THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 3. NO. 4.

DECEMBER, 1946

AN INVESTIGATION OF THE RAT PEST PROBLEM IN QUEENSLAND CANEFIELDS: 5. POPULATIONS.

By W. A. McDOUGALL, M.Sc., Entomologist, Bureau of Sugar Experiment Stations.

TABLE OF CONTENTS.

SUMMARY.

1. Line-trapping, elimination trapping, feeding stations, signs of the presence of rats and tag-trapping (i.e. live-trapping, marking and retrapping in stipulated areas or grids) are, on the basis of field data presented, discussed as methods for population studies.

2. A method of tag-trapping has been developed for estimating the active Rattus conatus population in a population system without undue interference with the rats.

3. Work over larger areas has consisted of tag-trapping on as many standard grids (4 rows of 5 traps with a 10-yd. interval) as possible under varying conditions.

4. Rat movement has been found to be of paramount importance in these studies. Details of various movements are given: the longest recorded movement of a marked rat is 19 miles. Normal peaks of R. conatus movement occur during mid-winter and mid-summer, and when a large population is available for the winter movement a rat plague in canefields is experienced.

5. Age determination is discussed and data on population composition (in age groups) of monthly samples for three years in the Mackay district are presented.

6. The best indication of a population upsurge is the presence of both young and old rats. Care has been taken to distinguish between true upsurges and redistributions and concentrations of populations. Apart from the usual yearly upsurge during autumn, connected with the normal yearly breeding season, only one upsurge was observed in the Mackay district between 1936 and 1946. This was in the spring of 1938.

7. Estimates of absolute active spring populations on two farms are given for the last three years of a population decline..

8. The influence of food, harbourage, diseases, weather conditions, predators and parasites on population fluctuations is discussed. It is concluded that weather, through its effect on environment during general movement periods, is the prime factor governing survival and therefore fluctuations.

INTRODUCTION.

It has been common knowledge for a long time that rodents vary tremendously in numbers from year to year, and from one season to another, appearing and disappearing in their hordes without any apparent cause. Much has been written on these fluctuations and Elton (1935) has stated that, while rodent fluctuations have always been recognized, the universal existence of the phenomena has not always been realized. The earlier literature on the investigations of rodent populations was mostly speculative, though it did attempt to cover a wide field. In recent years, however, general information on the presence and abundance of rodents and trapping indices have been reinforced by more definite data obtained from live-trapping, marking and retrapping in stipulated areas. In this paper such a procedure is termed "tag-trapping."

Dice (1941) and Elton (1942) reviewed work and general ideas on the subjects of rodent and other mammal populations and census methods; and Blair (1941, 1942), Chitty (1942), Evans (1942), Storer *et al.* (1944), Hacker and Pearson (1944, 1946) and Aldous (1946) have reported rodent population investigations in England and America. A considerable amount of work also has been done by Russian workers, but, except for a translation of a paper by Kalabukhov (1935), the author has been dependent on reviews for information from that source.

From the literature it appears that the Murid species of most concern in the past to Australian agriculturists has been *Mus musculus* L. Osborn (1932) recorded for one night during a plague a catch of approximately 200,000 mice weighing 3 tons, and Winterbottom (1922) published photographs of large mice catches from wheat stacks. In Queensland, fluctuations in rat populations in the canefields have been noted for many years (McDougall, 1944a), but they have been poorly recorded and apparently little general interest has been taken in observations. As indicative of the probable unreliability of some estimates, it may be mentioned here that the rat population in the Herbert River district during the 1933-34 plague was variously set down as from 60 to 2,000 rats in each rat-infested acre.

When serious investigational field work with cane rats was initiated in 1936, there were no recognised sound methods of evaluating the efficacy of control measures. The author considered that, if attempts to lessen rat damage to cane are directed against, or are in any way concerned with rat populations, then the checking of such attempts should be on a pest population basis. Studies reported in this paper, and also in a succeeding paper in this series, were designed with this end in view. They fall naturally into two phases; viz., the correlation of preliminary laboratory information with relevant field data, and the relationships between pest populations and possible control measures under varying field conditions. Most of the detailed work reported here has been done with *Rattus conatus* Thomas in rugged country in the Mackay district on the central coast of Queensland (Figure 7) where no artificial controls directed against rat populations in canefields have been carried out during the past 20 years.

Owing to the lack of suitable methods and a satisfactory technique of approach to the subject, the author has been forced to develop the methods concurrently with the collection of seasonal and yearly data: as a result, the presentation of observations in this report is of necessity intimately bound up with details of method.

METHODS.

General.

The selection of a type of trap and of a method of trapping most suitable for a particular purpose and the sizes of working areas was a recurring and troublesome problem in these population studies. No doubt detailed observations and data from large areas are desirable, but mechanical and labour difficulties associated with such a project are great and preliminary surveys indicated that a large percentage of results would be not only purely negative but actually wasted effort. On the other hand, conclusions based on work with small areas only have been found misleading for some purposes. The happy medium, or at least the best course, can be attained only by "trial and error" in the field: in this investigation, therefore, some of the earlier work did not yield useful information commensurate with effort. It was exploratory and not sufficiently systematic; for this reason field-trapping results for 1936 have not been used extensively for yearly comparative figures, though during that year grid work indicated higher population densities over larger areas than any encountered in succeeding years. Even in later years, results of composite plots, as in Appendix A, were discarded as being merely of passing interest. Detailed results obtained with and conclusions on different methods are given later. Eventually the author used a combination, with cross checking, of line-trapping, tag-trapping, and the overall help of signs of the presence of rats. Signs were used only as possible and very general indications: trapping results have been taken as the bases for all conclusions.

Emphasis has been placed on the use of standard equipment and the development and use of standard methods. For most of the marking of *R. conatus,* leg tags (McDougall, 1946) were used and for live-trapping on grids the Bureau trap with leather-linseed oil bait (McDougall, 1944b) was employed exclusively. It is very desirable that live traps be used in all population work, but this was not practicable under working conditions encountered by the author, so break-back traps with leather-linseed oil baits were used for routine elimination trapping and for most of the line-trapping.

Live grid results have been correlated with elimination trapping or trapping-out, feeding station grids, rat damage to cane, and signs of the presence of rats.

Feeding trays at stations were of galvanized iron, $7\frac{1}{4}$ in. square with $\frac{1}{4}$-in. turn-up on all sides, and with covers of the same material. These trays and covers are illustrated in an earlier part of this series (McDougall, 1946) and are similar in principle to those used by Doty (1938, 1945).

For pellet counts a wire loop enclosing 1 square yd. was used. After some preliminary sampling, results obtained by dropping the loop in grid formation, commencing from 1 to 10 yd. from two edges of the grid or field, were found satisfactory. Only pellets in appearance not older than two days were counted.

Damaged and undamaged stalks were counted, with the aid of tally counters, in alternate 10 yd. of cane row throughout the varying areas, and rat bites were counted in every tenth damaged stalk.

Estimates of economic loss were made along lines indicated earlier (McDougall, 1944a).

During 1938 onwards, sex, weight, and age estimate were recorded individually for all specimens handled. During 1937 monthly weights in bulk were taken and large numbers of rats were also weighed individually.

Age Determinations.

The determination or estimation of the age of a rat in the wild state is an old problem, but without some reasonable attempt at its solution little real progress could be made with the field ecology of *R. conatus.* No single criterion, or set of criteria, is in general use for the determination of rat ages and most difficulties are encountered during adult life, i.e. during the most important portion. The examination of skulls and teeth was found to provide nothing more than categories such as young, adult or old, and was sometimes of use on the rare occasions when carcasses or skeletons were encountered in the field. Variations in the length of the hind foot were found valueless for age determination.

Litter mates of the same sex when reared either as a litter or in separate cages often record large differences in weight at specified ages. With some old rats there is a gradual decrease in weight over the last six months of life; for others the decrease is negligible, or it may be quite large over a short time before death. Large weights of some of the caged males, as recorded in Appendix B, are not encountered in the field and such specimens when dissected were carrying excess fat. In the case of females there are also weight variations due to pregnancies. Analyses of samples of caged males (see Appendix B) show that up to 100 g. body-weight, the age could be determined to within $\pm$ 10 weeks and over 100 g. to within $\pm$ 44 weeks, i.e. within limits of no practical value. Though weight-age data cannot be used direct to determine age it can be a help as a complement to experience and continuous handling of field populations of the particular species, and with other cage data as a background.

The continuity of work cannot be too strongly stressed: for the author this meant daily work with *R. conatus* in the field for 3–4 years and at least weekly observations over several years. Colour, texture, and condition of coat, appearance of head, general appearance, and behaviour of every rat were noted. Precocious over-weights for age and obvious under-weights so far as a practical grouping (see Figure 8 and Tables 16 and 18) was concerned were taken to cages for observation and periodical weighings over suitable periods. A similar course was taken when dealing for a specific purpose with a particular rat of doubtful age; and, at specified times such as midwinter and midsummer, routine population samples were taken to cages. Recorded weights of each rat in the sample were plotted as growth curves and these were fitted to the standard curves; a direct reading was taken as a help in estimating age at capture provided it agreed with all known information. These growth slopes were useful with rats up to 18 months of age. Many of the rats caged for further observations concerned with age determinations were kept until senile.

Population compositions based on age determinations by the above methods and as used in this investigation are strictly non-factual in the sense that they cannot be submitted to formal statistical analyses. The author considers that this does not detract very much from their practical value and that their use is warranted.

Line-trapping.

Continuous traverses up to 7 miles, with traps every 5 to 10 yd., were undertaken, and approximately 8,500 specimens of different species were trapped by this method. The use of a standard distance between traps for line-trapping lessens labour considerably: it was found unnecessary to mark each trap site, which was usually cleared with a hoe, and occasional gross directional marks were sufficient for quick and efficient work.

Table 1.

LINE TRAPPING: (First night catches only).

Farm and/or Locality.	Date.	Trap Sites.	Trap Interspace.	No. of Traps.	Details of Catch and Remarks.
			Yards.		
Abergowrie (Herbert R.) District	13–19.6.36	In virgin rain-forest	10	130	64 *R. assimilis* } No pregnant females 12 *U. caudimaculatus* } 5 Scrub turkeys (*A. lathami*)
		In a narrow strip of "blady" grass (*Imperata cylindrica* var. *major*) along fence	10	44	17 *R. conatus*
S. and T. Highleigh, Gordonvale	29.6.36	In cane undamaged by rats	5	30	1 *R. conatus* male
		In undamaged cane adjacent to rain-forest	5	20	2 *R. assimilis*
Gordonvale	9.7.36	In forest country within 200 yards of farm stables	10	10	5 *R. rattus*
R., Mount Sophia (Gordonvale)	10.7.36	In long grass along creek	10	10	2 *R. conatus*
	10.7.36	Along edge of Palm Tree Swamp ..	5	17	5 *M. littoralis*: nests found in grass and in scrubs in the swamp 1 *H. c. reginae*
C., Hambledon ..	8.7.36	In rat-damaged cane	5	23	4 *M. littoralis* 3 *R. conatus* 2 *R. rattus*
Mossman	15.7.36	In broken creek country	10	30	4 *M. littoralis* 4 *R. rattus* 1 *R. conatus*

South Johnstone ..	19.7.36	In grass along headland	10	21	7 *M. littoralis* 1 *R. conatus*
	19.7.36	In virgin rain-forest very close to cane..	10	12	3 *R. assimilis*
	20.7.36	In rat-damaged cane near buildings ..	10	39	12 *R. rattus* 1 *R. conatus* 3 Bandicoots (2 species)
		In lantana near cane	5	17	6 *R. rattus*
B.O.M., Mackay ..	2.4.37	Along hollow near cane: poor ground cover	5	33	3 *R. conatus*, young females, stomachs empty 1 *R. conatus*, old male, stomach containing cane
		Along hollow near cane	5	14	1 *R. conatus*, non-pregnant female, stomach containing cane and grass 2 *R. conatus*, young female and male, stomachs containing grass 2 *M. littoralis*, males, stomachs containing grass
		In second growth rain-forest	5	16	Nil
	25.5.37	Around creek, edge of cane and amongst stinking Roger (*Tagetes glandulifera*) and blue top (*Ageratum conyzoides*). Stony	10	12	1 *R. conatus*, old male 2 *M. littoralis*, females, non-pregnant
		In a mixture of cane and stinking Roger. Damp spot	10	23	18 *R. conatus* 3 *M. littoralis* } No pregnant females
		Through spur of rain-forest	10	6	Nil
		Back into cane and lower ground ..	10	16	9 *R. conatus* 3 *M. littoralis* } No pregnant females though 3 young were found in an *M. littoralis* nest
		Through heavy cane on high stony land near creek	..	181	1 *H. c. reginae* female, non-pregnant

[*Continued on page* 164.

Table 1—continued.

LINE TRAPPING: (First night catches only)—*continued.*

Farm and/or Locality.	Date.	Trap Sites.	Trap Interspace.	No. of Traps.	Details of Catch and Remarks.
			Yards.		
H. and S., Mackay ..	13.4.37	In rain-forest near cane	5	25	Nil
		In gorge amongst stand-over cane with heavy trash ; stony and dry	5	31	Nil
		In same cane : a damp spot	5	14	1 *R. conatus*, female, R6L3*, stomach containing cane 1 *R. conatus*, sub-adult female, non-pregnant, stomach containing cane
		In same cane : a ridge	5	6	Nil
		In same cane : damp but stony ground..	5	17	2 *R. conatus*, old males, stomachs containing cane 4 *R. conatus*, females, R6L3, R6L3, R3L2, one non-pregnant, stomachs containing cane 1 *R. conatus*, sub-adult female, stomach containing cane
		In same cane : a dry ridge	5	13	Nil
		In blady grass ; uneven and stony ..	5	18	2 *R. conatus*, sub-adult females, stomachs containing grass 1 *R. conatus*, female, R6L3, stomach containing grass
W.F., Mackay ..	6.7.37	Along edge of damaged cane (var. Pompey) against rain-forest	5	19	7 *M. cervinipes* (3 females, non-pregnant), stomachs containing cane 1 *R. conatus*, female, non-pregnant ; stomach containing cane
Eungella (Mackay district)	July, 1937	Rain-forest	Variable	173	51 *M. cervinipes*. No pregnant females

* Denotes 6 embryos in right uterine horn and 3 in the left horn.

Table 1 contains sample results of extensive line-trapping, which was discontinued in 1937 following the satisfactory development of tag-trapping. It was concluded that line-trapping is essentially a spot testing method for exploratory work, or for special purposes such as cordons around grids, and is useful as a complement to other methods if its true value is understood. It did indicate that indigenous species in Queensland cane areas are confined to certain habitats, but this is shown in more detail by grid results. It may indicate the presence of rats in certain habitats in different seasons, but only subsequent tag-trapping will provide a detailed and useful knowledge of population density, population composition, rat movements and species.

Chitty (1936) foreshadowed improved methods to succeed line-trapping in rodent population studies, and contributed to the work in 1937. Storer *et al.* (1944) remarked that "Permanent and moving lines of snap traps were employed to remove all rodents from small areas to estimate local populations and, by repetition at intervals, to learn the extent of reinvasion. Because of local movements of rodents from closely adjacent areas, these trap lines provided little reliable information on actual population densities. Recourse was made later in the season to live traps which made possible the capture, marking, and release of rodents for more accurate estimates of populations."

Trapping-out.

Trapping-out was originally undertaken to obtain an indication of population densities which might be encountered (Table 2) but later it was used extensively in association with tag-trapping.

The following is a description of one of the earliest experiments at Abergowrie, in the Herbert River district, during June, 1936. It indicates a high population density and the possibilities of trapping during light and continuous rain and also demonstrates the rather poor experimental technique in use at the time.

On June 17, the eastern half of an isolated area of two-thirds of an acre was poisoned with $\frac{1}{4}$ oz. packeted thallous sulphate treated whole wheat, 1:500, linseed oil sprayed baits; 4 baits to a place (i.e. at the rate of 768 per acre) on a 21 x 4 grid of 5-yd. interval.* On June 18 a take of 81·5 per cent. and a consumption of 16·3 per cent. were recorded and these had not improved by June 20, when a 21 x 4, 5-yd., bb. grid* was substituted for the poison grid. On June 21 and 22, 49 and 35 *R. conatus* were taken and 5 were found dead amongst the cover; traps were then closed as light rain as over the previous three days and nights became heavier. The unpoisoned half of the area was trapped in the same manner from June 18 to June 20 when 52, 42 and 41 rats were caught on successive nights. Altogether (including preliminary line-trapping) 267 rats were trapped in this small area. On June 22, some 500 used burrow openings were dug in and by the morning of June 23 most of these had been reopened: this indicated only partial and probably very incomplete trapping-out.

* See page 167.

Table 2.

Trapping-out Data.

Plot.	Locality.	Grid.	Date.	Catch.	Remarks.
1	B. farm, Mackay. P.O.J.213, ratoon cane	bb., ·2 ac., 5-yd. interval	May–June, 1937	474 *R. conatus* ; 3 quail	This small field apparently isolated. Traps sprung on June 26 following three nights with catch nil. Percentage damaged stalks at May 30 less than ·5 per cent.
		16 traps at random	Aug. 30, 1937	15 *R. conatus*	
		88 trap nights	Nov., 1937	19 *R. conatus*	
2	B. farm, Mackay. Standover P.O.J.2714	bb., 2 ac., 10-yd. interval	June, 1937	219 *R. conatus* 64 *M. littoralis*	Traps clear of rats during last three nights. Grid No. 4 of Table 6 in this apparently isolated field of cane, Aug. 31–Sept. 5, 1937. Percentage damaged stalks at June 14 less than ·5 per cent.
3	B.O.M. farm, Farleigh. N.G.15	bb., 1 ac., 10-yd. interval	Aug. 28–Sept. 3, 1940	47 *M. littoralis* 3 *R. conatus*	At end of August patchy attack covering approx. $\frac{1}{4}$-ac. ; in the patches 38 per cent. of stalks attacked, with average of 3·2 bites per stalk. Field harvested during September to prevent appreciable economic loss

Experience with trapping-out indicates that, as might be expected, there is a relationship between grid interval and the completeness of trap-out, even in settled populations; if the interval is greater than 10 yd. only partial elimination is possible. This point, as well as reinfestations of trapped-out "isolated" areas (Table 2, plots 1 and 2) or parts of infested areas, is discussed in more detail when dealing with tag-trapping.

Signs of the Presence and Abundance of Rats.

Chitty (1942) remarked: "Live census methods for rats have not, except in ship deratization work, been well developed along these or other lines. Droppings (faecal pellets) are the most reliable signs used by inspectors on board ship; and their estimates of infestation usually check very closely with numbers found dead after fumigation. The operation, however, is a highly skilled one, and since allowance must be made for type of food and rate of desiccation of the droppings, probably cannot well be applied elsewhere."

