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Abstract: We studied the breeding biology and population structure of the roof rat, *Rattus rattus*, living in wholesale grain and commodities shops in Rawalpindi, Pakistan. Rats were trapped from the grain market monthly for a period of 14 months. A total of 2327 rats was autopsied, consisting of 1175 males and 1152 females. The sex ratio did not differ significantly from 1:1 ratio. Males were fecund in every month, without significant seasonal differences. Females were pregnant in every month and overall the adjusted prevalence of pregnancy averaged 39.8 percent. Litter size during the last quarter of pregnancy averaged 6.09±1.73(S.D.). Based upon the proportion of females visibly pregnant for the first and subsequent times and the proportions non-pregnant but showing evidence (placental scars) of past pregnancies, it was calculated that an average female had 1.86 pregnancies and lived an average of 5.5 months while doing so. Thus production of young at birth was 1.86 x 6.09 = 11.3/female. Immatures (animals weaned but not yet sexually mature) constituted only 13.1% of the total collection and recruitment was continuous during the study. This is indicative of high mortality among juvenile animals. The evidence of wounds and scars on both sexes of adult rats supported the idea that there is a high degree of social strife and aggression in the sampled population. Population estimates based upon cumulative captures each month indicate that the rats are at, or near, saturation densities in the grain shops most of the time, thus requiring continuous breeding and recruitment to maintain their numbers. The reproductive potential of the present population is compared to several others from urban areas in Asia.

INTRODUCTION

The common rat found in grain storage facilities, wholesale commodities markets, cities, towns, and farm houses in Pakistan is the roof rat, *Rattus rattus*. The form that inhabits the Indus Plains and the upland areas in northern Punjab lives indoors and has been identified by Taber et al. (1967) as *Rattus rattus rufescens* (Gray). This is a brownish-grey backed commensal form with a venter that can be either creamy white or light grey with a rufous tint. The typical mammary formula is 2 + 3 = 10, with an occasional pairing of the postaxial mammae to give a 3 + 3 = 12 formula.

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Since this species is the most common rat to live in grain storage facilities, wholesale grain markets and farm and village houses, it is an economic and public health pest of significant importance. Previous studies dealing with the reproductive biology and population dynamics of this subspecies in similar habitats were carried out by Beg et al. (1983) in populations trapped indoors in the city of Faisalabad, Pakistan and by Rana et al. (1983) and Advani and Rana (1984) in houses and grain shops in and around Jodhpur, India. Beg et al. (1983) found that trapping success was lowest in winter and peaked in summer, pregnancy was seen throughout the year, the proportion of young was highest in the winter and averaged 31% during the year. The prevalence of pregnancy in sexually mature females averaged 46% for the 12-month study. Rana et al. (1983) found that females were pregnant throughout the year, the annual prevalence of pregnancy was 25.5%, the proportion of young averaged 54% for the entire sampling period and was lowest only during January to April. Because of these differences in reproductive and population parameters and because there is a need to understand its reproductive biology and population dynamics in order to use control methods with proper timing, we undertook a study of roof rat populations from the wholesale grain market in Rawalpindi, Pakistan. Populations here were found to be occurring essentially at saturation densities in the small grain shops and large samples could be taken each month with comparatively modest effort. This report details the results of a 14-month study of these rats.

METHODS

1. Description of Grain Shops

The Rawalpindi grain market consists of several hundred dealers occupying ground floor small shops measuring 25 m^2 to 45 m^2 in floor area. They average about 40 to 50 years in age. The shops have capacities of 500 to 800 bags of commodities (50 to 80 metric tons). None of the shops are rat-proof and only steel roll-down doors close off the entrances at night. The main grain handled is rice. Other foods available are lentils, grams, sorghums, wheat flour and groundnuts. The amounts of grains and other foods sold per year per shop varies greatly. Large dealers may sell up to 60,000 bags, while small dealers sell only 1000 to 1500 bags per year (Brooks et al. 1987).

2. Trapping

Rats were trapped in commercial wire-mesh live traps (41 x 14 x 14 cm) and in Sherman-design galvanized steel live traps (25 x 7.5 x 8 cm), which were more suited for catching smaller rats. These were baited with fresh potato, onion, guava or banana, whichever was in season. Trapping was done for 4 consecutive nights each month from April 1987 to May 1988. Ten wire-mesh live traps and 5 Sherman-design traps were set in each of 8 shops, selecting 8 different shops each month. The Sherman-

design live traps were not available during the first 2 months of the study.

