, is attributable to the presence of squirrels. The latter with their high damage potential (Lee 1995) would account for more of the crop loss in the field. The much lower estimate for rat damage in Jerangau is also partly due to the presence of the forest rats that were unable to gnaw through the cocoa pods. The presence of the forest rats, if they were able to compete spatially with *R. tiomanicus,* would be beneficial ecologically in the establishment of cocoa plantings. In comparison, the estimated rat damage in Hilir Perak (0.77) which is intermediate, was mainly caused by *R. tiomanicus*. As laboratory findings showed on the average a rat would damage half a pod a day, the field estimate of 0.77 would include the factor of rats that have learned to feed upon the cocoa pods. Williams (1973) reported an increase in cocoa pod damage level with a longer duration of rat association to the crop. A relatively strong relationship is noted for the Hilir Perak data ($r = 0.86$) in contrast to the lesser fit of Jerangau rat ($r = 0.59$) and rodent estimate ($r = 0.73$). Within the range of yield fluctuation, there is a general correlation between the number of ripe pods and the amount of damage (Williams 1973), for the constant search pattern of a rat population would result in a level of attack directly related to the number of pods at risk. This would be reflected by the general relationship between the rat numbers and the damage. The periodic fluctuation in population dynamics is apparently in tandem with that of the cocoa pod damage and yield (Chan 1983).

In the body measurements, Yong (1968) noted the overlapping of values for the tail, hind foot, head and body, and ear. Of these four parameters, the more accurate and better correlation is the tail which has a lesser degree of variation. Apart from age and body weight, tail length could be useful to correlate age and body weight of *R. tiomanicus*. This factor would facilitate the interpretation of the animal size (body weight) that is fed upon by the barn owl in view of the availability of the total tail length when rat carcasses were retrieved from the owl nesting sites.

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