The principle that the successful use of signs as indicating the presence and abundance of rats is highly skilled cannot be too strongly stressed. Elsewhere (McDougall, 1944b) the habits of cane rat species have been described and at least each genus exhibits some different signs of presence; actually in cane those which attack the crop have one sign in common, the rat bite, which varies in detail with some of the species. On the other hand it has been known for many years that considerable rat populations may be present in a canefield without attacking the cane (note examples in Table 14). The author found this method of live census when available too unreliable and inexact for experimental work (note Table 14), though in some instances it was helpful in saving labour. In conjunction with line-trapping it was also useful for rough survey purposes in population studies and for preliminary surveys connected with control application.

Tag-trapping.

Marking and releasing rats from line-trapping was found to have very limited value, therefore tag-trapping, as previously defined, is concerned with traps in grid formation. Examples and explanations of grid designations in this report are—

1. 3 x 7, 20-yd. x 10 yd., B. or F.S.
2. 4 x 5, 20-yd. interval, bb.

Grid 1 consists of three parallel rows 20 yd. apart and each row containing 7 Bureau traps or feeding stations spaced 10 yd. apart in the rows.

Grid 2 consists of 4 rows each of 5 break-back traps, with a grid interval of 20 yd. For most routine work a similar trap and row interspace was used and this important distance is called the grid interval.

In the course of these investigations 129 single live grids on 105 sites were used purely for population studies in various lay-outs and grid combinations as given in Appendix C. Most of these were temporary grids, i.e. used for comparatively short time periods and finalized by trapping-out. Permanent

Table

EXAMPLES OF DETAILED RECORDS

Farm B. August 17-29, 1937.

Grid: 3 x 7: 10 x 10: Bureau and break-

In lodged Q.813 estimated at 34 t.p.a.;

(R. before tag number denotes a

Trap No.	Live trapping.*				
	Aug. 17.	Aug. 18.	Aug. 19.	Aug. 20.	Aug. 21.
1	F, 31, med.	F, 51, young.	F, 66, med.	F, 79, med.	M, 83, large
2	F, 32, med.	Bandicoot	F, 67, med.	R. 67	M, 84, med.
3	F, 33, med.	*R. conatus*, F, med. dead	R. 45	M, 77, med.	R. 33
4	F, 34, med.	F, 52, large	R. 52	M, 78, large	R. ?*
5	M, 35, large	F, 53, very old	M, 68, med.	R. 36	R. 37
6	F, 36, med.	M, 54, large	M, 69, med.	..	R. 69
7	M, 37, large and old	F, 55, large	F, 70, med.	R. 70	R. ?*
8	F, 38, old	M, 56, large	M, 71, young	R. 56	M, 85, young
9	M, 39, old	57 *M. littoralis*, F	..	..	M, 86, large
10	M, 40, old	R. 40	M, 72, large	..	R. 40
11	M, 41, young	M. 58, med. large	R. 58	M, 80, med. large	R. 58
12	F, 42, young to med.	F, 59, med.	R. 42	R. 45	R. 42
13	M, 43, med.	R. 45	..	..	R. ?*
14	F, 44, med.	..	R. 43	..	M. 87, large
15	..	F, 60, med.	M, 73, large	R. 59	F. 88, med.
16	F, 45, old	F, 61, med.	R. 46	R. 46	R. 46
17	M, 46, very old	R. 46	R. 61	F, 81, young	..
18	M, 48, young to med.	M, 62, med.	M, 74, young	..	..
19	F, 49, med.	M, 63, old	R. 63	F, 82, med.	R. 74
20	F, 47, med.	M, 64, large	M, 75, large	R. 63	F, 89, small
21	F, 50, young to med.	F, 65, med.	R. 50	R. 50	R. 50
	1st night	2nd night	3rd night	4th night	5th night
Remarks ..	1 trap missed	1 trap missed 1 Bandicoot 1 *M. littoralis*	2 traps missed	6 traps missed (mechanical)	2 traps missed
Deaths ..	..	1 non-tag 1 sick when tagged†	..	..	..
No. of new tags	20 (12 females, 8 males)	14 (8 females, 6 males)	10 (3 females, 7 males)	6 (3 females, 3 males)	7 (2 females, 5 males)
No. of returns	..	3	9	9	12
A.P. ..	..	$20 \times \frac{18}{3} = 120$	$33 \times \frac{19}{9} = 70$	$43 \times \frac{15}{9} = 72$	$49 \times \frac{19}{12} = 78$

* Sex, tag number and age or size given; all *R. conatus* unless otherwise stated; tag numbers not taken in

† Did not return; taken as dead.

FROM A TEMPORARY GRID.

back traps.
damaged stalk count on August 18.
recapture or return of the tagged rat to a live trap.)

Trapping-out with "break-backs."*					
Aug. 24.	Aug. 25.	Aug. 26.	Aug. 27.	Aug. 28.	Aug. 29.
51	31	*R. conatus*	..	..	Nil
72	33	*R. conatus*	Tagged *R. conatus**	..	..
R. conatus	..	68	*M. cervinipes*	*R. conatus*	..
M. littoralis	*R. conatus*	*R. conatus*	*M. cervinipes*	*R. conatus*	..
R. conatus	36	..	..	..	..
55	..	*R. conatus*	*R. conatus*	..	..
37	..	..	38	Tagged *R. conatus**	..
86	..	..	..	..	..
39	*R. conatus*	..	..	..	..
R. conatus	40	48	..	..	..
..	44	..	..	69	..
42	73	41	*R. conatus*	..	..
..	43	32	..	..	..
..	87	*R. conatus*	*R. conatus*	..	..
59	83	88	..	*R. conatus*	..
61	60	..	..	..	..
..	..	*M. littoralis*, F.	..	*M. littoralis*, F.	..
74	62	49	..	..	..
47	*R. conatus*	*R. conatus*	82	*M. littoralis*, F.	..
35	64	Tagged *R. conatus**	..	Tagged *R. conatus** (eaten)	..
..	50	65	*R. conatus*	..	..
1st night	2nd night	3rd night	4th night	5th night	6th night
15 rats taken (+ 1 *M. littoralis*)	16	14 (+ 1 *M. littoralis*)	7 (+ 2 *M. cervinipes*)	6 (+ 2 *M. littoralis*)	..
12 with tags	13	8	3	3	..

A.P. = 70

Trap-out (including deaths) 60

39 of 56 tags recaptured

some cases.

grids or grid sites—i.e. those where regular and periodic tag-trapping is carried out over the longest convenient time period and as used by other workers—were also set out. However, the usefulness of this type of grid is limited in cane districts (see page 204 and Tables 15 and 16).

The more important technical difficulties usually associated with tag-trapping are—

1. The effects on the rats of the actual tagging and releasing in daylight.
2. Interference with functions such as mating, suckling and protecting young.
3. The marginal error caused by rats leaving and entering the grid area.
4. Interference by grids of small intervals with natural wanderings of the rats.
5. The possibilities of recording the larger movements of rats.
6. "The possibilities of recording movements are affected practically by the difficulty of setting sufficient traps to fill all positions simultaneously and ensuring that at each there will be no fewer traps to fill than animals to occupy them" (Chitty, 1937). The author uses the term R/T to denote the numerical relationship between the number of rats (R) and the number of single-action traps (T) mutually available with respect to position and unit time (one night).

Difficulties 1 and 2 concern all types of live grid systems and can be dealt with at this juncture; the others will be discussed later. On several occasions the full number of tagged rats recorded as missing when a grid had been finalized were found alive elsewhere. In recording the progress of tagging, rats found sick in traps or behaving unnaturally when released were noted. These, which included decrepit specimens, were sometimes found dead within a few yards of release points and, with the few rats found dead in traps or "killed at the actual time of tagging," were recorded as "deaths" or "killed during tagging" (see Tables 3, 4, 6, 8 and 9). Details of rat behaviour following release in daylight after marking are not known. Occasionally when working a live grid a released rat will spring a trap 20 or 30 yd. away within a few minutes of release or will enter a burrow close handy. The removal of 3-day-old pups from the nests in cages, keeping them in tobacco tins on a laboratory table for 24 hours and then returning them to the mothers, has little apparent effect on the families. The oestrous cycle of *R. conatus* is of short duration; and, though no information is available on the correlation of normal oestrus and night activities, copulation has been observed in cages during the day and is known to occur in burrows at all times. The author has found no significant difference between paired (see page 209) tagged and non-tagged grids worked when *R. conatus* is breeding and under comparable conditions and has concluded that these two difficulties or errors can be considered negligible for practical purposes.

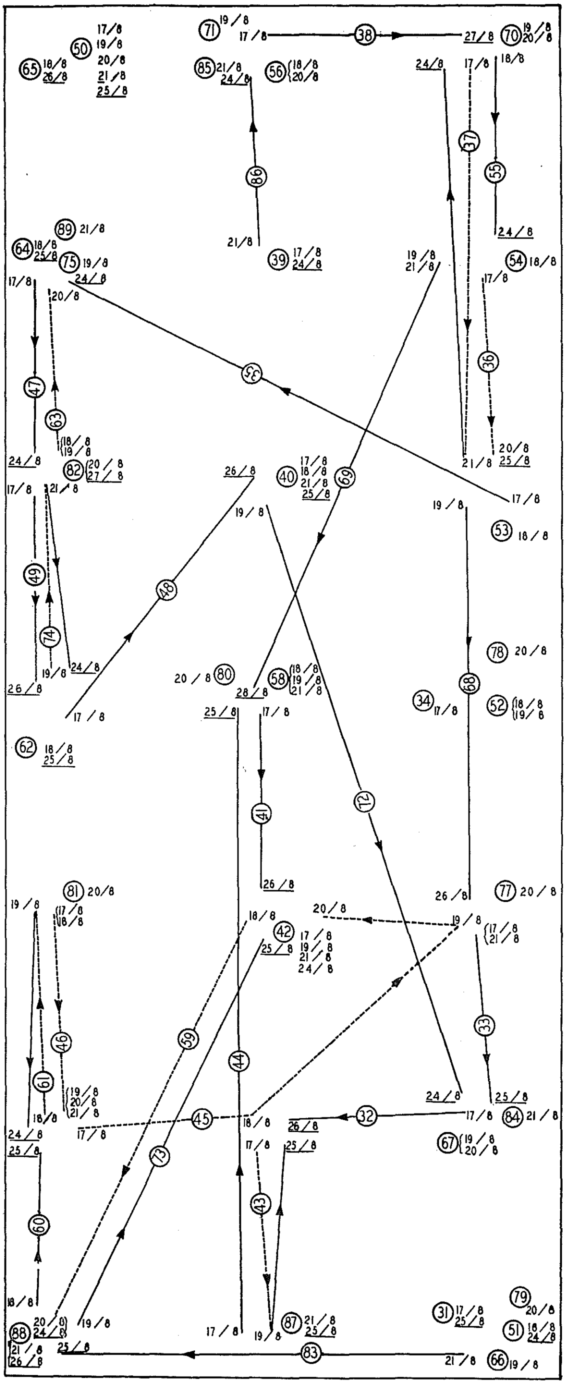


Figure 1.
Movement chart for a single 3 x 7, 10-yd. interval grid.

Table

EXAMPLE OF DETAILED RECORDS

Farm B. July 27-August 19, 1938:
Grid: 4 x 5: 10 x 10: B and bb.
In Q.813 estimated at 20 t.p.a.;
(R before tag

Trap No.	Live trapping.*						
	July 27.	July 28.	July 29.	Aug. 2.	Aug. 3.	Aug. 4.	Aug. 5.
1	M, 822, 109	M, 950, 97	R. 822, 102	822, 109	950, 107	949, 102	M, 93
2	M, 934, 68	..	F, 949, 100	934, 73	M, 80§	F, 104	..
3	M, 935, 70	M, 951, 61	R. 935, 68	595, 102	951, 73	non-tagged M, eaten	*R. conatus* non-tagged, eaten
4	..	..	..	F, 131	..	..	F, 90
5	M, 936, 73	F, 596, 90†	R. 936, 71	596, 106	M, 78§	936, 77	..
6	..	M, 952, 85	F, 962, 78	965, 80	M, 90	M, eaten	*R. conatus* non-tagged, eaten
7	F, 595, 90†	M, 953, 59	..	F, 134‡	M, 84	..	F, 120§
8	M, 937, 120	R. 943, 110	M, 963, 104	..	953, 71	938, 73	..
9	M, 938, 66	M, 954, 59	R. 954, 57	937, 122	939, 75	M. 122	F, 85
10	F, 939, 68	M, 955, 46	..	..	..	..	M, 44
11	F, 940, 51	F, 956, 53	..	956, 63	..	940, 61	..
12	F, 942, 75	R, 942, 68	M, 964, 92	F, 129‡	942, 80	945, 87	F. 66
13	M, *Melomys* 34 (dead)	M, 957, 100	R. 957, 99	943, 112	M, 82	957, 111	..
14	M, 943, 104	..	..	..	..	..	960, 75
15	M, 944, 73	M, 958, 70	M, 965, 77	..	958, 80	F, 85	944, 85
16	F, 600 (dead), 90†	M, 959, 90 F, 960, 61	..	959, 106	*R. conatus* non-tagged, eaten	*R. conatus* non-tagged, eaten	M, 46
17	F, 945, 80	F, dead, 44	R. 595, 92	946, 84	..	F, 48	..

4.

FROM A TEMPORARY GRID.

Plot 1 (one of a series of adjacent plots).

damaged stalk count made on August 5.
number denotes a recapture or return of the tagged rat to a live trap.)

Trapping out with "break-backs."*

Aug. 8.	Aug. 10.	Aug. 11.	Aug. 12.	Aug. 16.	Aug. 17.	Aug. 18.	Aug. 19.
F, 143§	F, 87	..	..	..	..	..	Nil
..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..
..	F, 92	..	..	..	..	..	..
..	..	..	..	..	..	M, 63	..
..	..	..	..	F, 68	..	..	..
F, 66	..	..	..	M, 138	..	..	..
..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..
M, 85	..	..	..	..	95	..	..
..	M, 134	..	..	..	..	*Melomys*, eaten	..
F, 92	*R. conatus* non-tagged, eaten	..	..	..	..	..	..
..	..	..	935, 75	..	..	..	..
..	..	M, 95	..	..	..	..	..
..	..	..	..	..	55	..	..
..	..	..	..	..	..	..	..

[continued on page 174.

Table

Farm B. July 27-August 17, 1938:

Grid: 4 x 5: 10 x 10: B and bb.
In Q.813 estimated at 20 t.p.a.;
(R before tag

18	F, 946, 84	R, 946, 79	M, 966, 95	Half-eaten F, non-tagged	M, 107	F, 71	*R. conatus* non-tagged, eaten
19	..	F, dead, 87	..	*R. conatus* non-tagged, eaten	966, 102	..	M, 39
20	M, 947, 85	M, 961, 97	..	M, 97	M, 107	..	947, 78
—	1st night	2nd night	3rd night	1st night	2nd night	3rd night	4th night
Remarks ..	1 *M. littoralis* 1 trap missed, 2 traps set tight	1 trap missed, 2 traps set tight	Light rain	16 rats	15 rats	14 rats	14 rats
Deaths ..	1 female	2 females	..	10 with tags	7	6	3
No. of New Tags	15 (6 females, 9 males)	13 (3 females, 10 males)	6 (2 females, 4 males)				
No. of returns	..	3	6				
A.P. ..	..	$\frac{15 \times 18}{3} = 90$	$\frac{28 \times 12}{6} = 56$				

* Sex, tag number, and weight in grams given.
† Rats previously tagged during May on same plot site ; the early grid was not trapped out.
‡ Tagged rats from adjacent plot.
§ Tag Nos. 628, 831, 842, and 843 from adjacent plot site tagged during May and June.

‡, § All non-tagged rats for this July-August grid.

4.—continued.

Plot 1 (one of a series of adjacent plots).

damaged stalk count made on August 5.

number denotes a recapture or return of the tagged rat to a live trap.)

..	..	..	..	M, 138	..	..	..
964, 85	..	..	..	..	..	..	..
..	M, 106	..	..	..	..	..	..
7th night	9th night	10th night	11th night	15th night	16th night	17th night	18th night
5 rats	5 rats	1 rat	1 rat	3 rats	2 rats	1 rat	Nil
1	..	..	1	..	..	..	..

A.P. = 54
Trap out (including deaths) = 80
28 of 34 tags recaptured

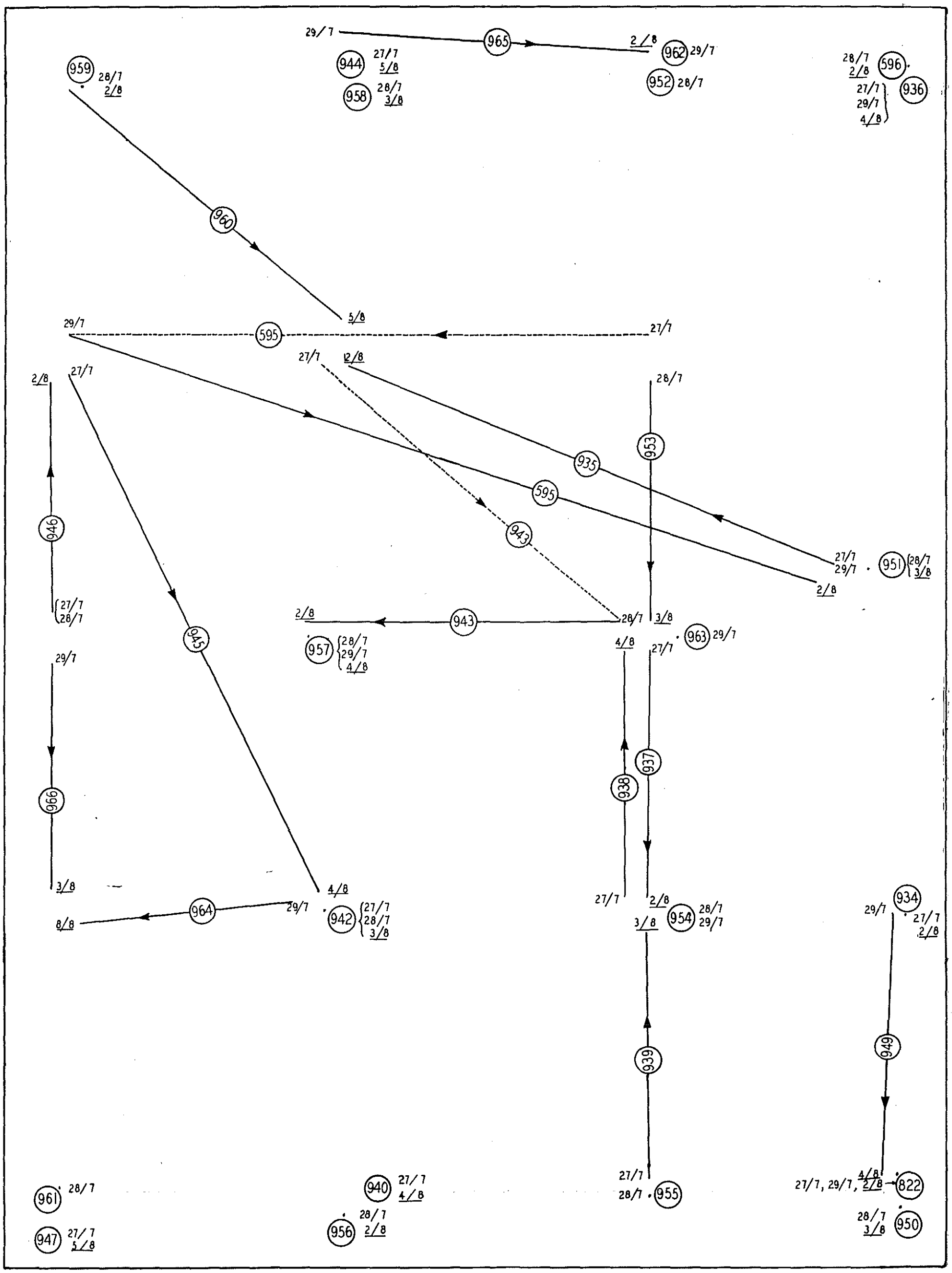


Figure 2.
Movement chart for a single 4 x 5, 10-yd. interval grid.