3. Autopsy Procedure

Rats were returned alive to the laboratory and were chloroformed for autopsy. Each specimen was weighed and measured before autopsy. The following reproductive data were recorded: for females the condition of the vaginal orifice (perforate or not), condition of uterus (nulliparous, pregnant, placental scars), condition of ovaries (whether corpora lutea were visible or not), number of embryos, their crown-rump length and whether any were resorbing; for males the position of the testes, length and weight of testes and whether the tubules were visible or not in the cauda epididymis.

Animals were considered as sexually mature adults by calculating the 50% points at which females showed visible corpora lutea and males showed visible tubules in the cauda epididymis (Davis 1964). Animals equal to or exceeding these values, in body weight (BW) and in head and body length (HBL), were considered as adults; all others were classified as immatures.

To compare roof rat populations, the embryo rate (the crude pregnancy rate times the unadjusted embryo number = the number of embryos per 100 females of all sizes) and the reproduction rate (the number of embryos per 100 head of population, males and females) were calculated following Harrison (1952). These are felt to be more indicative of a population's reproductive potential than the reproductive rate as defined in Southwick's procedure (1966). Visible pregnancy in the roof rat was considered to cover 16 days of the gestation period.

A total of 2327 specimens was autopsied. Slight discrepancies in totals given resulted when all data could not be taken from all specimens.

4. Population Estimates

The population estimates from each monthly sample were calculated from the linear regression of cumulative captures on daily captures (Blower et al. 1981). Since the captures each month were taken from a different set of 8 grain shops, not much can be generalized about seasonal population changes. However, it is useful to have an idea of the population density from which each sample is drawn. Trap success was also compared with the population estimates to see if there was a correlation.

RESULTS

1. Characteristics of the Sample

The characteristics of the sample are given in Table 1. The males and females are given by body length size classes with the

equivalent mean body weights. Non-pregnant females only were used for computation of body weight. Males grew to a greater body weight than females but did not exceed in head and body length. There was no significant difference in mean body weight at equivalent HBL's between sexes until 160 mm and larger, at which point males were significantly heavier (P = .01). Males predominated in the largest size classes. The largest male captured weighed 273.5 g and measured 214 mm. The heaviest female weighed 216.8 g and measured 199 mm; however the longest female measured 215 mm HBL. The mean weight of pregnant females was 163.2 gm ± 29.5, ranging from 84.4 g to 216.8 g.

The proportion of males to females in the 2327 rats sexed was 50.5:49.5, which does not differ significantly from a 1:1 sex ratio.

2. Reproduction

a) Sexual Maturity

The 50% points of sexual maturity criteria in BW and HBL are given in Table 2. All females equal to or exceeding 80 g or 139 mm HBL were regarded as matures for all calculations relating to pregnancy, sex ratios, etc. Similarly, all males equal to or exceeding 96 g or 152 mm HBL were defined as mature adults.

Table 1. Head and body length, body weight and sex ratio of *Rattus rattus* from Rawalpindi, Pakistan (Mean ± S.D.)

Head and Body Length Size Classes (mm)	Males No. Animals	Males Body Wt. (g)	Females No. Animals	Females Body Wt. (g)	P
80 - 89	1	18.5 --	3	18.0± 1.7	ns
90 - 99	12	24.6± 2.9	13	23.9± 3.5	ns
100 - 109	18	34.2± 3.8	23	32.9± 4.3	ns
110 - 119	12	40.3± 6.6	18	44.1± 6.9	ns
120 - 129	29	51.8±10.2	27	53.7± 7.2	ns
130 - 139	21	67.8±11.5	29	65.8±10.9	ns
140 - 149	53	88.6±12.5	73	86.5±11.0	ns
150 - 159	102	106.0±13.7	102	103.3±13.2	ns
160 - 169	158	127.9±17.5	192	122.9±14.4	.01
170 - 179	296	150.1±18.5	308	146.0±17.4	.01
180 - 189	286	170.9±20.1	235	166.1±18.9	.01
190 - 199	150	191.8±23.1	109	176.6±18.3	.01
200 - 209	34	205.0±19.9	18	181.9±23.6	.01
210 - 219	3	231.3±43.2	2	206.4 --	--
Totals	1175		1152		
Means, BW	146.8±51.3		138.1±46.7		
" , HBL	171.4±21.3		167.9±22.0		

Table 2. Size (HBL and BW) at which 50% of males have visible tubules in the cauda epididymis and 50% of females have visible corpora lutea in the ovaries

Criteria	Males		Females	
	HBL	BW	HBL	BW
Visible epididymis tubules	152	96	-	-
Visible corpora lutea	-	-	139	80

b) Prevalence of Breeding Activity

1. Males

Fecund males were observed in every month of the year. Male fertility begins when the testis weight reaches between 0.7 and 0.8 g and a length of 16 to 17 mm. Many animals with testis smaller than these measurements were nevertheless observed to be scrotal. There was little seasonal fluctuation in the mean testis weights when adjusted for the mean body weights of the males in each monthly sample (Table 3). There was a suggestion that testis weight declined between November to February (except for the January sample), which are the cooler winter months.

Table 3. Mean testis weight by month, adjusted for the mean body weights of adult male rats in each sample

Month	No. males examined	Mean BW	Mean testis weight (mg) per 100 g BW
Apr. 87	39	141.2	698
May	51	158.2	679
Jun.	86	145.2	655
Jul.	99	142.3	688
Aug.	52	137.4	700
Sep.	99	148.5	646
Oct.	72	142.0	682
Nov.	70	153.2	626
Dec.	100	150.5	621
Jan. 88	65	146.5	684
Feb.	88	142.1	628
Mar.	62	146.4	730
Apr.	60	145.7	700
May	94	142.4	688

2. Females

a) Prevalence of Pregnancy

The adjusted prevalence of pregnancy, as judged by visible embryos in all adult females (80 g or > BW), is given in Table 4.

Table 4. Pregnancy in adult female (80 g or >) *R. rattus* by month

Month	No. observed	No. visibly pregnant	% Pregnant
Apr. 87	174	52	29.9
May	53	27	50.9
Jun.	72	26	36.1
Jul.	82	46	56.1
Aug.	65	20	30.8
Sep.	95	37	38.9
Oct.	60	19	31.7
Nov.	60	26	43.3
Dec.	82	39	47.6
Jan. 88	39	15	38.5
Feb.	61	31	50.8
Mar.	56	18	32.1
Apr.	46	19	41.3
May	76	31	40.8
Totals	1021	406	39.8

The prevalence of pregnancy for the entire sampling period was 39.8%. There was breeding in every month, with no apparent seasonal differences. The proportion pregnant in monthly samples varied from 29.9% to 56.1%.

When breeding activity was examined by body weight and head and body length (Table 5), it is apparent that pregnancy first starts in the 140-149 mm HBL size class but really becomes significant in females 150 mm HBL or over. The lightest pregnant

Table 5. Relationship of HBL and BW to visible pregnancy in female *Rattus rattus* from Rawalpindi

Body size class (mm)	No. exam.	Pregnant No.	Pregnant Percent	Body wt. Class(g)	No. exam.	Pregnant No.	Pregnant Percent
<140	113	0	0.0	< 80	132	0	0.0
140-149	73	4	5.5	80- 90	88	5	5.7
150-159	102	29	28.4	100-119	116	24	20.7
160-169	192	88	45.8	120-139	191	64	33.5
170-179	308	123	39.9	140-159	229	93	40.6
180-189	235	103	43.8	160-179	214	105	49.1
190-199	109	53	48.6	180-199	117	66	56.4
200-209	18	5	27.8	200-219	54	37	68.5
210-219	2	1	50.0	220-239	12	12	100.0
Totals and Percent (>139 mm or 80 g)	1039	406	39.1		1021	406	39.8

female weighed 84.4 g and the four females in the 140-149 mm size class measured 145, 148, 149 and 149 mm HBL.

b) Parity

The breeding life of the females can be deduced from the proportions in a primigravid status vs those that are multigravid and from the proportion of non-gravid females bearing one, two or three or more sets of placental scars. Data on parity in the *R. rattus* females are summarized in Table 6. Primigravid females constituted 53.7% of all pregnancies. The 1:0.86 ratio between primi- and multigravid means that, on the average, a female that becomes pregnant for the first time will have an 86% chance of living long enough to have a second pregnancy.