Tables 3 and 4 illustrate the recording of data from single grids all of which were charted as in Figures 1 and 2 (actual charts from Tables 3 and 4); and where grids were in series each series was charted as a whole (see Figure 3 where, for convenience, only inter-grid movements in a composite series are shown). A distinction has been made between live-to-live and live-to-dead trap movements. In charts the former are indicated by dotted lines and the latter by full lines, and the date of a dead trap record is underlined. Distances between points of capture were measured from the charts of grids and recorded for each grid or group of grids as in Table 5.

When cane or other ground cover is burnt off an indication of the distribution of used burrow openings can be obtained. It is not exact, as it is sometimes difficult to decide after the burn if a particular burrow has been used recently. On the other hand, rats may still be in residence for some days after the destruction of cover. Attempts at mapping *R. conatus* burrow distribution before the destruction of cover are not worth while. On this point and for other species Pemberton (1925) remarked that when "rat burrows become concentrated in the dikes or banks . . . they are . . . more easily found than in canefields." In Figure 4 the recorded movements of rats in two 3 x 7 live and bb. grids with an overlap between the grids, and a line of traps in nearby cover, are given. Areas containing burrow openings are marked and this typically uneven distribution (which occurs even in areas of very heavy population densities) is also illustrated in Plate 1; this and Plate 2 are examples of a type of rat-infested country encountered in the Habana area, Mackay district. Figure 4 is concerned with grids where R/T is 1 to 2, and the relative positions of burrow areas and recorded movements might be taken as indicating a close relationship between these factors in rat behaviour. To a great extent this is true, but from inspections of a large number of charts of grids there is a complicating factor of favoured movement and/or search areas which are apparent in both Figures 4 and 5 (note that journeys between grids in Figure 5 are more prevalent in one section). These favoured movement areas are better appreciated in large scale work—Trippensee (1933-34) calls them "highways of travel" for the cottontail—and when dealing with scattered populations (see page 210). Actually an inspection by an experienced operator does not always provide reliable information on favoured movement areas connected with a small grid. The rats make use of small differences in environment not noticeable by the field worker, who, in setting out a grid in rat-infested country, can make use only of gross changes in environment. An extreme is illustrated in Figure 6: *R. conatus* was not taken in traps on the stony ground in grid 1.

Table 5.

RECORDED INTRA-GRID MOVEMENT.

Grid No.	Tag No.	Description of Rat.		Recorded Movements in Yards.	
		Sex.	Weight, Size, or Age.	Live-to-live Trap.	Live-to-dead Trap.
1	31	Female	Medium size	. .	Under 10
(see Fig. 1 and Table 3)	32		Medium	. .	10
	33		Medium	Under 10	10
	36		Medium	10	Under 10
	38		Old	. .	10
	42		Medium size, though young	Under 10	Under 10
	44		Medium	. .	30
	45		Old	10–20	. .
	47		Medium	. .	10
	49		Medium	. .	10
	50		Medium (young)	Under 10	Under 10
	51		Young	. .	Under 10
	52		Large	Under 10	. .
	55		Large	. .	10
	59		Medium	20–30	. .
	60		Medium	. .	10
	61		Medium	10	10
	65		Medium	. .	Under 10
	67		Medium	Under 10	. .
	70		Medium	Under 10	. .
	82		Medium	. .	Under 10
	88		Medium	. .	Under 10
	35	Male	Large	. .	20–30
	37		Large and old	20	20
	39		Old	. .	Under 10
	40		Old	Under 10	Under 10
	41		Young	. .	10
	43		Medium	10	10
	46		Very old	Under 10	10
	48		Medium (but young)	. .	10–20
	56		Large	Under 10	. .
	58		Large-Medium	Under 10	. .
	62		Medium	. .	Under 10
	63		Old	10	. .
	64		Large medium	. .	Under 10
	68		Medium	. .	20
	69		Medium	Under 10	20–30
	72		Large	. .	30–40
	73		Large	. .	20–30
	74		Young	10	10
	83		Large	. .	20
	86		Large	. .	10
	87		Large	. .	Under 10

Table 5—continued.

RECORDED INTRA-GRID MOVEMENT.

Grid No.	Tag No.	Description of Rat.		Recorded Movements in Yards.	
		Sex.	Weight, Size, or Age.	Live-to-live Trap.	Live-to-dead Trap.
2	595	Female	6–12 months	20	30–40
(See Fig. 2 and Table 4)	596		6–12 months	..	Under 10
	939		4–6 months	..	10
	940		Under 4 months	..	Under 10
	942		4–6 months	Under 10	Under 10
	945		6–12 months	..	20–30
	946		6–12 months	Under 10	10
	949		6–12 months	Under 10	10
	956		Under 4 months	Under 10	Under 10
	960		4–6 months	10–20	10–20
	822	Male	4–6 months	Under 10	Under 10
	934		4–6 months	..	Under 10
	935		4–6 months	Under 10	20–30
	936		4–6 months	Under 10	Under 10
	937		6–12 months	..	10
	938		4–6 months	..	10
	943		4–6 months	10–20	10
	944		4–6 months	..	Under 10
	947		4–6 months	..	Under 10
	950		4–6 months	..	Under 10
	951		Under 4 months	..	Under 10
	953		4–6 months	..	10
	956		4–6 months	..	Under 10
	957		4–6 months	Under 10	Under 10
	958		4–6 months	..	Under 10
	959		4–6 months	..	Under 10
	964		4–6 months	..	10
	965		4–6 months	..	10
	966		4–6 months	..	10

SUMMARY.

—	Live-to-live.			Live-to-dead.		
	≤ 10	10–20	>20	≤ 10	10–20	>20
Female	12	3	1	23	1	3
Male	12	2	..	28	5	4
Total	24	5	1	51	6	7

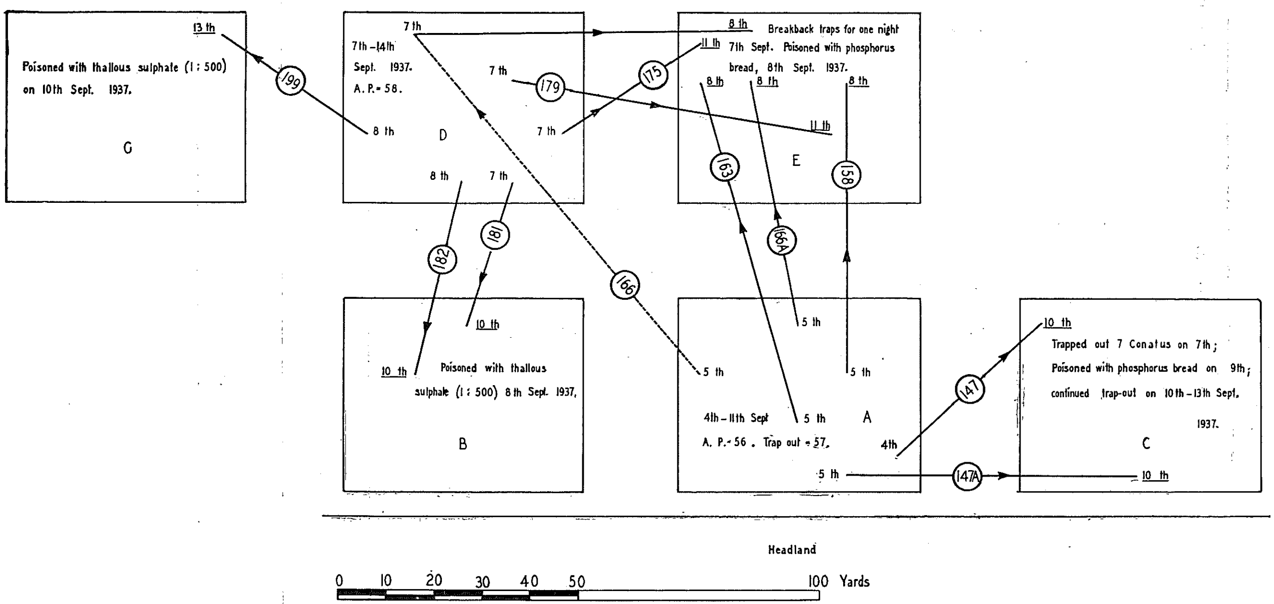


Figure 3.
Example of inter-grid movement chart for a grid series.

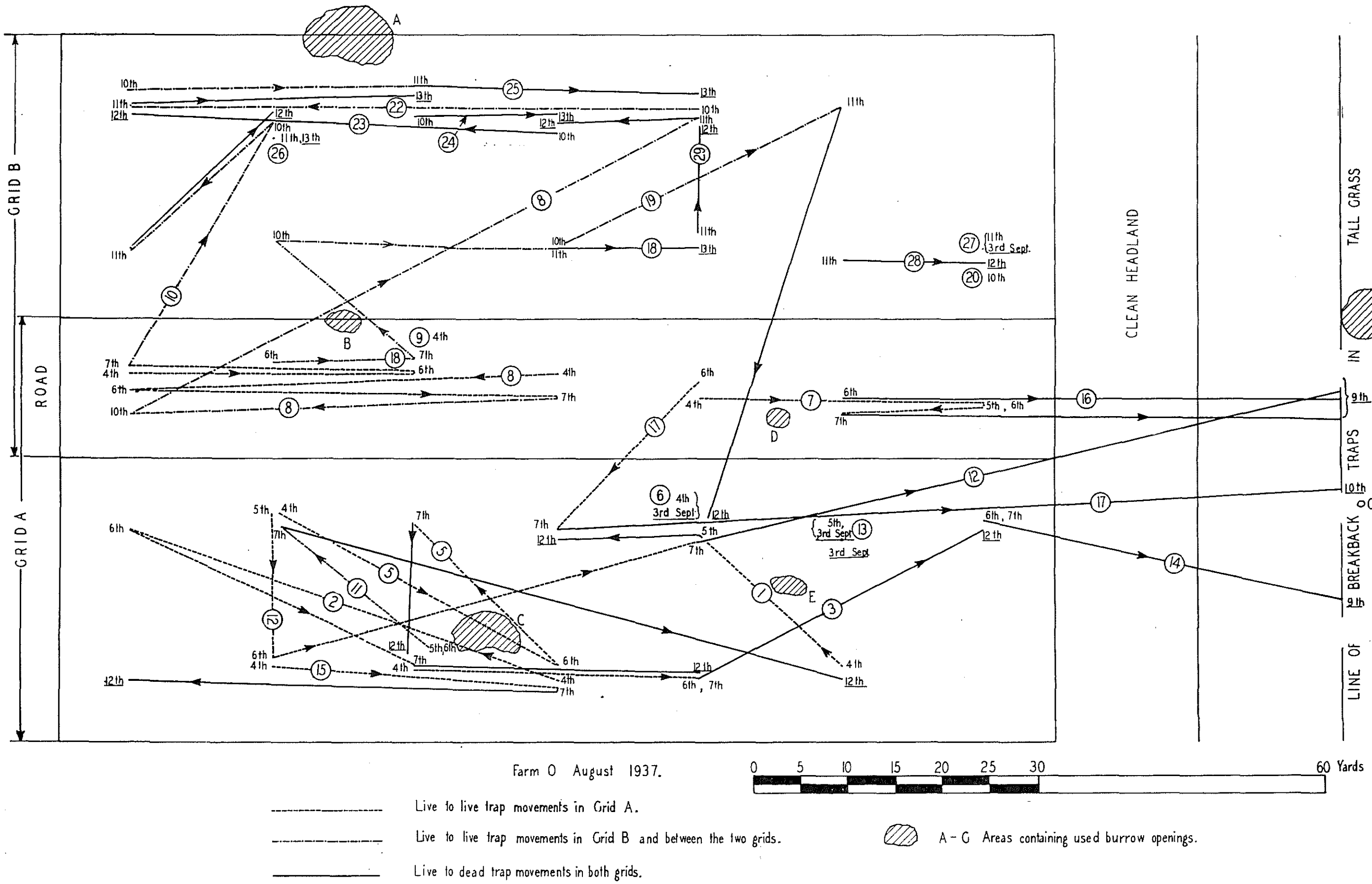


Figure 4.

Movement chart for two partially overlapped 3 x 7, 10-yd. interval grids and a trap-line. Note recorded movement across a clean headland; Tag No. 9 was found dead within 2 yd. of original site; and Tags Nos. 6, 13, and 27 were taken a' original trap sites 3 weeks after trap-out.

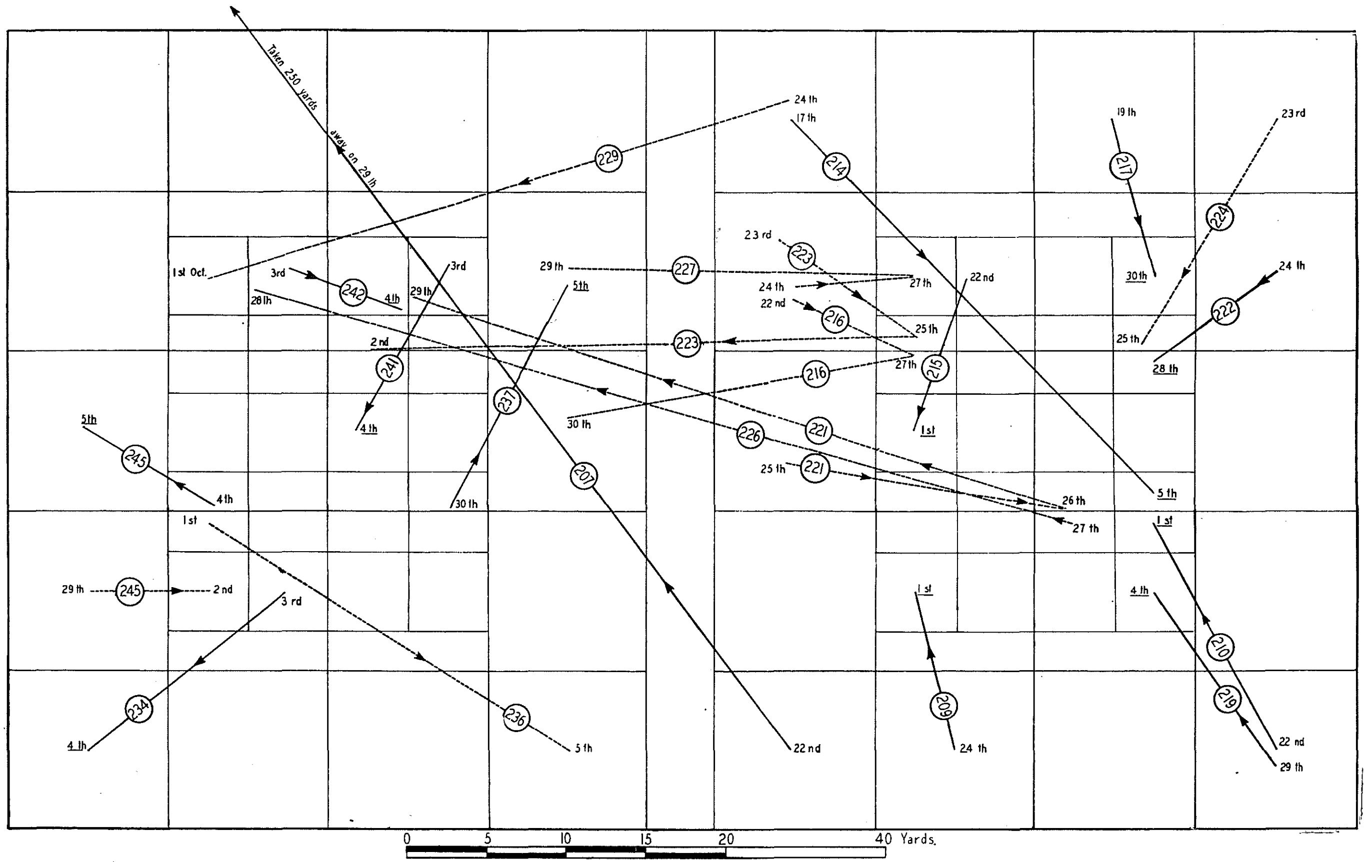


Figure 5.

Inter-grid movement chart for super-imposed grids in series.

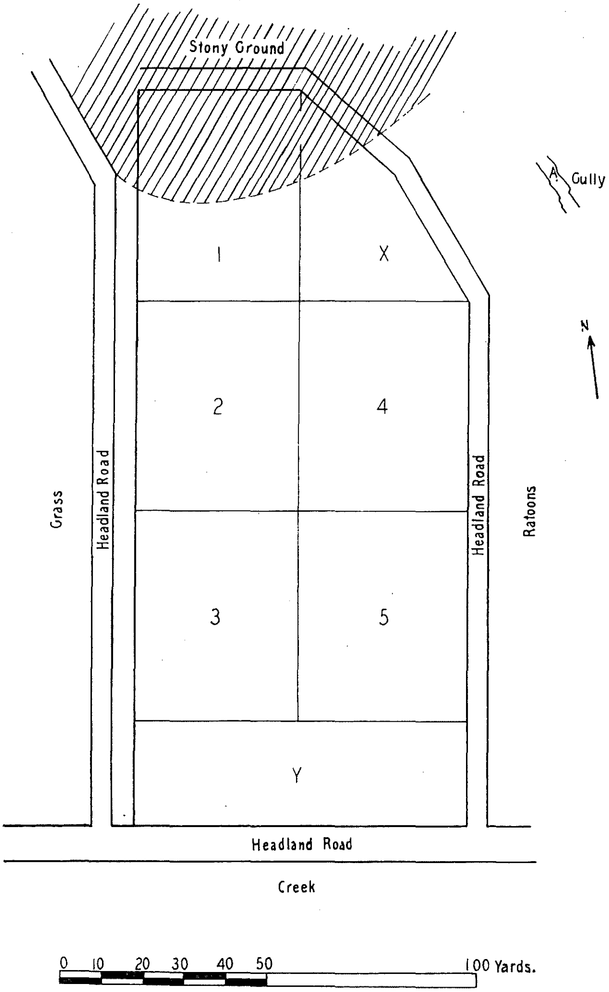


Figure 6.
Layout of a contiguous grid system.