If we know the mean interval between consecutive conceptions (span), we can also estimate (in a rough way) the probability of dying for parous females. The calculation of the "span" takes some care, however, since we should exclude primigravids because an animal pregnant for the first time cannot have a "span". In the above example, the observed prevalence of pregnancy (p) among animals that had previously had a litter is 188 out of 604 (multigravid plus those non-gravid but with placental scars), equaling 0.31 and the span is calculated as 16/0.31 = 51.6 days. Therefore, a parous female, breeding first at about 68 days of age (Bentley and Taylor, 1965), can expect to live another 51.6 days and an additional 44.4 days (0.86 x 51.6 days) toward a second pregnancy before dying, a total of 164 days, or about 5 1/2 months.

Table 6. Corpora lutea and parity in *Rattus rattus*

HBL size class (mm)	No. exam.	C.L. visible	Nulliparous	Parous				
				Primi-gravid	Multi-gravid	Non-gravid with scars 1 set	2 set	3 set
80 - 89	3	0	3	0	0	0	0	0
90 - 99	13	1	13	0	0	0	0	0
100 - 109	23	1	23	0	0	0	0	0
110 - 119	18	1	18	0	0	0	0	0
120 - 129	27	6	27	0	0	0	0	0
130 - 139	29	12	29	0	0	0	0	0
140 - 149	73	58	63	4	0	6	0	0
150 - 159	99	95	51	24	5	19	0	0
160 - 169	183	186	34	69	19	53	13	0
170 - 179	299	293	25	59	64	95	52	4
180 - 189	228	225	10	42	61	50	58	7
190 - 199	107	107	5	17	36	17	27	5
200 - 209	17	15	3	3	2	4	5	0
210 - 219	2	2	0	0	1	1	0	0
Totals	1126	1002	304	218	188	245	155	16

c) Litter Size

Litter size was obtained by noting the number of grossly visible uterine swellings or embryos. Results are summarized in Table 7. The number of embryos per female ranged from 1 to 16. In the total of 2682 embryos, 80 (3.0%) were found to be resorbing. When litter size was examined by embryo size (CR = crown-rump measurement), roughly corresponding to the 2nd, 3rd and 4th quarters of pregnancy (Table 7), it was seen that early visible embryo counts averaged 6.90/female and decreased to 6.09 during the last quarter. This decrease would indicate an intrauterine loss of 0.81 embryo, or a mortality of 11.7% in embryos from all causes in contrast to the 3.0% observed as directly resorbing.

Table 7. Embryo size and litter size

Embryo size (CR, mm)	No. females observed	(Litter Size) Mean ± SD
0 - 6	156	6.90 ± 2.22
7 - 16	125	6.74 ± 2.00
17 and >	125	6.09 ± 1.73
	n = 106	

The relationship with body size of the female and the size of the litter is given in Table 8. There is an increase in litter size with increasing body size (and presumably age) of the female.

Table 8. Size of female (HBL) and litter size

Head and body length	n	Mean No. embryos	± S.D.
140 - 149	4	6.5	± 1.7
150 - 159	29	5.7	± 1.8
160 - 169	88	6.1	± 1.7
170 - 179	123	6.5	± 2.0
180 - 189	103	6.9	± 2.2
190 - 199	53	7.4	± 2.0
200 >	6	9.0	± 2.0

3. Population Structure

a) Sex Ratios

The sex ratios for immature animals and adults were not alike. Males predominated among the immature rats (Table 9), while the sex ratio among adult animals was essentially even. In

one month the sex ratio among adults animals was highly skewed: in August 1987 females predominated significantly (x^2 = 4.48 p = >0.05) over males (60 to 40). In the other months there were no significant differences in the ratios. Data for April and May 1987 were not used because the smaller traps suitable for capturing immature rats were not available.

Table 9. Sex ratios among immature and adult *Rattus rattus* (male: female)

	Males	Females	Ratio (male:female)
Immatures	142	123	54:46 (n = 265)
Adults	935	944	50:50 (n = 1879)

Sex ratio changes with age are frequently seen in mammal populations. As a general rule among mammals, the sex ratio in older cohorts becomes more imbalanced favoring females.