Working with *R. conatus* on grids, various movements can be noticed, and the two extremes are (1) a settled system in which continued tagging results in practically all rats being tagged, and (2) a travelling population in which over a number of nights, even if moderate catches are tagged, only a few are recovered in the grid area. The continued natural additions of immature rats to the active population, if appreciable, simulates to some extent a travelling population; this can be checked by noting the ages of the new arrivals and continuing the tagging to indicate movements by the older rats. Between these extremes there are two types of movement discernible and discussed in detail later:—(*a*) continued movement in or out of the grid area, rats moving as individuals; (*b*) sudden movement of rats in or out of the grid area, the rats moving either as groups or as comparatively large portions of the population.

Storer *et al.* (1944), working with rodent populations in the Sierra Nevada of California, remarked when referring to various species:—"It was possible to distinguish two elements in the population: resident and non-resident. The resident population was determined by mapping the home ranges of individuals and was taken to include only those which ranged exclusively within the trapping boundaries" and "On the relatively small areas we used it was difficult to determine which individuals were resident; only those which seemed to spend most of their time inside the boundaries of the grids were so considered." Figs. 1, 2 and 4 demonstrate the possibilities of indicating home range of *R. conatus* on a single grid and Figs. 3, 4 and 5 record movements when some extra-grid trapping, with respect to one or more grid areas, is undertaken. From data derived from the combinations of grids in Appendix C some rats did not move more than 30 yd. during a period of three weeks; others had moved 600 yd. within two nights and in some instances returns to the original trapping sites were recorded; and groups of rats in settled populations have been found feeding regularly 60 yd. from their burrow areas. It is also evident that individual territorialism does not exist to any great extent. The difficulties encountered by Storer *et al.* are similar to those to be overcome in Queensland canefield grid work and it was concluded that in developing a temporary grid for practical use in an economic problem a population system would have to be used, which would render unnecessary a detailed consideration of a mass of data on behaviour and possible movements of individual rats.

At at early date it was apparent that, in such a project, emphasis must be given to time and space because of local movement of and amongst rat populations.

As favoured movement or search areas must be taken into account, the actual land occupied by the grid is not considered of primary importance; it is only a working base connected with a population system. This idea overcomes to some extent the consideration of the marginal error caused by rats entering and leaving grid areas (see page 170). Under certain conditions the actual area used by a settled system can be defined reasonably well by poisoning with a proven poison. Firstly a larger area is tagged or partially tagged; then, after poisoning on the grid area only, areas of complete kill can be mapped from trap-out data. These areas may coincide with a well-placed grid area or an even environment may cover the grid area plus one or more "bulges." *It was found that for general purposes there is an optimum grid size and grid interval with which best results are obtained when tag-trapping R. conatus; i.e., the 4 x 5 with 10-yd. interval, which was used over a number of years as the standard grid.* Larger grids include for consideration a wider variety of environment, tend to obscure local rat movements, do not lessen errors associated with standard grids, and are not suitable for routine work. Smaller grids,

Table 6.

TAG-TRAPPING DATA.

Grid No.	Date.	Farm.	Form grid.*	A.P.	Trap-out. 1st nt. catch.	Trap-out. Total catch.	No. of rats tagged.	Percent. A.P. tagged.	No. of tags in trap-out	No. of tags missing.	Per cent. of tags† in trap-out.	No. of rats‡ killed while tag.	Grid area in sq. yds.	Remarks.
1	Aug. 4–13, 1937	O	3 × 7	32	14	35	27	84·4	22	5	62·9	5	2,100	Apparently an isolated area
2	Sept. 4–11, 1937	O	4 × 5	56	14	57	37	66·1	20	15	38·6	7 (incl. 2 tags)	2,000	Grid only part of a larger infested area
3	Aug. 17–28, 1937	B	3 × 7	70	20	69	56	80·0	37	18	67·8	2 (1 tag)	2,100	Part of a large infested area. One F *M. littoralis* tagged but not recovered. 10 *M. littoralis* and 2 *M. cervinipes* trapped out. (This grid is adjacent to grid in Table 3)
4	Aug. 31–Sept. 5, 1937	B	4 × 5	24	12	24	12	50·0	12	Nil	50·0	1	2,000	4 *M. littoralis* also tagged but not taken in trap-out
5	Oct. 5–25, 1938	G	3 × 13	42	12	..	39	..	..	..	..	2 (2 tags)	3,900	This grid over-tagged. Rain interfered with trapping-out. 12 tags taken first night. On 24th and 25th only 7 rats (6 tags) present
6	July 27–Aug. 19, 1938	B	4 × 5	56	16	80	34	60·7	28	6	35·0	3	2,000	
7	May 7–11, 1938	B	4 × 5	11	..	11	8	72·7	8	Nil	72·7	Nil	2,000	
8	May 27–June 18, 1938	B	4 × 5	20	3	9	12	60·0	5	7	55·5	Nil	2,000	Some specimens weighing 20 g. tagged
9	Aug. 18–Sept. 1, 1938	B	4 × 5	20	9	15	18	90·0	11	7	73·3	Nil	2,000	
10	Aug. 24–Sept. 1, 1938	B	4 × 5	9	2	2	9	..	2	5	..	2 (2 tags)	2,000	

* All grids with 10–yd. interval. † Includes known "dead" tags. ‡ Included in trap-out total.

which usually mean a smaller grid interval also, tend to approach the unsatisfactory condition of line-trapping and are not as flexible with the time factor: both these detractions concern rat movements.

The smallest interval of time for sampling rat populations is one night and data so obtained is termed by Dice (1931) "catches of the 'first trap-night.' " That author concluded "that the number of individuals trapped per 'first trap-night' does not give a fully reliable index of the relative abundance of the several species living in a habitat." Working primarily with one species (*R. conatus*), this spot method is found unreliable (note Table 6), as it does not take into account variations in rat activities and trapping conditions from night to night or the factor R/T. Efficient trappers and good trapping equipment are essential for all population work but conditions are encountered in the field which cannot be completely counteracted: e.g., the effect of rain on trapping, the developing of mechanical defects in traps, the filling of traps by other rat species or other animals, and sometimes interference with set traps from several sources. These uncontrollable conditions also detract from the value of "trap-nights" (number of traps used × number of trapping nights) as an accurate quantity in population work: the author uses the term in Table 2, Plot 1, where it is concerned with an introductory project only. With R/T, the only controllable entity is the number of traps. To overcome the difficulties outlined in this paragraph a standard number of traps with standard grid interval was used, with time of tag-trapping the only and known variable, and the ultimate figure required was concerned with an apparent population. The author generally used only one trap per trapping place and partial tagging, which, with most of the population densities encountered, gave a satisfactory tag-trapping time interval.

In a few instances in settled populations, with densities at the rate of 1,500–2,000 active *R. conatus* per acre, the "post system" or multiple trap unit as used by Chitty (1937) and others was operated. This consists of a group of traps closely associated with each trap site; some suggestions on this set-up in experimental design are given by Leslie and Davis (1939). However, this author's experience with such high-order field rat densities was during 1936 and was not extensive: more numerous trials of a multiple trap unit under other circumstances were not warranted.

The idea of using marked or partially marked populations for study has been applied in other problems possibly to a greater extent than with rodents; e.g., by Jackson (reported in a series of papers, 1932-41) when working over large areas with tsetse fly, and by Gilmour *et al.* (1946) with the sheep blowfly (*Lucilia cuprina* Wied.) in Australia. However, with canefield rats only a simple mathematical treatment of partially tagged grid results has been attempted. An uncorrected grid population or apparent population (A.P.) may be obtained from the following:—

$$\text{A.P.} = \frac{\textit{No .of previously tagged rats} \times \textit{No. of rats caught on a particular night},}{\textit{No. of tagged rats caught on a particular night}}$$

in which the particular night is taken as the first night during which about half a reasonable catch consists of recaptured tagged specimens. Tables 6, 7, 8 and 9 illustrate results with different grids, with varying grid intervals, and with several combinations of grids. Under stipulated conditions an A.P. is a good estimate of the number of active rats (the population system) associated with a grid (the working base area) during a known time period of tag-trapping. The obtaining of an A.P. is a method of evaluating a population without undue interference, such as by sample "dead" trapping. When the bulk of the population is moving it is not practicable to obtain a satisfactory A.P., but in an endeavour to do so valuable information concerning population movement is gathered. For most experimental work, other than population sampling, A.P.'s have been used only comparatively with twin grids as the smallest field unit and often with more emphasis on changes in the A.P. than on the A.P. itself. Twin grids can be expanded to three or more comparable grids depending on the extent and uniformity of rat habitat and rat movements: one at least is always the check grid, the others the test grids. At any rate results from a number of twin grid units must be available for the consideration of any particular project. Care is necessary in setting out twin or multiple grids to avoid treatment in any grid interfering with population systems of the others. In this regard one of the most easily avoided errors is encountered when cane rows run across rat habitat on a slope. For convenience traps may be worked along the rows but results should be considered in grids with the slope.

Table 7.

TRAP-OUT RESULTS COVERING A GRID (OF KNOWN A.P.) AND SURROUNDINGS.

Grid No.	Date.	Farm.	Results and Remarks.
1	Aug. 31–Sept. 3, 1937	A	4 × 5 live grid, 10-yd. interval; area 2,000 sq. yd. in centre of apparently isolated infestation A.P. = 53; 42 rats tagged Complete trap-out of apparent habitat; 9 × 8, bb., 10–yd. interval; area 7,200 sq. yd. No. of rats taken on live grid site = 24, including 20 tags No. of rats taken in surroundings = 75, including 20 tags Total = 99, including 40 tags. (Also 2 *M. littoralis*)
			After trap-out two lines of bb. traps with 10–yd. intervals were used for trapping in area surrounding the trapped-out area; 7 *R. conatus* were taken.

Table 8.

Grid Data with Varied Grid Intervals and Trap Interspaces.

Grid No.	Date.	Farm.	Grid.	A.P.	No. of rats tagged.	No. of new tags on each grid.	No. of rats killed during tagging.	Trap-out.	No. of tags missing.	Grid area in sq. yd.	Remarks.
1	Oct. 5–19, 1937	B	4 × 5 20–yd. interval	51	39	39	Nil	Over large grid using bb. grid with 10 yd. interval. Total catch 52, including 33 tags	15	8,000	2 *M. littoralis* tagged but not recaptured; 3 others taken in trap-out
			4 × 5 10–yd. interval	18	13	5	Nil		..	2,000	
			4 × 5 5–yd. interval	21	14	4	Nil		..	500	
2	Sept. 28–Oct. 9, 1937	G	4 × 5 10–yd. interval	22	20	20	2 (incl. 1 tag)	4 × 5, 10–yd. interval. Total catch 13, including 10 tags	3	2,000	1 *M. littoralis* tagged but not recaptured
			4 × 5 5–yd. interval	11	11	5	2 (incl. 1 tag)		3	500	
3	Sept. 22–Oct. 2, 1937	G	4 × 5 10–yd. interval	29	21	21	2 (incl. 1 tag)	4 × 5, 5–yd. interval (*i.e.*, only covers the smaller grid). Total catch 21, including 19 tags	3	2,000	Rats commenced to move between Oct. 1 and 2
			4 × 5 5–yd. interval	14	13	2	Nil		3	500	

C	4	Nov. 2–20, 1937	Gr.	3 × 7 20–yd. interval	27	23	23	Nil		..	8,400	A.P. for grid of 10–yd. interval not available. Traps were closed before half the catch on a particular night were return tags. This grid was trapped out from 13–20th Dec. on the 20 × 10 grid; 43 rats taken including 24 of the original tags
				3 × 7 20–yd. × 10 yd.	47	25	5	Nil		..	4,200	
				3 × 7 10–yd. interval	..	16	5	2 (2 tags)		..	2,100	

Table 9.

TRAP-OUTS OF TAGGED GRIDS.

Farm Gr. All live grids 4 x 5 and all grids with 10-yd. intervals.

Grid No.	Date.	A.P.	No. of new rats tagged.	Per cent. A.P. tagged.	No. of rats killed during tagging.	Trap-out.	Remarks.
1	Oct. 16–19, 1937	20	15	75·0	Nil	Nov. 2–8 over whole area, including 5 grids, 9 × 4 (Fig. 5) of 2·84 ac. 104, *R. conatus* including 39 tags (44 tags missing) 6 *M. littoralis*, including 1 tag 11 *M. musculus*	5 *M. littoralis* tagged
2	Oct. 20–21, 1937	39	28	77·0	5 (incl. 3 tags)		3 tags from grid No. 1 appeared in this grid
3	Oct. 23–25, 1937	27	19	74·0	4 (incl. 3 tags)		1 tag from grid No. 2 appeared in this grid. 1 *M. littoralis* tagged
4	Oct. 26–28, 1937	34	21	85·3	1 (1 tag)		8 tags from other grids appeared in this grid and 2 *T. g. ultra* tagged
5	Oct. 29–Nov. 1, 1937	66	8	?	1 (1 tag)		22 tags from other grids appeared in this grid

Table 10.

MEAN WEIGHTS ON SUCCESSIVE TRAP NIGHTS.

(Grids Nos. 1 and 2, 8 x 5, 10-yd. interval; No. 6, 4 x 8, 10-yd. interval; all others, 4 x 5, 10-yd. interval.)

Grid No.	Trap nights.* 1st.	2nd.	3rd.	4th.	5th.	6th.	Regression Coefficient.	
3	105·3	83·1	83·9	73·8	69	†	− 8·21 ± 1·27	Trapping Out.
	15	15	14	13	14			
4	92·2	82·0	93·7	95·0	73·5		− 1·21 ± 3·70	
	11	10	7	3				
5	103·1	94·4	99·4	55·0			− 6·12 ± 7·91	
	11	13	7	1	0	0		
6	114·1	115·0	125·5				5·17 ± 8·47	
	10	4	4					
8	75·2	66·9	56·5	66·6	—	62·5	− 3·75 ± 3·25	
	13	16	13	5	—	2		
12	90·1	88·3	95·5				1·8 ± 6·62	
	9	3	2					
14	80·1	60·3	51·8	101·3			− 2·44 ± 5·09	
	30	10	4					
15	106·6	80·4	110·0	78·7			− 9·38 ± 4·55	
	17	5	1	3				
17	101·9	92·6	91				− 5·95 ± 6·28	
	10	5	4					
1 †	80·1	109·0	83·2				4·25 ± 9·12	Tag Trapping.
	16	9	8					
2 †	71·6	73·8	105·7				15·13 ± 8·23	
	21	12	9					
3	85·6	75·4	86				− ·37 ± 3·73	
	16	17	12					
4	78·9	72·7	63·9	50·0	74·8	71·3	− 1·30 ± 2·49	
	8	7	8	6	5	9		
5	85·9	82·8	76·6				− 4·55 ± 5·37	
	13	12	9					
6	82·1	88·5	71·0				− 4·73 ± 6·50	
	12	10	8					
7 †	68·8	70·4	78·2	74·9			2·78 ± 4·32	
	9	10	13	9				
9 †	89·1	62·2	65·2				− 13·10 ± 6·47	
	9	9	6					
11 †	81·4	99·3	79·6	82·7			− 1·35 ± 3·18	
	13	12	10	13				
12	105·9	79·3	97·4				− 3·91 ± 1·03	
	10	10	11					
13 †	97·7	89·9	77·2	94·9			− 1·73 ± 3·29	
	15	14	9	14				
16 †	72·7	83·7	80·0				3·79 ± 7·10	
	6	3	5					
17	98·8	100·6	98·3	106·8			1·93 ± 4·26	
	12	8	7	6				

* Data for trap nights given as mean weight in grams and number in sample.
† Data for trap-outs not used owing to rat movement.

The value of A.P. and twin grids has been tested experimentally and specifically on the following points:—

1. *To find if trapping deals completely with a population system and if tag-trapping deals selectively with parts of the population.*

Only trapping-out is of use in attempting the first part of this project. The author is aware of the very important fact that closed systems for rodent field work should be avoided, but in this instance there is only one alternative (q.v.); also, results from fenced or cordoned grids were discarded if the check grids indicated any appreciable population movement during tagging and trapping-out. Grids were fenced with hessian sunk 6 in. into the ground and with $2\frac{1}{2}$ ft. above ground hung on wire and steel posts: one or two furrows were thrown up against the fence barrier on the outside and any cut tunnels were closed. The enclosed population was either completely or partially tagged and then trapped out. In settled populations the trap-out under good trapping conditions is comparatively sudden when R/T is small: as a typical example the recorded nightly catches in a non-breeding population from a 4 x 5, 10-yd. interval bb. grid were 20, 14, 6, 0, 0, 0 (see also Table 10). When trapping-out in breeding populations rats weighing less than 18g. were not counted (see McDougall, 1946). All enclosed grids were retrapped at intervals approximating to 1, 2, 4 and 8 weeks after trap-out and occasionally a tagged rat and/or a rat which by age determination could have been active at the time of the original trap-out was taken.

Grids were cordoned with staggered inner lines of break-back and outer lines of Bureau traps, all at 5-yd. intervals, and an occasional rat remained on the grids after trap-out. These rats, less than 1 per cent., are comparable to the few specimens of suitable size and age which temporarily would not feed or behave in a normal manner in food and poison tests (McDougall, 1944c), and are considered of little consequence in population work.

During trapping-out in settled populations average weight per night decreases as the trap-out proceeds (Table 10—weighted average of coefficients is — 3·38, which differs significantly from zero) and in catches of the first night there is sometimes a preponderance of females (McDougall, 1946). When tag-trapping there is no significant difference in average weight per night: figures for 13 grids are given in Table 10 and an examination of these shows that none of the individual grid regression coefficients is significant and that the weighted average is not significantly different from zero. However, when tagged rats associated with A.P.'s are compared with the subsequent complete trap-out catch it is found that both are sound samples of the active population.

2. *The effects on A.P. of removing or adding known numbers of rats from or to grid areas.*

From 21 well-placed grids with known A.P.'s varying numbers of rats have been trapped out and the expected A.P.'s of the remaining population have been determined by further tag-trapping. When there is no sudden movement

Table 11.

PARTIAL TRAPPING OUT OF GRIDS WITH KNOWN A.P.

Farm B. All grids 4 x 5, 10-yd. interval; B and bb.

Grid No.	Date.	A.P.		No. of rats tagged.	Per cent. A.P. tagged.	Trap-out.	No. of tags in trap-out.	Per cent. of tags in trap-out.	No. of tags missing.	No. of rats killed during tagging.	Remarks.
		Actual.	Expected.								
1	July 13–15, 1938	32	..	16	50·0	..	..	..	..	Nil	Following 1c another live grid was intended. However, on July 26–August 2 all rats moved off the grid and later 7 of the missing tags were taken elsewhere (2 at 600 yds. away). On August 4–7 the grid area was invaded and 15 non-tagged *R. conatus* were taken
1A	July 20	..	..	..	..	12	7	58·3	..	..	
1B	July 21–23	19	20	11	57·9	..	..	..	..	1 tag	
1C	July, 26	..	..	..	..	4	3	75·0	16	..	

Table 12.