Sex ratio phenomenon are particularly important in population dynamics because where a reduction in the percentage of females occurs, there is likely to be a reduction in the rate of population growth. This effect is dependent upon the proportion that older cohorts represent in the population.

b) Age Structure

The recruitment of young animals into the population was essentially continuous throughout the year (Table 10), with only one low during the months of September through November. There

Table 10. Recruitment of young *Rattus rattus**

Month	Captures	Immatures	Adults	%Immatures
Jun.	176	31	145	17.6
Jul.	190	22	168	11.6
Aug.	129	21	108	16.3
Sep.	198	18	180	9.5
Oct.	138	14	124	10.1
Nov.	133	7	126	5.3
Dec.	193	25	168	12.9
Jan.	112	17	95	15.2
Feb.	160	27	133	16.9
Mar.	136	21	115	15.4
Apr.	117	15	102	12.8
May	184	26	158	14.1
Total	1866	244	1622	13.1

* April and May 1987 captures are deleted because small live traps for immature rats were not available at those months.

was never any large outpouring of young animals as frequently observed with temperate climate small mammals. The recruitment of immatures in each month shows a significant correlation with the prevalence of pregnancy in the month before ($r = 0.742$, $t = 3.5$, $p = .005$) (Fig. 1).

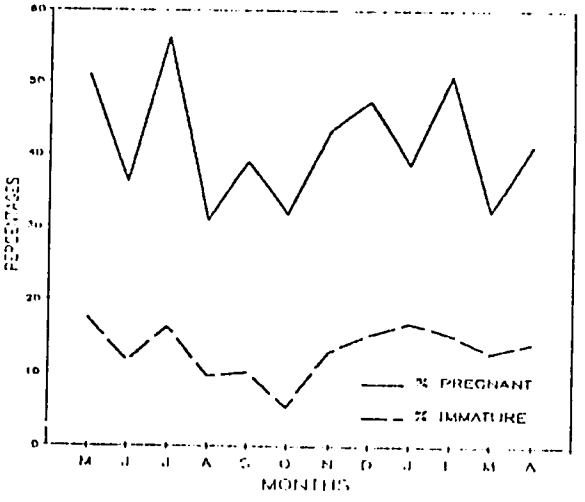

Fig. 1. Correlation of pregnancy and immatures.

c) Population Estimates

The population estimates are given in Table 11. These estimates are based upon the linear regression of cumulative captures on daily captures (Blower et al. 1981), in which 4 nights of removal trapping was carried out. Sometimes, the captures increased on the second or third night, rather than decreasing; resulting in estimates that had low correlation coefficients (this happened in 8 of the 14 trapping periods). The basic assumptions regarding removal trapping may have not been met, such as animals being equally trappable on all nights (some rats may have been trap-shy the first night).

Table 11. Roof rat captures, trap success and estimated populations from Rawalpindi

Month	Captures/day 1	2	3	4	Total Captures	Trap Nights	Captures/ trap night	Estimated population
Apr. 87	63	59	53	45	220	320	0.69	785
May	45	23	21	21	110	320	0.34	149
Jun.	51	53	39	33	176	480	0.37	389
Jul.	51	57	42	40	190	480	0.40	573
Aug.*	43	39	24	23	129	420	0.31	210*
Sep.	54	48	52	44	198	480	0.41	1034
Oct.	35	44	29	30	138	480	0.29	455
Nov.	43	40	27	26	136	465	0.29	254
Dec.	46	61	43	43	193	465	0.41	908
Jan. 88	35	34	28	15	112	465	0.24	191
Feb.	41	42	40	37	160	480	0.33	1239
Mar.	36	39	36	25	136	480	0.28	407
Apr.	36	34	31	16	117	465	0.25	211
May	45	50	47	42	184	480	0.38	1850
Totals	624	623	512	440	2199	6280	0.35	8655

* 7 shops only.

The important point about the captures and capture rates is that, aside from April 1987, the numbers taken per trap night varied only between 0.24 to 0.41. Between June 1987 and May 1988, the number of rats removed was essentially unchanged. This indicates essentially stationary populations, with most differences in population estimation occurring because of differences in trapping results (more rats captured on second or third nights, disturbances in shops that might have affected captures, lack of "closed" populations, etc.).

Despite some misgivings about the regression estimates, they provide a guide to animal densities in the small grain shops. The captures on the fourth night are 70% of those taken on the first night, indicating that several more nights of trapping would have been profitable. The overall estimated densities are about 600 rats per month (75 per shop), which does not seem unreasonable after working in the market environment.

d) Intraspecific Strife

Evidence for intraspecific strife was taken from observations of scars, wounds, fractures, and missing body parts on the collected animals. The most frequently observed evidence of fighting was that part of the tail was gone (Table 12). In aggressive encounters among rats, the loser often breaks off the exchange by turning its back on the victor and fleeing. The winner quite often uses this last chance to bite at the lower back or tail of the fleeing animal. Wounds on the tail resulting from bites were the next most frequent. Fractures and swellings of tails were seen much less often. The finding that many females were wounded and had missing body parts (43% of total sample) is indicative of extreme strife since aggressive exchanges are usually confined to between males. Altogether, animals bearing evidence of aggressive exchanges constituted almost 23% of the total collection.

Table 12. The frequence of scars, wounds and missing body parts in *Rattus rattus*

	Females	Males
Part of tail gone	125	194
Wounds on tail	58	76
Fracture of tail	15	17
Swollen tail	4	1
Wounds or abscess on body	20	13
Wounds or swollen legs	5	2
Fracture of hind foot	1	0
Missing hind leg	0	1
Totals	228	304

When we examine the size groups sustaining the most wounds and scars, the rate is seen to increase sharply among both sexes in the 170 to 179 mm body size (Table 13). Part of this could be due to, and probably is, cumulative encounters. It also suggests that prepubertal animals are little involved in aggressive social encounters.

This high percentage of wounded animals, especially among both sexes, is indicative of a high density population where space for nesting, resting, hiding and movements to and from feeding areas are at a premium due to sheer animal numbers. The density estimates derived, of between 149 to 1239/8 grain shops (we are discounting the 1850 animals estimated in May 1988), with a total floor area of 280m^2, would indicate that there were between 0.5 to 4.0 rats occupying every square meter. Under these densities, conditions for individual aggressive exchanges, killing and abandonment of newborn, and poor survival of immatures are highly likely.

Table 13. Frequence of wounds, etc. by body size groups in *Rattus rattus*

HBL size class	Females No. exam.	Females No. with wounds	Females %	Males No. exam.	Males No. with wounds	Males %
80 - 89	3	0		1	0	
90 - 99	13	0	0.0	12	0	
100 - 109	23	0	0.0	18	0	
110 - 119	18	0	0.0	12	0	0.0
120 - 129	27	0	0.0	29	3	10.3
130 - 139	29	1	3.4	21	1	4.8
140 - 149	73	6	8.2	53	6	11.3
150 - 159	102	16	15.7	102	12	11.8
160 - 169	192	25	13.0	158	33	20.9
170 - 179	308	78	25.3	296	84	28.4
180 - 189	235	55	23.4	286	96	33.6
190 - 199	109	30	27.5	150	47	31.3
200 - 209	18	4	22.2	34	9	26.5
210 - 219	2	0	0.0	3	0	0.0
Totals	1152	211	18.3	1175	291	24.8

DISCUSSION

The basic findings of this study are these:

1) Sexual maturity in male rats is defined as visible tubules in the cauda epididymis; 50% of the males showed this character at an HBL of 152 mm and a BW of 96 g. The sexual maturity criterion in females was the presence of visible corpora lutea; 50% of the females showed this at an HBL of 139 mm and a BW of 80 g.

2) Fecund males were seen in every month, with no significant seasonal change in testes weight noted.

3) Pregnant females were seen in every month. When the prevalence of pregnancy was adjusted just for adult (sexually mature) females, the rate ran from 29.9% to a peak of 56.1%, and averaged 39.8% for the entire 14-month study period.

4) Crude litter size ran 6.60 but when adjusted for the last trimester of visible pregnancy was 6.09±1.73(S.D.).

5) Females were found to have an average of 1.86 pregnancies in their lifetime, producing a total of 11.3 young. The average life expectancy of these females was 5.5 months.

6) Young, sexually-immature animals were trapped in every month and averaged 13.1% of the total sample over the period of the study.

7) Rat populations from which the samples were trapped were at equilibrium and saturation densities as judged by population estimations, intraspecific strife and trapping results at the start and end of the study.

8) The population level is regulated by matching survival of immatures (recruitment of young) to the deaths among the entire population. Thus the recruitment rate (approximately 13% per month) must relate closely to the death rate per month.