ADDING RATS TO A GRID WITH KNOWN A.P.

Farm N: 4 x 5, 10-yd. interval (2,000 sq. yd.) ; $\mathring{B}$ and bb.

Grid No.	Date.	A.P.		No. of tags added and date.	No. of rats tagged.	Per cent. A.P. tagged.	Trap-out.	No. of tags in trap-out.	Per cent. of tags in trap-out.	No. of tags missing.	No. of rats killed during tagging.	Remarks.
		Actual.	Expected.									
1	June 12–14, 1940	14	..	..	10	71·4	..	..	..	..	3	1 *M. littoralis* tagged on 12th ; recaptured on 15th.
	June 15–16	22	19	5 on 15th	16	72·7	..	..	..	..	1 tag	
	June 16–21	?	26	4 on 16th	22	..	24, including 7 of the added tags	16	72·7	2 added tags and 4 other tags	1 tag	No *M. littoralis* in trap-out.

Table 13.

FEEDING STATIONS.

All feeding stations on 4 x 5, 10-yd. interval grids.

Farm and Grid No.	Date of feeding tests.	A.P. (and type.)	No. of tagged adults and mean weight in grams.	No. of sub-adults and mean weight in grams.	Estimated maximum intake per night by rat population in grams.	Intakes in grams on successive nights.										Remarks.
						1st.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	
A1	May 12–16, 1938	26 direct	7 106·4	9 57·0	169·1 ..	106 ..	140 ..	.. ..	822 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	From July 22–29 rats moving in this grid ; A.P. not available at this time and nightly catch was 6–9 *R. conatus* : total 44. Trapped-out Aug. 10–18, 32 rats taken.
	July 6–9, 1938	30 direct and in-direct	6 102·1	9 78·4	233·6 ..	10 ..	288 ..	867 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	
A2	June 21–July 1, 1938	31 direct and in-direct	5 101·8	23 70·6	233·8 ..	326 ..	1,017		388 ..	754		586		459 ..	472 ..	Trapped-out Aug. 10–19 ; 32 *R. conatus* and 5 *M. littoralis*.
	Aug. 1–9, 1938	34 direct	12 129·1	17 73·0	276·3 ..	452 ..	686 ..	610 ..	647 ..	1,848			793 ..	.. ..	.. ..	..
A3	May 31–June 9, 1938	11 in-direct and direct	8 117·1	2 79·0	77·3 ..	127 ..	154 ..	254 ..	322 ..	317 ..	401 ..	476 ..	580 ..	639 ..	.. ..	..
A4	May 31–June 9, 1938	12 direct	5 119·0	7 43·3	69·4 ..	241 ..	107 ..	281 ..	358 ..	447 ..	496 ..	449 ..	536 ..	550 ..	.. ..	..

Table 13—continued.

FEEDING STATIONS—*continued.*

All feeding stations on 4 x 5, 10-yd. interval grids.

Farm and Grid No.	Date of feeding tests.	A.P. (and type).	No. of tagged adults and mean weight in grams.	No. of sub-adults and mean weight in grams.	Estimated maximum intake per night by rat population in grams.	Intakes in grams on successive nights. 1st.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	Remarks.
A5	June 24–29, 1938	3 in-direct, nil direct	..	..	..	85	55	77	207	..	..	..	..	..	..	May 27–June 2 A.P. 20. Trapped-out June 15–18, 17 *R. conatus*. Re-trapped June 30–July 2, 3 *R. conatus*.
B6	July 12–15, 1938	20 in-direct	2 89·0	12 64·5	135·1 ..	284 ..	459 ..	541 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	On July 21 an invasion of this grid commenced. A.P. at end of July, 45.
	June 10–16, 1938	..	..	..	..	51	564 (2nd–5th)				262	253	..	..	..	Population moving. 6–8 rats tagged each night on the check grid.
B7	June 15–22	32 in-direct	5 93·0	11 68·5	225·3 ..	473 (1st–4th)				500 ..	.. ..	.. ..	.. ..	.. ..	.. ..	Towards end of July population settled.
B8	Dec. 16–17, 1938	..	..	..	..	237	291	..	..	..	..	..	..	..	..	Trapped-out Nov. 30–Dec. 15, 27 *R. conatus*. After feeding tests again trapped-out, 3 *R. conatus*.
B9	Dec. 16–17, 1938	..	..	..	..	590	789	..	..	..	..	..	..	..	..	Trapped-out Dec. 13–15, 21 *R. conatus*. After feeding tests again trapped-out, nil.

B10	Nov. 9–19, 1938	..	..	..	..	2,490 All wheat supplied eaten			5,660 All wheat supplied eaten			No wheat supplied			294	Population moving. 12 *R. conatus* taken on 8th, 59 from Nov. 20 to Dec. 8, but rats still moving into grid. See grid 11.
B11	Nov. 9–23, 1938	..	..	..	..	1,811 All wheat supplied eaten			4,273 All wheat supplied eaten			No wheat supplied		2,837	998	Population moving. Trapped-out Nov. 24–Dec. 22, 48 *R. conatus*. Grids 10 and 11 25 yards apart in same environment.
H12	Aug. 22–29, 1938	22 ..	7 122·3	15 71·7	.. 123·6	.. 174	302		103		275		..	..	..	Settled population ; all rats tagged.
H13	Oct. 28– Nov. 1, 1938	44 direct	8 96·3	12 70·4	311·9 ..		1,029 ..		275 ..	..	..	..	..	..	..	During nights of 24th and 25th there was a large influx. A.P. increased from 20–26 to 40–44. Population remained settled until Nov. 9 (A.P. 43) when rats commenced to move away.
A14	Oct. 4–11, 1936	28 direct	..	..	..	68	133	133		750			..	..	..	Mixed population of *R. conatus* and *R. culmorum*. All rats tagged.
B15	June 27– Oct. 5, 1939	25 direct	9 118·1	11 77·7	202·9 ..	475 ..	325 ..	402 ..	448 ..		2,605			..	..	Trap-out July 12–15 yielded 27 *R. conatus* and 2 *M. littoralis*.

of populations, data as given in Table 11 are typical of this type of experiment and it was concluded from the results that the A.P. gave a correct measure of the population.

There is a serious shortcoming (page 222) in the addition of rats to grids as a method of studying population numbers and the same amount of work was not undertaken along this line. However, as a matter of interest, figures for one experiment are given in Table 12.

3. *Evaluating effects of differential treatment of each of the twin grids; e.g., elimination of rats or the use of feeding stations on the treatment grid only.*

This subject forms the basis for a good deal of discussion later on population dispersal and movement. Differences between A.P.'s and subsequent trap-out catches—as shown in Table 6, grids 6, 8 and 10—are also referable to this subject, though in these instances the longer time periods of the experiments should be noted.

Field work with poisons, baits and foods based on the use of A.P. and twin or multi-grids is discussed in Part 6 of this series.

Feeding Stations.

Most of the work on feeding stations was carried out with twin grids (each 4 x 5 with 10-yd. intervals) using whole wheat in excess quantities as the standard test food and paying particular attention to the possibility of the feeding stations interfering with normal rat movement and behaviour. Apparent populations were determined in two ways:—

1. Directly, by determining the A.P. in each grid then continuing the tag-trapping in the check grid after feeding stations had been set out in the other.
2. Indirectly, by obtaining the A.P. in one grid at the same time as the feeding stations were being used in the other.

With *R. conatus* in a settled population at least a 10-yd. interval of feeding stations is necessary to contact all rats in the grid area. Grid intervals of 30 to 40 yd. which have been used by local workers on occasions in some districts of Queensland for help in the estimation of rat populations could not give even reasonably approximate estimates. Doty (1938, 1945) suggested four feeding stations to one acre as being sufficient to contact all rats during control work in Hawaiian sugar plantations.

There is usually a build-up of food intake over a short period following the setting up of feeding stations in rodent populations. Doty (1938) and Chitty (1942), when working with *R. norvegicus,* found the intake increased progressively over a period up to nine days. Chitty (1942) suggested that the number of rats which are feeding increases for several days and a "peak" rate of feeding is reached which is seldom exceeded unless the colony is being reinforced by breeding or immigration. Roebuck *et al.* (1944) recorded a build-up over "a day or two" for the mouse, *Apodemus sylvaticus.* With

R. conatus it was found that in a settled population the build-up of intake was most pronounced over the first two nights irrespective of whether stations were in grid formation or in a more isolated distribution. (See Table 13.)

Very frequently in this work the actual intake of food from the stations varied considerably from the estimated.* Sometimes unexpectedly large nightly intakes were recorded due to interference to the feeding stations by large fauna such as wallabies, rat kangaroos, pigs and scrub turkeys; this was very obvious as trays and covers were usually upset or deranged.

Grids 8 and 9 (Table 13) are examples of appreciable intakes of wheat when *R. conatus* had been trapped out and influxes of rats were negligible. Also in one 8 x 5, 10-yd. interval feeding station grid set out in flat forest country at Rosella in the Mackay district, in a locality where there were no signs of *R. conatus,* 40 lb. of whole wheat was consumed over a period of eight days. During the same time, some of the break-back traps which were set around each station had been sprung but no rats captured, and several tray covers had been disturbed. Obviously rats were not responsible for the disappearance of the wheat, but though an occasional bandicoot with a cracked skull was found near the traps no particular animal species could be held wholly responsible. The same may be said for all excess intake during rat feeding experiments in Queensland canefields.

Occasionally a feeding station grid showing a reasonably constant, or steady increasing, intake over several nights decreased considerably and permanently, though the rat population had not moved or altered to any extent. In some instances this happening was obviously due to emigration of other animals.

The importance of interference by other animals with intakes from an open system has not been generally recognized in Queensland and there is very little information as to what species may be involved. Elsewhere (McDougall, 1944a), animals other than rats and mice taken in rat traps in canefields and adjacent places have been listed, but there has been no attempt at a quantitative evaluation. In this connexion, Dice (1931) pointed out that the difficulty of securing a complete or nearly complete list of fauna in each of a number of small areas would be considerable.

In rodent control work with feeding stations it is the usual practice in urban and other populated areas to attempt to deny the other animals access to the stations by protection or special design of the stations. In Hawaii, some stations in the field took the form of specially constructed boxwood shelters and Doty (1938) remarked that the only noteworthy objection was the awkwardness which the transportation of any considerable number of these would involve if

$$\text{* Estimated intake} = \left[\left(\begin{matrix}\text{No. of tagged}\\ \text{adults} \times \text{mean}\\ \text{weight} \times \cdot 064\end{matrix}\right) + \left(\begin{matrix}\text{No. of tagged sub-}\\ \text{adults and immatures} \times\\ \text{mean weight} \times \cdot 11\end{matrix}\right)\right] \times \frac{\text{A.P.}}{\text{No. of rats tagged}}.$$

The factor ·064 is the mean standard intake of whole wheat by adults in cages (McDougall, 1944) and ·11 is a similar figure for sub-adults and immatures. These figures are an indication of the stomach capacities of the respective classes.

Table 14.

EXAMPLES OF DATA ON PELLET COUNTS, DAMAGE OF STALKS AND ECONOMIC LOSSES.
All grids with 10-yd. intervals.

Farm and Grid No.	Grid type.	Cane var. and est. tonnage per acre.	Average No. of pellets per counting place.	Rat population and date.	Damage to cane.				Remarks.
					Per cent. stalks damaged.	Degree of stalk damage.	Est. probable economic loss.	Date of inspection.	
B.1	4 × 5	H.Q. 426 Rt. at 10	. .	A.P. = 53 (31.8.37–3.9.37)	16·9	1·9 bites per stalk	3 cwt. cane on grid area	1.9.37	Cane in dirty condition (This is grid figured in Table 7)
B.2	3 × 7	Q. 813 Pl. at 30	. .	A.P. = 70 (17–21.8.37) Trap-out = 69 (22–28.8.37)	22·9	3·8	Negligible	22.8.37	Cane lodged; harvested in early Sept. Amount of cane left on plot less than 1 cwt. Rat attack commenced 2nd week in July. *Melomys* spp. present in this grid (Grid 3, Table 6)
B.3	5 × 8	P.O.J.2714 Rt. at 15	1·6 (11.3.38) 1·8 (12.3.38)	A.P. = 32 (6.3.38)	Nil	. .	. .	7.3.38	
G.4	4 × 5	H.Q.426 Rt. at 18	Nil (21.5.38)	A.P. = 11 21–24.5.38)	Nil	. .	. .	23.5.38	
G.5	4 × 5	H.Q.426 Rt. at 18	3 (21.5.38)	A.P. = 12 (21–24.5.38)	Nil	. .	. .	22.5.38	Note intake of wheat on this grid (Grid 4, Table 13)
H.6	4 × 5	Co.290 Rt. at 15	. .	A.P. = 23 (17–19.8.38)	Not sufficient to warrant counting	. .	. .	18.8.38	

H.7	4 × 5	P.O.J.213 Co.290 Rt. at 12	Nil (9.7.38)	A.P. = 32 (13–15.7.38)	Nil	..	..	19.7.38	Cane in dirty condition
H.8	4 × 5	Co.290 Pl. at 24	1·05 (10.8.38)	A.P. = 22 (11–17.8.38)	5·4	1·2	Negligible	15.8.38	No *Melomys* spp. attacking cane
H.9	4 × 6	Co.290 Pl. at 25	4·6	A.P. = 23 (7–10.8.38)	7·5	1·1	Negligible	6.8.38	No *Melomys* spp. attacking cane
O.10	4 × 5	P.O.J.2725 Pl. at 30	9·05 (20.9.38)	A.P. = 32 (20–23.9.38)	7·7	2·4	Negligible	20.9.38	Trap-out 12 – 14.10.38 = 21, but pop. became unsettled early in Oct. Only *R. culmorum* present
O.11	4 × 5	P.O.J.2725 Pl. at 30	12·20 (10– (14.10.38)	Trap-out = 13 (14.10.38)	1·1	1·1	Negligible	13.10.38	Mixture of *R. culmorum* (10) and *R. conatus* (3)
M.12	4 × 5	P.O.J.2878 Pl. at 22	1·0 (23.9.39)	Trap-out = 11 (23–28.9.39)	5·0	1·3	Negligible	28.9.39	

Table 15.

Examples of Records from Permanent Grid Sites.
All grids 4 x 5, 10-yd. interval unless otherwise indicated.

Year.		1937.	1938.	1939.	1940.
Farm and Grid No.	Grid situation.		Observations.		
B.1	P.O.J.213 (·2 ac.)	May–June : T.O.* = 474 *R. conatus*. Aug. and Nov. : Sampling trapping indicates presence of rats. (See Table 2, Plot. 1.) Dec. : T.O. = Nil	Feb. : T.O. = 27 *R. conatus* and 1 *T. g. ultra* July : T.O. = 59	Not planted to cane. Line trapping indicates no obvious rat populations	
B.2	D.1135† (1 ac.)	May : T.O. = 20. Sept. : Seepage ceasing. T.O. = 10	Seepage ceased. Not planted to cane : no obvious rat populations.		
B.3 (a) B.3 (b) B.3 (c)	Q.813	(a) Aug. : A.P. = 75 (b) Aug. : A.P. = 35 (c) Aug. : A.P. = 65 111 tags left in the three grids	Jan. / May. / July. / Aug. (a) Nil A.P. = 31 A.P. = 85 A.P. = 99 (b) Nil A.P. = 24 A.P. = 37 (c) Nil A.P. = 26 A.P. = 42 A.P. = 39 127 tags left in the three grids ; cane harvested end of August	July. (a), (b), (c) T.O. = Nil Volunteer growth	1940–45 out of cane ; grazed, no rats
B.4	Star dover from 1936	Nov.–Dec. Nil; June. T.O. = 219; Aug. A.P. = 24, T.O. = 24 (See Table 2, Plot 2)	Feb. : T.O. = Nil		

B.5	P.O.J.2714 (1 ac.)	May. A.P. = 11; July. A.P. = 17; Nov. Rats moving, heavily poisoned, T.O. = 18			
B.6	Co.290	Oct. A.P. = 51; Nov.–Dec. Rats moving, none tagged; 33 tags left in grid	June. A.P. = 25; July. A.P. = 27; Aug. Rats moving; Sept. A.P. = 55; 33 tags left	Jan. T.O. = Nil; July. A.P. = 22	
B.7	H.Q.426	Sept.: T.O. = 40	May. T.O. = 11; Aug. T.O. = 16; Field harvested in Aug.	May. T.O. = 11; July. A.P. = 10; Field harvested in Aug.	
B.8	Saccaline sorghum	..	June. A.P. = 21; July. Rats moving, trapped 59; Sept. Heavily poisoned; Nov. A.P. = 29	Jan. T.O. = 5; Feb. T.O. = 24; Mar. T.O. = 8; May. T.O. = 6; Field ploughed out in June	
O.9 (*a*) (*b*)	P.O.J.2725	Sept.: (*a*) A.P. = 30 (all *R. culmorum*) (*b*) A.P. = 35 (all *R. culmorum*)	Jan. (*a*) T.O. = 3 *R. conatus* (*b*) T.O. = Nil; Nov. (*a*) T.O. = 3 *R. conatus* (*b*) T.O. = Nil		
G.10	Light grass	July. A.P. = 40; Oct. T.O. = Nil	Jan. T.O. = Nil; June. T.O. = Nil		

* T.O. = trap-out.
† 1935: Nov.: T.O. = 29 *conatus*. 1936: Jan.: Nil, Mar.: T.O. = 93. Dec.: T.O. = 21.

they were placed in sections at a distance from an auto road (*sic*). In Queensland, however, open baiting systems have been the only attempt at control on a commercial scale, since the costs of control are very important when appreciable rat attacks occur only sporadically and the damage is often in the nature of a nuisance. Experimentally it was found that in Queensland canefields the working of open feeding stations is more laborious than tag-trapping and at the same time yields comparatively poor quantitative data. With regard to protected feeding stations, this author considers that their cost and the difficulty of handling them preclude their use even for experimental purposes.

Attending feeding stations amongst high rat population densities under wet conditions was the filthiest work encountered by the author during this investigation.

WORK OVER LARGER AREAS.

The author found that the best extension of population work over large areas consisted basically of tag-trapping on as many grids as possible under varying conditions.

Storer *et al.* (1944) remarked that "the total active population showed definite seasonal trends" and "seasonal changes in weather doubtless played an important part in determining the extent of activity." It is obvious that there are seasonal and annual fluctuations in population densities of *R. conatus* at stipulated places. Table 15, showing some records of permanent grid sites, illustrates this very clearly, and Table 16, containing data from a selection of grids over shorter time periods, also shows the turnover of population. Non-recovery of tagged rats is an indication of population movement from a particular place and for most tag-trapping at Mackay there were large numbers of marked animals which were never recovered (see Table 6). Other workers—e.g., Chitty (1937), Evans (1942) and Storer *et al.* (1944)—have reported similar experiences. On one occasion 617 rats of varying ages were marked during October and November for the special purpose of recovery during the following calendar year, and only one was retaken. This was a female tagged at 9 months in November and re-trapped during the following February four miles from the tagging place.

An examination of results from grids with known population compositions indicates a definite, normal sequence in population turnover, activity and behaviour. During late summer and autumn there is a steady turnover of population and at the same time an increase in density on grids where environment remains suitable for continued habitation by *R. conatus*. This turnover is definitely not related to grid size and so-called "home range," as it has occurred in partially tagged plots up to 12 acres. During winter—i.e., late June, July and August—there is a marked increase in activity and general movements and sharp alterations in population densities. From late August to October-November (i.e., spring) there is a settling down followed by another period of obvious movement. Periods of least movement coincide with the actual or potential peaks of breeding seasons (McDougall, 1946).

D

Table 16.

POPULATION COMPOSITION ON SEMI-PERMANENT GRIDS.

All grids 4 x 5, 10-yd. interval, unless otherwise indicated.

Grid No.	Situation.	Date.	Density.	Population composition.* Age in months and sex.						Remarks.
				Under 4.	4–6.	7–9.	10–12.	13–18.	19–24.	
1	In Q.813	6–9.5.38	A.P. = 24	..	4 3 F, 1 M	3 3 F	2 1 F, 1 M	5 4 F, 1 M	1 1 M	
		27–29.7.38	A.P. = 59	12 3 F, 9 M	15 4 F, 11 M	5 4 F, 1 M	1 1 F	1 1 F	..	One tag from another plot present; one of the May tags taken, viz.:—the F originally 10–12 months
		2–19.8.38	T.O. = 67	11 2 F, 9 M	33 11 F, 22 M	15 7 F, 8 M	5 4 F, 1 M	3 3 F	..	5 of the May tags taken, viz.:—2 F originally 7–9 months and 3 F originally 13–18 months. Rats moving during T.O.; 4 tags from other plots
2	In Q.813	10–12.5.38	A.P. = 26	4 4 M	5 3 F, 2 M	3 2 F, 1 M	3 3 M	2 1 F, 1 M	..	6 tags from other grids: 3 F, 3 M
		22–30.6.38	Rats moving, 33 tagged	19 9 F, 10 M	9 4 F, 5 M	3 3 F	2 1 F, 1 M	..	..	4 tags from other grids. 4 May tags taken, viz.:—4 F; 3 originally 4–6 months, the other 7–9 months
		10–18.8.38	T.O. = 31	6 2 F, 4 M	12 6 F, 6 M	8 F 8	4 3 F, 1 M	1 1 F	..	One May tag taken, a F originally 7–9 months; 3 June tags taken, viz.:—2 F, 1 M, originally under 4 months

Table 16—continued.

POPULATION COMPOSITION ON SEMI-PERMANENT GRIDS—*continued.*

All grids 4 x 5, 10-yd. interval, unless otherwise indicated.

Grid No.	Situation.	Date.	Density.	Population composition.* Age in months and sex.						Remarks.
				Under 4.	4–6.	7–9.	10–12.	13–18.	19–24.	
3	In Q.813	6–9–5.38	A.P. = 12	3 2. F, 1 M	3 3 F	. .	3 2 F, 1 M	1 1 F	2 1 F, 1 M	8 tags from other plots; viz.—1 F originally under 4; 2 F, 4–6; 2 F and 1 M, 7–9; and 1 F and 1 M, 13–18 months
		7–9.7 38	A.P. = 31	8 3 F, 5 M	12 5 F, 7 M	5 2 F, 3 M	. .	1 1 F	1 1 F	Over-tagged. One May tag retaken, viz.—a F originally 10–12 months
		10–19.8.38	T.O. = 41	9 4 F, 5 M	8 1 F, 7 M	6 1 F, 5 M	5 3 F, 2 M	3 1 F, 2 M	. .	Also 10 mutilated. 2 June tags retaken, viz.—a M and a F originally 4–6 months, 6 tags from other grids taken. Six (5 in last two days) *M. littoralis* taken
4	In Q.813	18–20.5.38	A.P. = 46	9 4 F, 5 M	9 6 F, 3 M	4 3 F, 1 M	5 3 F, 2 M	2 2 F	. .	1 *M. littoralis* tagged. 12 tags from other grids present
		19–26.8.38	T.O. = 20	2 2 M	1 1 M	4 1 F, 3 M	7 4 F, 3 M	3 3 F	1 1 F	2 rats mutilated. No tags taken
5	In Co.290	3–6.5.38	A.P. = 37	7 2 F, 5 M	5 2 F, 3 M	4 4 F	2 2 M	2 1 F, 1 M	1 1 M	2 tags from other plots present
		20–23.7.38	A.P. = 45	13 6 F, 7 M	13 6 F, 7 M	4 3 F, 1 M	2 2 F	1 1 F	. .	3 May tags taken, viz.—3 M originally 4–6 months. 2 tags from other grids present

6	In Grass	22–30–6–38	A.P. = 22	5 3 F, 2 M	6 3 F, 3 M	2 2 F	5 5 F	..	..	Over-tagged
		22–25.7.38	A.P. = 32	5 5 M	4 2 F, 2 M	3 3 F	3 3 F	1 1 F	..	1 tag from another plot present. 5 May tags retaken
		24–26.8.38	T.O. = 10	..	3 2 F, 1 M	1 1 F	..	..	..	6 mutilated by crows. 2 tags from other grids taken
		7–9.6.38	A.P. = 28 (8 × 5 10–yd. grid)	3 2 F, 1 M	11 2 F, 9 M	2 1 F 1 M	5 2 F, 3 M	..	1 1 M	3 tags from other grids present. Over-tagged
7	In Co.290	29.7.38 to 6.8.38	Centrally placed 4 × 5 10–yd. grid, rats moving. 26 tagged	7 4 F, 3 M	10 3 F, 7 M	5 2 F, 3 M	3 3 F	1 1 M	..	One May tag retaken, viz.—an old male originally 19–24 months. 5 tags from other plots present
		17–26.8.38	A.P. = 32	8 3 F, 5 M	11 4 F, M 7	1 1 M	4 3 F, 1 M	..	..	Sudden influx of rats on night of 18th. A.P. therefore is for period 23–26, two July–Aug. tags retaken, a M originally 7–9 months and a F originally 4–6 months
		17–19.5.39	A.P. = 31	6 2 F, 4 M	8 3 F, 5 M	3 1 F, 2 M	2 1 F, 1 M	..	..	Three tags from other grids present
		21–24.6.39	A.P. = 25	5 2 F, 3 M	10 5 F, 5 M	2 2 M	5 3 F, 2 M	3 3 F	..	Fully tagged. 9 May tags taken, viz.—F under 4 months (2), 4-6 months, 10–12 months, 13–18 months, and 4–6 months (2), and 7–9 months (2)
		12–15.7.39	T.O. = 29	Individual weights not available 13 F, 16 M			..	..	..	16 tags taken; also 2 *M. littoralis*

* For A.P. composition, tagged sample is given.

Normal maximum *R. conatus* movement occurs during the two most drastic climatic changes of the year, i.e., midwinter and midsummer, and there will be pronounced movements apparent on most grids at these times. However, in a normal year, due to variability of environment, there may be considerable variation in the timing of movement on particular grids and on larger areas under observation. For instance,* the five grids featured in Fig. 5, which were in poorly grown P.O.J.213, showed movement of rats from grids 1, 2, 3, and 4 into grid 5 and area Y during late November, but at the same time rats in other grids under observation in grass nearby had not moved as late as the end of December.

Doty (1945), in Hawaii, stated: "Certain fields located next to favoured cover are subject to devastating rat damage each winter season (December, January, February) when rat migration is at its peak." In Queensland canefields the winter movement is usually of primary importance, though in some years when rats are not abundant it is overshadowed by movement commencing in October-November.

The distance moved by individual rats varies within wide limits. On one occasion a series of grids set in a field of saccharine sorghum showed no movement at all† during October. At the other extreme were repeated records of movement up to half-a-mile within a week and many instances of travelling over long distances during periods greater than one week. During four years of work 197 rats were recovered three to six miles in a straight line from their tagging places, 17 at six to nine miles, one at 12 miles, one at 15 miles, and one at 19 miles. The last mentioned animal was a young male tagged in February, 1938, and not recovered until nine months later. It should be noted that these records were made when observations on particular rats in the field were possible over only four general movement periods under harsh conditions and in a district where no general trapping is undertaken.

There is a decided tendency for a moving population to scatter rather than move in mass to the nearest suitable environment (so far as a field worker can judge). This has been observed repeatedly during tag-trapping and has been demonstrated artificially by tagging populations in cane and trapping, after harvesting or partial harvesting, in grids suitably placed adjacent to the cane

---

* Other examples of rat movement are mentioned elsewhere in the text as follows:—Table 8, grids 2 and 3 (early October, 1938); Table 4 (early August, 1938—rats moving in during trap-out); Table 9, grid 5 (October-November, 1937); Table 11 (July-August, 1938); Table 13, grid 1 (late July, 1938), grid 6 (late July, 1938), grid 7 (June-July, 1938), grid 10 (November-December, 1938), grid 13 (October-November, 1938); Table 14, grid 10 (early October, 1938); Table 15, grid 5 (October, 1937), grid 8 (July, 1938); Table 16, grid 7 (August, 1938).

† Details are—During October, 1943, a 2-acre field of saccharine sorghum was divided into 4 bb. grids of 10-yd. interval; grids 1 and 3 were trapped over four nights and yielded 20 and 22 *R. conatus*; traps were then closed for four nights; grids 1 and 3 then retrapped for three nights for a nil yield; grids 2 and 4 trapped for two nights and yielding 15 and 13 *R. conatus* traps closed for two nights; then whole area trapped for three nights and yielding 5 and 8 *R. conatus* on grids 2 and 4.

and/or in the standing cane. During June, 1938, contiguous grids A in grass and B in cane were completely tagged. Overnight there was an increase in the population of B and a nearly complete evacuation from A. Only one-third of the tags from A accounted for one-seventh of the population increase in B and some of the missing tags were taken elsewhere.

Working on the premises that detail is the sure foundation for expansion and that observations from a wider aspect bring detailed results into better perspective, it is now possible to return to the discussion of some points in population behaviour and methods of study.

Table 5 is concerned with the influence of reduction in R/T on individual rat movement within a grid. It is apparent from inspections of similar data from a large series of grids that trapping-out has little discernible influence on movement within a grid over the time interval of the trapping. Also the successful use of twin grids and evidence from partial tagging over large areas followed by elimination trapping or poisoning in certain portions only has led to the conclusion that trapping and handling during tag-trapping have negligible influence on population movement.

Feeding stations may be discussed under the headings (*a*) effect on population movements and feeding habits and (*b*) use in overcoming difficulties associated with I/F, i.e. the ratio of total possible food intake per night by the rats present (in Queensland canefields this should also include intakes by other animals) to the amount of food presented. I/F is important for control work whether by direct poisoning or by the pre-baited feeding station method, but (*a*) concerns the study of populations. Most published work on pre-baited feeding stations has been done with *R. norvegicus* and according to Doty (1945) "the plan [of pre-baiting] consists in feeding rats *unpoisoned* grain in specific places until a large part of the surrounding rat population has discovered the new source of food and formed the habit of visiting these feeding places." Working in tagged or partially tagged *R. conatus* populations it has been found that in a settled population the presence of one or more feeding station grids as parts of a larger area does not effect dispersal within the area: also, after settling down following movement into an area containing twin grids consisting of a check and feeding stations there is no significant difference between the grids in population increase. *R. conatus* will also move through a feeding station with 10-yd. interval or larger areas covered by feeding stations similarly placed. It is concluded that feeding stations have little influence on *R. conatus* movement and dispersal.

From the data already presented and particularly those concerned with movement it is also concluded that measurements of movements of individual rats within a standard grid do not provide very useful information, and any interference by tag-trapping and feeding station grids of small interval with the natural wanderings of *R. conatus* is of little importance (see page 170).

An analysis of results (as in Table 16) indicates that in the population turnover of any series of grids there is no particular age group or sex which exhibits any outstanding movement. A tendency on the part of breeding females to remain more settled than males could be expected, but grid results, and in some years general trapping, indicate that this tendency is at least secondary to the general population movements. Some tagged females have been known to produce two litters in the field in different nests and gravid females have been removed from one locality to another and settled in without ill effects on the litters which arrived in due course.

SCATTERED POPULATIONS AND DISTURBANCES.

So far only obvious or concentrated populations have been dealt with in detail. For practical purposes scattered or sparse *R. conatus* populations are defined as those less than at the rate of 10 active rats per acre. Study of these populations is most difficult and is one of the instances where the use of live traps is preferable but not always practicable owing to large distances and areas to be covered. For example, after search and trapping traverses it may be desirable to find out if some of the rats are resident or actually on the move. This is only possible if live trap traverses are followed by tag-trapping on grids. One observation from this type of work is that, at least in scattered populations, difference between movements of males and females is discernible: previously (McDougall, 1944b) it was stated that "strays of *R. culmorum,* as with other species when trap lines are taken through unlikely rat country, were usually old males." These old males are usually travellers.

Traps have been placed repeatedly within two feet of used burrow openings, but in directions opposite to the pads, and have remained empty. In order to examine scattered populations the old and well-known directions for trapping most wild animals should be followed; i.e. the traps should be placed correctly near burrow openings, on pads, or near recent feeding or other signs of activity—or in other words within the area of recent travel and/or search. Actually even this is not sufficient for sure trapping, for it is evident that a rat works with some degree of preoccupation. This is also evident when baiting and will be discussed more fully elsewhere (Part 6).

During the past 10 years in an area of some 1,500 square miles of the Mackay District, *R. conatus* has appeared transiently in densities in some places up to 40 rats per acre. In 1937 the field rat was present in a small wet area 8 miles west of Mt. Christian and under similar circumstances 5 miles west of Sarina; in 1938 it appeared in two acres in West Plane Creek; in 1939 *R. conatus* was present at the rate of 5 rats per acre in a small part of H.Q. 285 centrally placed in 90 acres of plant cane at Palmyra; in July, 1939, this rat was present at the rate of 8 per acre in a built-up irrigation drain in the TeKowai area—this population increased to 29 per acre by March, 1940, but when the channelling was concreted rats disappeared from the mound; in 1941 the field rat appeared on a farm on the Mt. Jukes-Seaforth road; twice in 10 years it appeared in small numbers in one field on the Sugar Experiment Station; and on several occasions in areas where its existence was not known or suspected domestic cats have been

Table 17.

SPRING ESTIMATES OF CONCENTRATED *R. conatus* POPULATIONS.

Year.	Farm.	Acres infested by rats.	Densities per acre. Maximum.	Densities per acre. Weighted average.	Estimated total number of active *conatus*.	Remarks.
1935	B	400†	..	..	..	For Nov. T.O. on 1 ac. = 29 (Table 15, grid 2) after cane had been burnt for harvesting.
	O	450†	..	..	..	
1936	B	300†	..	..	..	Only 1 plot result is available; density was 200 *R. conatus* plus 56 *M. littoralis* per acre.
	O	250†	..	..	..	
1937	B	155	1,000	67	10,000	
	O	66	150	61	4,000	
1938	B	100	200	50	5,000	
	O	30*	80	50	1,500	
1939	B	21	50	29	600	
	O	4	..	21	82	82 *R. conatus* trapped from the four acres.
1940	B	5	36	20	100	Trapped out 2 acres on this farm, April to June; 241 *R. conatus* taken.
	O	No concentrated populations noticed or reported.				
1941	B	This farm was out of cane production during the years 1941–45; however, when a fodder crop was planted in suitable ground some rats usually concentrated therein; for example, during Oct.–Nov., 1944, 69 *R. conatus* and 2 *R. culmorum* were taken during a trap out of $1\frac{3}{4}$ acres of saccharine sorghum.				
1945	O	The author ceased "working" this farm after 1940. During the next five years approximately 60 acres were under cultivation to cane each year and the farmer reported that he had not encountered *R. conatus* on the farm during that time.				

* Plus 10 acres inhabited chiefly by *R. culmorum* at densities as high as 60 active rats per acre.
† Farmers' estimates.

noticed with specimens of *R. conatus*. During August, 1940, congregations could not be found on a farm sometimes heavily rat-infested and tagging was undertaken in a scattered population. Following the disturbance caused by abnormal rain for the time of the year rats, including 3 tags from scattered populations, appeared in appreciable numbers and attacked cane; they disappeared within three weeks and some were found as scattered populations later.

During 1943-44 the Mackay district experienced the worst drought since 1931 and there were few reports of the presence of *R. conatus* in the district; it was not profitable to trap for experimental purposes. However, in October, 1944, this species appeared in densities approximating to 20 per acre in several places over an area of 1 to 2 acres. During the winter, spring, and early summer of 1946 a severe drought was again experienced and only scattered populations up to 4 rats per acre could be found by gridding. In normal years, even on farms at other times heavily infested, rats exist if at all mostly in low densities (note Table 17).

The genesis of scattered populations is the very small suitable environments such as under a stone, near a fence post or a tree stump, etc. Evans (1942) suggested that habitats which will maintain only low densities may be essential to the ultimate survival of a species, the inference being that small isolated communities are not as likely to be seriously affected by parasities, predators, etc. as are concentrated populations.

DISCUSSION.

Three primary factors are associated with fluctuations in population densities in a given area; viz., reproduction, movement and mortality. Diseases, predators, parasites, food supply, climatic conditions, and variations in environment are often regarded as influencing these factors and a number of hypotheses have been advanced. Unfortunately the original purpose of many of these hypotheses to provide ideas and stimuli for the collecting of further field data has not been fulfilled. Instead, during the passing of time and by constant repetition many of the ideas have seeped into rodent literature to such an extent that they now appear as substantiated theories on which pest control practices can be safely founded.

With the breeding and life-history work it was possible to build up a reasonable account of happenings (McDougall, 1946) from cage and correlated field data during a population decline and from field data over the latter half of a plague year and the succeeding year as reported by Gard (1935). However, cage work with cane rats, except in checking age determinations and indicating the physiological life span, is of very little value for population studies.

The information therefore available for this discussion on populations consists of general field observations over many years, inferences from very sparse records and some detailed data on the rat population itself during a decline merging into normal times. King (1932) has stated that it is an accepted truth that there can be no real understanding and consequently no logical treatment of an abnormal condition until the normal is known and understood, and from the author's experience of plagues of pests in Queensland canefields it would seem desirable for investigations to be initiated during normal times. On the other hand, however, it would be unwise to read too much into available data on rat populations obtained mostly during the decline. For a full discussion at least similar information is required for large upsurges and peak periods: therefore some of the data obtained by the author are presented for record purposes and with suggestions for further work when opportunity occurs.