How do these findings compare to other studies of *Rattus rattus* from urban environments in South and Southeast Asia? There are four such studies: Harrison's (1952) examination of reproduction in *R. rattus diardii* from Kuala Lumpur, Malaysia; Brooks et al. (1978) report on *R. rattus khyensis* from Rangoon, Burma; Advani and Rana (1984) and Rana et al. (1983) studies on *R. rattus rufescens* in Jodhpur, India, and Beg et al. (1983) report on *R. rattus rufescens* from Faisalabad, Pakistan.

Size at Sexual Maturity

The sizes of each sex at sexual maturity are dependent upon the average sizes of rats in each population. Large rats will mature at larger sizes than small rats. The average sizes of rats differs in the 5 populations. Obviously, from Table 14, it can be seen that *R. rattus* from both Rangoon and Jodhpur are the smallest in average size. The average for Jodhpur is low because so many immatures were trapped; however the maximum body weights recorded are not notable. Rats from Kuala Lumpur, Faisalabad and Rawalpindi are larger. The average weight at onset of sexual maturity of rats from the several studies are given in Table 15. Some data has been recalculated from the cited studies where it was not given in the text.

Table 14. Average body sizes (weight, g, and lengths, cm) by sex of *R. rattus* from several Asian cities.

City	Avg. Body weight (Max.)		Avg. body length (Max.)	
	Males	Females	Males	Females
Kuala Lumpur	122.4(240)	124.5(250)	-	-
Rangoon	89.2	78.9(169)	152.6(199)	148.2(199)
Jodhpur	75.9(192)	77.1(179)	-	-
Faisalabad[a]	94.2	87.5	162.9	153.7(207)
Faisalabad[b]	114.2	119.5	157.4	160.5
Rawalpindi	146.8(274)	138.1(247)	171.4	167.9(215)

a Beg et al. (1983).
b Vertebrate Pest Control Project, unpublished data.

The Rawalpindi rats, being large, mature at a fairly large body weight as compared to the other populations. Jodhpur rats, being some of the smallest, mature at a comparatively larger weight than those from Kuala Lumpur, Faisalabad and Rangoon. Or they may be maturing at an older chronological age. The rats from Faisalabad and Kuala Lumpur appear to mature at roughly the same body weight and the average weights of rats of both cities are also roughly equal.

Table 15. Body weight (g) at sexual maturity in several populations of *R. rattus*

City	Males	Females
Rawalpindi	>96	>80 (corpora lutea)
Jodhpur	>80	>70 (corpora lutea)
Kuala Lumpur	>61	55 (pregnant)
Faisalabad	>60	54 (pregnant)
Rangoon	>50	>47 (corpora lutea)
Rangoon	-	65 (pregnant)

Thus, in terms of body weight at sexual maturity, the rats from Rawalpindi are larger, but not necessarily older, than rats from the other urban locales.

Male Fecundity

Males from Rawalpindi showed very little seasonal changes in testes weights and were fecund in all months. Sexually active males were seen in all months in Rangoon and Jodhpur but in Jodhpur the proportion of fecund males dropped to low levels in April, July and September. No data are reported on seasonal fecundity in male rats from Kuala Lumpur or Faisalabad.

Prevalence of Pregnancy

Pregnant females were seen in every month in Rawalpindi, Jodhpur, and Rangoon. Harrison (1952) does not specifically state if they occurred in every month in Kuala Lumpur. In Faisalabad, no pregnant rats were seen in November or December. The prevalence of pregnancy also varied seasonally in Jodhpur (as did ovarian weights). In Jodhpur it was lowest in June and October and highest in July and December. The annual prevalence of pregnancy was highest (46%) in Faisalabad and next highest in Rawalpindi (39.8%). Rangoon at 33% stood middle, while Jodhpur (25.5%) and Kuala Lumpur (26.0%) were least. When the prevalence of pregnancy figures are calculated as crude rates (number of pregnancies for all females) (Table 16) the order is changed little.

Litter Size

The comparative litter sizes are really in fairly close agreement. In Jodhpur, Faisalabad and Rawalpindi they varied from 6.60 to 6.19. In southeast Asia they were lower: 5.67 in Kuala Lumpur and 5.03 in Rangoon. These are crude litter sizes, however, unadjusted to account for the number actually seen at birth. Quite often, litter size decreases as pregnancy progresses, so that counts taken in the last trimester of visible pregnancy better approximate the true number to be seen at birth.