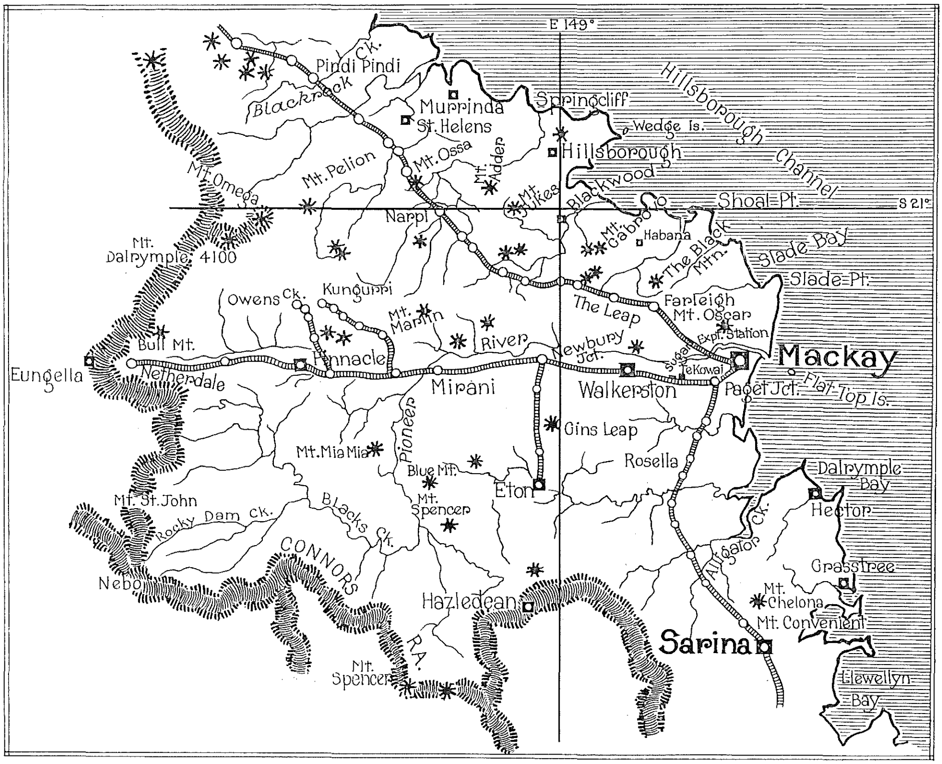


Figure 7.

Map of the Mackay district, where most of the intensive investigational work was carried out.

Before discussing the possible causes of fluctuations in populations it is necessary to devise means of recognizing, measuring and studying them.

In Table 17 estimates are given of concentrated active *R. conatus* populations, comparable for the month of September in different years, on two farms in the Habana area, Mackay. These estimates were based on elimination trapping on standard grids in different types of habitat, and with due regard to population systems occupying areas which need not coincide with working or grid areas. Similar estimates are practicable in autumn; for example, on farm B during March-April, 1938, it was found that concentrated populations occupied 56 acres with a mean density of 21 per acre. Field conditions for this type of work in a normal year, however, are more favourable during spring. On the two farms the decline occupied the maximum time observed, i.e. 5 to 6 years, though it is possible that the unusual spring population in 1938 (note Figures 8 and 9 and

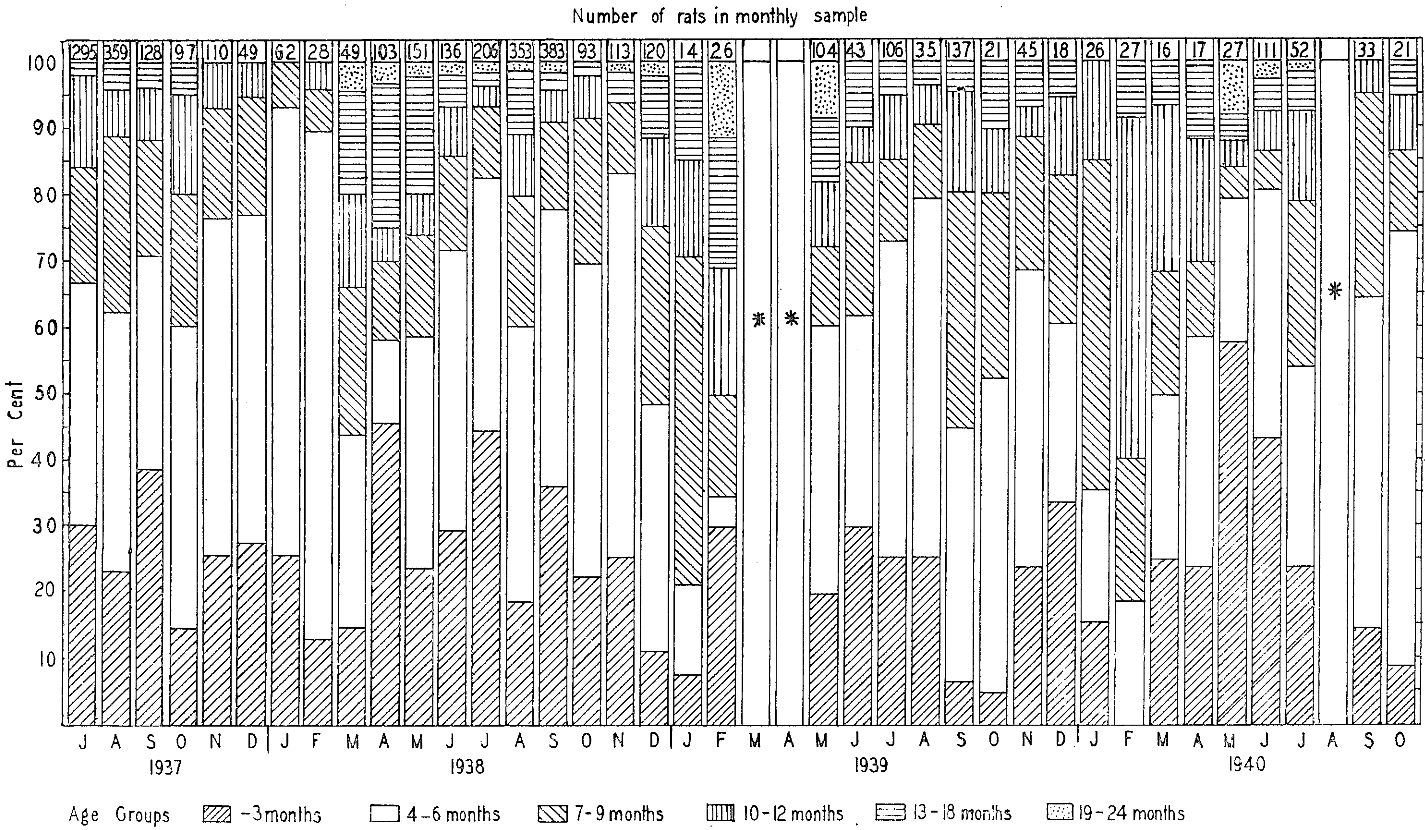


Figure 8.

Population composition by age groups as percentages of monthly samples from complete trapping out.

* Only pregnancy samples and weight samples (Figure 10) taken.

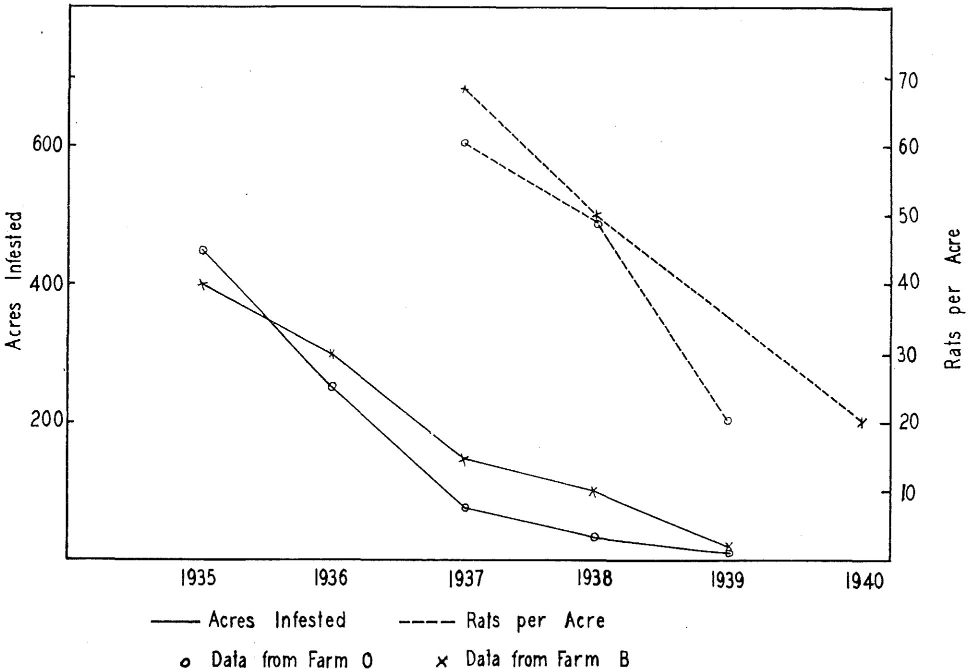


Figure 9.

Spring estimates of concentrated *R. conatus* populations.

Table 17) may have been a contributing cause of delay. Considering the area as a whole, population crash was complete within three years of the peak and on some farms *R. conatus* remained only as scattered populations as early as the spring of 1935.

Selected farms were not trapped even for experimental purposes but from continued observations the population decline on these followed the usual course. Table 18 gives the dissection into age groups of absolute number censuses

Table 18.

AUTUMN AND SPRING ESTIMATES OF CONCENTRATED *R. conatus* POPULATIONS ON FARM B—1938.

Age groups.	Estimated absolute numbers ; March–April, 1938.	Estimated absolute numbers ; Sept., 1938.		Remarks.
		Expected.*	Actual.	
Under 4 months	356	. .	1,804 }	1 of September catch from another farm
4– 6 months . .	245	. .	2,131 }	
7– 9 months . .	208	356	642 }	4 of September catch from other farms
10–12 months . .	114	245	221 }	
13–18 months . .	225	208 } + 114	160 }	3 of September catch from other farms
19–24 months . .	42	225 }	55 }	
Over 2 years . .	. .	42	Nil	

* Not allowing for movement and deaths.

on farm B for the autumn and spring of 1938 and similar figures for other farms agree in principle. It is concluded that the difference in absolute numbers over times covering a general movement on an area as large as a farm (area of farm B is 720 acres) does not represent the fluctuations of a static population—note also Table 16 for standard grids.

In dealing with cane rats it has been found impracticable, except over small time intervals with twin grid work, to postulate an observable closed system. These small time intervals are of very limited value for general population studies. It cannot be too strongly emphasized that, if rat movement is not given paramount importance, discussions on canefield rat populations would have little relationship to field conditions (see also Part 6). Sampling therefore provides the only worthwhile data and the lack of a basic static population precludes much formal statistical analysis. Descriptive treatment of data from continuous field work looms large in this report: on the other hand, many of the concepts and hypotheses derived from mathematical and theoretical speculations on populations (see Elton, 1942) have provided little help with the field problem under investigation.

Field experience during 1934-6 and data for 1937-39 (Figure 9) suggest that in years during a decline there is a positive direct relationship between area occupied and mean density of the active concentrated population. During years of scarcity of rats the scattered population is a very significant proportion of the whole; a state of affairs which is reversed during a plague. Also in normal years the conversion of scattered into concentrated populations may be due to some localized environmental factor or disturbance which is not always discernible. The author considers the appearance of *R. culmorum** on farm O in 1938 (Table 17) and the minor infestation of *Melomys littoralis* during August-September, 1940 (Table 2, Plot 3), as examples in other species. The comparatively small differences in total area occupied by appreciably different densities may be due, at least partly, to the redistribution of the available population and in normal years it is not advisable to use the areas occupied as a measure of fluctuation in populations. At other times it can be used profitably for comparative purposes, especially when dealing with large areas such as a farm and with large time intervals as shown in Tables 17 and 18. At present, curves for populations and areas occupied (see Figure 9) are not available for a mill area and environs. These are needed, as farms O and B were during 1938-40 merely the most extensive and obvious residua in an area previously widely infested by concentrated populations.

Curves for the mean rat weights of monthly samples for the years 1937-1940 are given in Figure 10. It is obvious that there are maxima during February-March and October. Data of this type do reflect population composi-

* Credible sources report the presence of a ground rat along the banks of the Burdekin River within cane areas during 1916, i.e., during an upsurge. This was probably *R. culmorum*. There is also some evidence of a minor upsurge in 1938. (Mackay District see p. 226.)

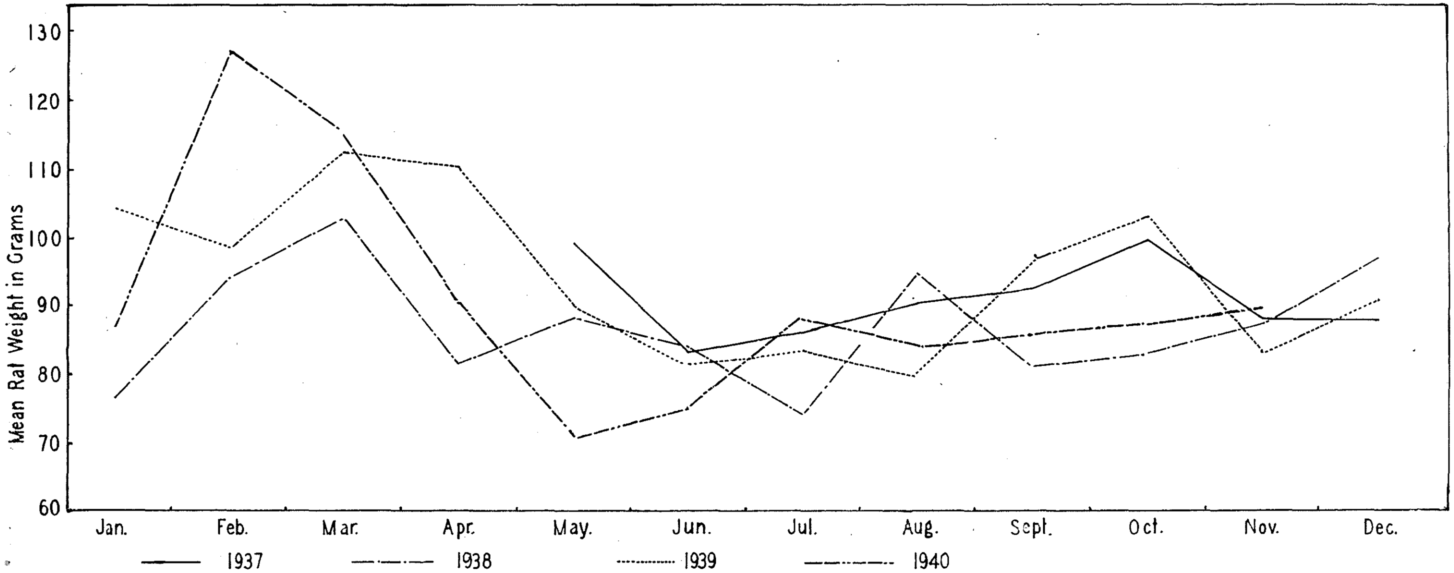


Figure 10.

Mean rat weights of monthly samples. Weights from complete trapping out only were used. Numbers of rats in each monthly sample were as under.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1937	..	..	..	..	64	295	111	173	225	100	115	72
1938	85	49	69	114	146	135	206	366	272	71	118	126
1939	24	26	19	26	104	43	56	35	139	29	45	28
1940	26	28	26	27	27	111	52	33	37	21	34	..

tion in some degree but the ultimate value would depend on the general use of such curves as a method of sampling population composition without resource to non-factual age determinations: in this they fail.

Figure 8 presents data on age group percentages in the Mackay district based on monthly samples from elimination trapping on standard grids in concentrated populations and from other trapping in scattered populations. Similar data for farms B and O do not differ to any extent from the general picture. This type of information is the best guide to population fluctuations and it is concluded that the presence of both young and old rats at the same time is the only available criterion of a population upsurge. The extent of the build-up depends on the time interval over which such a population composition exists. The use of this criterion of population composition takes into account both effective breeding and survival and will distinguish the concentration of populations from the true upsurge. The questions arise as to whether it is possible to have the presence of old rats without breeding, or breeding in the absence of older specimens. In canefields and environs either can happen and both have been observed, but they are transient. No attempt has been made to measure or compare the extent of upsurges for the reason that other than the usual and short-lived rises in population numbers during the autumn of normal years the only upsurge of *R. conatus* in the Mackay district from 1935 to 1946 was during 1938. This was not of economic importance and again due to lack of suitable observations on other upsurges its true effect on *R. conatus* populations on farms B and O is not clear: it may be responsible for the change of slope at "1937-38" (acres infested) in Figure 9.

Factors in Population Fluctuations.

Diseases.

In discussing the causes and factors governing fluctuations in populations, particularly those concerned with crashes, mention must be made of the importance often attached to diseases. Elton (1942) stated that "the most natural theory to account for the decline of voles after they have reached their peak is that overcrowding leads to an increase in parasites, and the flaring up of disease." Hamilton (1937) remarked that "all available evidence indicates that disease is the control factor that terminates these mass increases of rodents," but goes on to add concerning the Nevada plague of 1907-8 that, while the mice were ostensibly killed by disease, "all attempts to isolate specific bacteria met with failure." Kalabukhov (1935) pointed out that "at the time of 'mass appearance' another powerful factor begins to act, namely epizootics. When the density becomes such that there is intensive contact between the rodents, diseases characteristic of solitary individuals begin to spread in the mass. The relationship between density of population and the spread of infectious diseases is well known to epidemologists as Farr's law." The remarks of these authors cover the general published opinion concerning disease and its control of rodent population fluctuations. Definite supporting evidence, however, is negligible.

Elton *et al.* (1935) describe conditions under which a *Toxoplasma* may have been the cause or contributing agent of a population crash in voles on the Scottish border in the spring of 1934. This organism was not present during and after a population peak in 1938-39 and Elton (1942) pointed out that, even if in a particular instance disease does break out and kill voles at their peak, this does not prove that disease always controls the rhythm of the cycle, and he goes on to say that "it may be an occasional symptom, not a recurrent dominant cause; if we exclude, for the present, the possibility of some other organism which has entirely escaped the keen notice of pathologists, we are forced to look in other directions for an explanation" (of population crashes).

Bubonic plague (*Pasteurella pestis* (L. & N.) Berg.) was last reported (Cilento, 1942) in Australia (including Queensland cane districts) during 1921-22. From reports and discussions with field observers, there is no evidence that this fact had any effect on cane rat population trends at the time.

The causal organism of Weil's disease in man is harboured by rats in a number of countries (Buchanan, 1927), and Sawers (1938), working with *R. conatus* from canefields, has shown that as usual it is non-pathogenic to the rat carrier. On several occasions old rats from fields, which have died in cages within a few weeks after capture, have exhibited congested patches in the lungs.

Green and Larson (1938) have reported on "shock disease" in the snowshoe hare. Though not investigated, this suggests itself as a contributing cause of the deaths of old *R. conatus* and *Melomys* spp. individuals when handling and trapping, and of ground rats at other ages if handled very severely.