Reproduction Rates

To better compare the several populations, the "embryo rate per 100 of all females" has been calculated, and from this the "reproductive rate", as given by Harrison (1952). This is the number of embryos per 100 head of population, both males and females. These figures are given in Table 16.

Table 16. Comparative reproductive data and calculated parameters for *R. rattus* from several Asian urban localities.

City	Sex Ratio[a]	Crude Pregnancy Rate	Unadjusted Embryo No.	Embryo rate[b]	Reproduction Rate[c]
Kuala Lumpur	146	13.8	5.67	78	53
Rangoon	137	26.7	5.03	134	77
Jodhpur	121	25.5	6.60	168	92
Rawalpindi	100	35.2	6.60	232	116
Faisalabad	117	36.1	6.19	223	120

a Females/100 males
b Number of embryos for all females in population regardless of size
c Number of embryos for 100 head of population, males and females

The reproduction rate is equivalent to the number of births per 100 of all rats seen in the several samples, of whatever sex (Harrison 1952). As is seen, this rate is highest in rats from Faisalabad and Rawalpindi; lowest in rats from Kuala Lumpur, Malaysia. This reproduction rate in stationary rat populations can be interpreted as a measure of the death rate, since births should equal deaths. A low rate would indicate a low death rate and vice versa. However, the most extreme rates occurred in roof rats living in shops and markets in Rawalpindi and Faisalabad. The assumption that births equals deaths is not necessarily true. A better assumption would be that animals entering the population as young breeders (recruitment) would replace those adults that are dying. Thus a better measure of the death rate in adults is to look at recruitment of young, since between birth and first breeding, a heavy mortality can occur.

The percentage of immature rats (weaned nestlings up to sexual maturity) in the several populations is given in Table 17. From this it appears that roof rats in Rawalpindi and Rangoon suffer the least mortality while mortality is greatest in rats from Jodhpur. What the reasons are for the high recruitment of young rats in Jodhpur are not given by the authors but it may be surmised, in part, because of a relatively harsh environment. In Rawalpindi the main cause of rat mortality appears to be intraspecific strife. Apparently this is carried out at a rather constant level throughout the year. If recruitment of immatures is used as an indirect measure of the death rate, than this occurs at about 13% per month in Rawalpindi grain shops. This means that 50% of the population would die in 5 months and only 18% would live for 12 months. If the recruitment rate of Jodhpur rats is indicative of the death rate, then over 50% of the adult rats are dying each month. This is an extremely high death rate. The rates of recruitment for Kuala Lumpur and Faisalabad are about what one would normally expect in urban environments.

Table 17. Percent of immature rats in several urban populations

Locality	Number examined	Annual percent immatures in sampled population
Rawalpindi	2327	13.1
Rangoon	420	14.8
Kuala Lumpur	3385	25.2
Faisalabad	180	31.1
Jodhpur	442	54.3

Despite a high reproductive rate in Rawalpindi rats, the low proportion of immatures entering the population indicate a high mortality among nestling and weanling rats. This could be due to desertion of litters before weaning (very few lactating females were seen), predation by adult rats on nestling young, and high mortality on weanlings after leaving the nest.

Rat populations are maintained through a complex balance of sex ratios, early sexual maturity, pregnancy rates, litter size, juvenile and adult mortality, and recruitment of young into the population. These are modified, in turn, by biological and physical factors in the environment (food, space, climatic extremes) and by behavioral factors innate in the animals themselves (intraspecific competition, parental behavior and care of young). These events are clearly demonstrated by the breeding patterns and population structure of the Rawalpindi roof rats.

The implications for rodent control in such populations are not promising. Since they are suffering high juvenile mortality, taking steps to increase adult mortality through the use of poisons would only decrease the pressure on juvenile mortality. The birth rate would be adjusted by the rats following control to compensate for mortality and would be expected to increase, both prevalence of pregnancy and litter size.

Better measures to exert on the populations would be those that change the environment. Rat-proofing of the grain shops, even though difficult, would bring about population decreases. There are numerous holes in the walls between adjoining shops that could be filled to stop rat movements. Rat-proof doors could be installed in order to stop invasion by rats from the street. And grain shop sanitation would be another measure that would be beneficial. Keeping spilled grains swept up from the floors and repairing damaged bags would help. If these measures were instituted, along with poisoning, then population control would begin to be seen. It would have to be a continuous effort.

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