From 1935 rats have been taken from the fields in a number of districts and have been kept in cages, some of which have been overcrowded. Rats apparently sick in both scattered and high density populations have been caged for observation. In heavy *R. conatus* populations sections have been completely closed in and in some instances other rats have been added. During trap-tagging on a number of occasions all rats have disappeared from the grids being worked: usually some of the tagged rats have been recaptured elsewhere. An epizootic has never been observed in dormitory or field cages and there has never been a suggestion or sign of a disease killing rats of all ages in the field. It is concluded that outbreaks of disease are not a primary factor influencing rat population fluctuations in Queensland canefields. This conclusion is open to the criticism that the disease aspect of the problem has not been studied by an animal pathologist. However, the author has not encountered a situation where the submitting of material to a pathologist has been warranted. The finding of specific organisms in rats by routine search through a large number of specimens not related to definite field observations and happenings, has, in the author's opinion, only slight potential ecological interest.

Parasites and Predators.

With regard to parasites, Gard (1936) found that a large proportion of rats of both *R. conatus* and *M. littoralis* were carrying nematode worms in the stomach. Percentages of infestation were given as: June, 22·3; July, 12·2; August, 2·7; September, 2·0; October, 8·5; November, high; and it was noted that young rats were scarce and hardly ever seen. A tapeworm (Cestoda) was also found in some rats. The author was present at some of the dissections reported above, and though counts were not made infestations per rat were very heavy. During the winter of 1936 the author noticed worms in some old rats (*R. assimilis*) in the Ingham area and in the Mackay district (July-August, 1936) on one farm 14 of 85 older rats dissected contained *Prostospirura* sp. During the succeeding nine years this worm was found in only one old *M. littoralis*. It is evident that in the early years of population decline these worms were present only in the older rats in certain localities. Gard (1936) pointed out that those rats in and around canefields were much less infested than those in the grazing country, where the highest worm infestation occurred.

During April-May and September-October, 1936, egg-masses of the flies *Sarcophaga peregrina* Rob-Dev. and *Lucilia cyaneomarginata* Macq.* were deposited on dead rats in break-back traps and on live rats in Bureau and cage traps. It was found that the maggots do not attack the living rat flesh. During the 1934 rat plague some northern workers considered that large numbers of ''blow-flies'' were an indication of the success of their poisoning campaigns. It is now known that some of the poisons used at that time are actually very inefficient under the best of circumstances (Part 6). However, the presence of flies in large numbers indicates one reason why it is sometimes difficult to find more than a trace of rat carcasses shortly after efficient poisoning; in one experiment two *R. conatus* rats, each with two medium-sized egg-masses of *L. cyaneomarginata* attached, were killed at 8.30 a.m. on October 10, 1936, and placed in a glass jar with damp soil. Small maggots were noticed at 10 a.m. and two days later at 9 a.m. all that remained of the rats was hair and scattered bones. Fly emergence commenced on October 24, and was complete by the 26th.

Rats in traps are sometimes engorged by the brown snake (*Dermansia textilis* D. & B.) or mutilated by crows (*Corvus cecilae* Matthews). Brown snakes at the rate of 30 per acre have been killed while clearing traps. This snake will enter cage traps after rats, but the black snake (*Pseudechis porphyriacus* Shaw), though often seen on grids, has not interfered with trapping. A 6-foot brown snake engulfed two medium sized *R. conatus* and remained inactive for eight days. By working twin grids in a settled population with snakes actually present it has been found that crows and snakes, though they do attack rats in traps, have no measurable effect on A.P.

Some workers in Queensland canefields invariably refer mutilation of rats by an unknown agent to cannibalism. In general this is not correct: when a herbivorous species attacks one of its kind, or one of another species, slight

* Identified by M. Fuller (C.S.I.R.) 30.7.37.

damage is usually present only on the head and neck region. Furthermore, severe mutilation of cane rats is often found confined to definite areas in grids and the last of a trap-out in settled populations is sometimes mutilated.

It is concluded from the evidence available on settled populations that predators as a factor in population fluctuation have a status similar to that of diseases.

Food and Harbourage.

Earlier it was pointed out that cover plants or harbourage are the part of the desired environment usually providing food (McDougall, 1944a) and that the presence of lush growth does not always stimulate breeding (McDougall, 1946). The relationship between food-harbourage and rat population is definitely not one of direct cause. Heavy cane crops affording excellent cover are often grown practically free of attack in localities subject to rats, and the same has been observed for mixtures of grass and cane.

It is a popular belief in most Queensland cane districts that standover cane provides harbourage at a time of the year when other ground cover is scarce and so helps rat breeding. During the summer of 1936-37 *R. conatus* was more plentiful than in following summers and standover was present in quantities greater than usual in the Habana-Farleigh area. This type of crop was heavily trapped, often with fairly recent rat bites as a guide, for monthly population samples. Results were so disappointing and often so inferior to those of other habitats that thereafter standover was not given first priority for summer trapping. In the autumn of 1937 it was found that there were no significant differences between breeding and population densities in standover and in other types of cover. In December, 1937, and again in December, 1943, following reports of rats attacking standover cane, feeding station grids were put out. In five out of six instances the rats moved off the grids and out of the fields within two weeks of entry. On the 1943 grids partial tagging was done before presenting the feeding stations and some of the younger tagged rats were retaken on other farms within 6 miles of tagging. It is concluded that standover cane sometimes becomes part of the "highways of travel" during which time it may suffer rat attack, but the cane itself as a ground cover has no effect on *R. conatus* populations in regard to either numbers or dispersal.

General.

The movements of rat populations in respect of specific localities is one of the most important facts brought out by these investigations into the habits and activities of *R. conatus*. A general movement may be sudden or it may develop gradually, but for all colony sites it means a more or less rapid turnover of population, resulting in marked decreases or increases of both areas occupied and densities observed. It was often found that in the same field, and in what appeared to be identical environments, discrete colonies of similar A.P., and each occupying areas sufficiently large to accommodate two or more standard grids, exhibited very different movements. In one colony a general movement may start two or three weeks, or even up to six weeks, before the other. Often the artificial introduction of rats into the static population will, under these circumstances, initiate movement, but this does not happen in autumn and spring. General movements occur every winter and summer irrespective of weather conditions and population densities, and though they do coincide with depressions in breeding this may still be appreciable. This was recorded definitely during the winters of 1935 and 1938 (McDougall, 1946) and it appears to have occurred also in the winters of 1933 and 1934.

In contradistinction to the general population movements there have been occasions when some of the densest concentrations found—up to 2,500 active rats per acre over two acres—were static and there seems to be no apparent environmental reason for non-dispersal. Similarly in a dry spring *R. conatus* may often be found in what appear to be uncongenial habitats.

Perhaps a good case could be made out for the correlation of general movements at the two most drastic seasonal changes (i.e. midwinter and midsummer) with effects of changing environment on the rat. This could possibly include such concepts of mathematical ecology as population pressure and carrying capacity, though these would be more applicable to a closed system than to *R. conatus* populations. However, the author can offer no satisfactory explanation of the fundamental causes of seasonal movements.

There are a number of methods for studying rodent ecology. These range from simple studies of the relevant literature, through field inspection without trapping, detailed field work based on constant handling of the animal, to the relating of all data through changes observed in the body of the rat. In Queensland canefields, the attempted control of rats is for the most part still based on the first two methods. The author has concentrated on the third, which to a considerable extent provided a working basis, but a full picture cannot be presented until data are available on the functioning of the rat body. Seasonal variations in the functions of the endocrine glands, for instance, may be of paramount importance. A similar lack of knowledge interfered with the breeding studies (McDougall, 1946) when work was carried into the body of the rat, and the most obvious end-point of a mechanism governing the emplanting of the ova and the retention of embryos by the uterine wall was not reached.

The ecological approach to the problem of control does not necessarily mean that climatic conditions are considered a prime factor governing rodent population fluctuations, and Kalabukhov (1935) represents a fairly large school of thought when he states that so far there are no exact data to prove that in ordinary conditions, and in periods between mass increases, unfavourable climatic conditions cause a great mortality and by this means stop the growth of the populations. With *R. conatus* this author claims that climatic conditions control populations through both mortality and breeding in all years. Furthermore, the effects of disease, of parasites and predators, of variations in cover, food supplies, soil moisture, etc., should not be given the status of controls governing population fluctuations, though some or other of these may be integral parts of the mechanism through which climatic conditions act on populations. The main point is that in approaching a possible economic control of the rat pest through ecology it is very easy to err in placing too much emphasis on one small factor, particularly if, as often occurs, it is considered without its own relationship to climate.

With *R. conatus* it is not possible to define the full territory which could be occupied by the species at any particular time or just what constitutes complete occupation. Suitable habitat sites differ in both situation and extent in different years and are governed primarily by climatic conditions, and also to some extent by the planting of crops. Large areas supplying suitable living conditions may exist without the available population, but large populations cannot arise without the automatic and parallel creation of large areas with lush plant growth under damp conditions (for breeding and rainfall data see McDougall, 1946).

The occurrence of a plague—i.e. a manifestation of a normal, seasonal general movement when a large population is in existence—will follow only when the rat population as a whole will have encountered mild conditions during a number of general movement periods. At a population peak, therefore, just prior to a plague the presence of some very old rats—i.e. over two years of age—can be expected. The author has used the older age groups as the survival indicator (see page 218) and as one of the criteria for the presence of an upsurge, even when the increase in population is not of obvious economic importance. In contrast with the increase in numbers following movement periods under favourable conditions there are the population crashes which follow when a moving population encounters harsh conditions. These crashes occur in a similar fashion whether or not the upsurge has been sufficiently large to be called a plague; the absence of old rats is particularly noticeable and the record that during the drought of the winter and the spring of 1946 no rat older than nine months was captured is worthy of note.

Immediately prior to the seasonal movement which brings the large population to general notice in the form of a plague, country normally carrying some *R. conatus* population has been found too wet for the species, which has become concentrated on drier land where cane is grown. On the other hand, since 1935, when populations have been more or less normal, most concentrated populations in the Mackay district were found associated with crops of sugar cane, fodders and green manures in ground previously ploughed or cultivated to conserve soil moisture.

From the meagre information at present available it appears that the major portion of the plague population is associated with the cane lands for some time prior to the plague. It must be remembered, however, that even in normal years some rats associated with infestations in some fields have travelled up to 10 miles within a few months. In plague years also it would be expected that the population in a particular farm or field would comprise some travellers, since it would appear that during a plague individuals exhibit greater activity

Table 19.

RECORDED MURINE VISITATIONS IN EASTERN AUSTRALIA.

Period.	Species.	Locality or Area Record.	Remarks.
1903–4–5	*M. musculus* ..	South Australia	
	Cane Rats	Ingham and Mackay (Qld.)	
1909–10–11 ..	*M. musculus* ..	South Australia and Victoria	
	Cane Rats	Parts of northern and central cane areas (Qld.)	
1915–16–17–18 ..	*M. musculus* ..	South Australia, Victoria, New South Wales, Queensland	In 1916 deaths of humans from a disorder known at the time as "Sarina fever" occurred
	Cane Rats	Gordonvale and central cane areas (Qld.)	
1921–22	Cane Rats	Parts of northern and central cane areas (Qld.)	
1927–28–29 ..	Cane Rats	Ingham, Tully, and central cane areas (Qld.)	There are no previously published reports of rats attacking cane in the central district in 1928. Actually infestations in the Homebush area caused concern, whereas in the 1933–34 outbreak the Habana area was the centre of most interest
	M. musculus ..	South Australia, Victoria, New South Wales	
	R. conatus	Northern and central cane areas (Qld.)	
1932–33–34 ..	*M. littoralis* ..	At least northern and central cane areas (Qld.)	
	M. cervinipes ..	Northern and central cane areas (Qld.), in forestry projects in South Queensland and Northern Queensland	
	R. assimilis	In Queensland cane areas and in forestry projects in Queensland and Victoria	
	R. rattus	In all Queensland cane areas and environs	
	R. villosissimus ..	Gulf country (Queensland and Northern Territory)	
1939–40	*R. villosissimus* ..	Western Queensland	This rat approached the coastal sugar lands but did not descend to them; at the time it caused some concern to a Cane Pest Board in the Townsville area
1944	*M. littoralis* ..	Parts of northern cane areas (Qld.)	Infestations during and following Oct.–Nov. movement
1945	*M. littoralis* ..	Parts of northern cane areas (Qld.)	Infestations during and following early summer movement

than in normal years. This may be due to an increase in endocrine or other body functions but at present there are no data to support this reasonable claim. During a plague the author has observed main rat pads about six inches wide, three inches deep, resembling cattle pads in appearance, and extending for four miles along creek banks. As for the build-up prior to the plague: this can and probably does include populations resulting from migrations over considerable distances. In following the build-up of a population in a district or area, surveys such as shown in Table 17 will be required. The author considers that, due to difficulties concerning area, time, labour and rat numbers, marked rats can be used only as indicators (note Table 18).

Regular Cycles.

Elton (1942) has reviewed the literature on wild-life cycles and pointed out a regular periodicity of population rhythm for many animals. In discussing lemming cycles in Norway the author states in simple terms the basic idea: "Although we can now bring together evidence that the migrations arise from cyclical abundance, these migrations do not happen at each cycle peak in every area. They are very widespread in some lemming years, regional in others, quite local in others, and occasionally (as between 1913 and 1937) fail to develop at all. The intervals between migration years at any one place have therefore usually been irregular. It is only when we look at Norway as a whole, or at any rate in large divisions, that the cycle can be appreciated. Of the migrations we can say . . . *that somewhere in Norway* there has practically always been a migration every third or fourth year."

Table 19 gives records of some murine visitations in eastern Australia: those well outside cane areas are from Wood Jones (1923), Elton (1942) and Troughton (1943). The last-mentioned author stated that "there are many records of . . . inland plague occurrences of native species, such as the Gulf country visitation of 1869-70 when continuous rains caused exuberant vegetation, and rats (probably *Rattus villosissimus*) increased amazingly, swarming everywhere." Unfortunately, few of these records are generally available, none is in detail on the population itself, and all concern observations closely associated with the actual time of the plague.

There are indications of a 5–6 year cycle from records for cane rats. After the 1934 plague the idea of a regular cycle of $4\frac{1}{2}$ years was used topically in some Queensland cane areas to encourage the control methods then in vogue, and as a measure of the success of these controls. Such is the poorest possible use of a theory which, from literature, available evidence and experience with the species concerned, the author considers has no practical value in canefields. It is no more valuable than the often mentioned cycles of other cane pests and good crop years.

NOTES ON SPECIES OTHER THAN R. CONATUS.

It is not desirable to generalize on the results of work with one species and apply the conclusions to others, particularly if environments are very dissimilar. However, at the present time this cannot be avoided with the different cane rat pests, but at least canefield rat species have the field and climatic conditions as common factors. Further knowledge of the differences between the behaviour of various species under similar conditions should have an important bearing on the formulation of control methods.

Rattus culmorum T. and D.

The population composition of 100 specimens—48 males and 52 females—taken as a sample in September, 1938, was as follows: Under 4 months, 8; 4–6 months, 36; 7–9 months, 28; 10–12 months, 13; 13–18 months, 11; 19–24 months, 4. During the same month A.P.'s of standard grids containing only pure populations of this species varied from 10 to 48 and the populations were static to the extent of allowing complete tagging and practically complete trapping-out on grid sites. A pellet count on a grid with A.P. of 32 and containing 8·8 per cent. of damaged stalks yielded 9·0 per place.

Early in October, 1938, this species commenced to move, and by mid-October a grid with an original A.P. of 38 showed a decrease to 15 with a trap-out record of 8 September tags recovered with 7 new rats.

The population composition indicates that perhaps a small upsurge as well as a disturbance was responsible for the appearance of this species for two years. Observations were not over a sufficiently lengthy time period and were also many months too late for a definite conclusion to be reached on this point. After November, 1938, this species was not taken in traps until a live pair (both 7–9 months) was present in a concentrated *R. conatus* population in October, 1944.

Rattus assimilis Gould.

When trapping rain-forest on a number of occasions a few scattered specimens have been taken. The only information recorded on a concentrated population of the species is given in Table 20; it is meagre and indefinite and gives no indication of movement.

Table 20.

BREAK-BACK TRAP LINE WITH 5-YD. INTERVAL.

Situation.	Date.	Trap Line.	No. of Traps.	Results.
In rain-forest at Abergowrie, Herbert River district	13.8.36	North to South	34	14 *R. assimilis* 7 *U. caudimaculatus* 3 Scrub Turkeys
	17.8.36		24	12 *R. assimilis* 3 *U. caudimaculatus*
	15.8.36	East to West	24	15 *R. assimilis*
	16.8.36		24	12 *R. assimilis*

Table 21.

ELIMINATION TRAPPING WITH GROUND TRAPS IN A POPULATION OF MIXED SPECIES.

Grid No.	Grid Description.	Farm.	Habitat.	Date.	Catches on successive nights. 1st.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	Species.
1*	8 × 5, 15–yd. interval, bb.	B (Habana)	P.O.J.2714	June–July, 1937	17	14	11	29	14	11	5	7	7	2	1	3	*R. conatus*
					6	10	5	11	2	9	3	6	8	3	2	3	*M. littoralis*
2	8 × 5, 5–yd. interval, bb.	B (Habana)	Poona Pea	May, 1936	39	27	18	6	1	..	..	..	..	..	..	..	*R. conatus*
					..	..	..	7	6	3	..	..	..	..	..	..	*M. littoralis*
3	8 × 10, 10–yd. interval, bb.	B (Habana)	Cane	June, 1937	64	45	11	7	..	..	..	..	..	..	..	..	*R. conatus*
					..	..	..	3	5	4	1	..	..	..	..	..	*M. littoralis*
4	6 × 7, 10–yd. interval, bb.	M (Herbert River)	Cane	Aug., 1939	11	8	5	4	..	..	..	..	..	..	..	..	*R. conatus*
					2	7	2	2	2	..	..	..	..	..	..	..	*M. littoralis*
5	4 × 5, 5–yd. interval, bb.	P (Herbert River)	Cane	Aug., 1939	4	4	2	4	..	..	..	..	..	..	..	..	*R. conatus*
					3	2	..	..	..	..	..	..	..	..	..	..	*M. littoralis*
6	4 × 10, 5–yd. interval, bb.	Z (Herbert River)	Cane	Aug., 1939	10	2	1	..	..	..	..	..	..	..	..	..	*R. conatus*
					13	9	5	..	..	..	..	..	..	..	..	..	*M. littoralis*
7	4 × 5, 10–yd. interval, bb.	S (South Johnstone)	Cane	Aug., 1939	..	1	..	..	..	..	..	..	..	..	..	..	*R. conatus*
					6	5	6	3	2	..	..	..	..	..	..	..	*M. cervinipes*
					2	1	1	..	..	..	..	..	..	..	..	..	*M. assimilis*
8†	8 × 6, 10–yd. interval mixture of bb. and B	M (Farleigh)	Cane	Aug.–Sept., 1940	3	..	..	..	..	..	..	..	..	..	..	..	*R. conatus*
					17	15	11	4	..	..	..	..	..	..	..	..	*M. littoralis*

* Moving populations.

† Abnormal concentration due to some local disturbance. (See Plot 3, Table 2.)

Line-trapping has demonstrated that the species is not confined to the scrub-edge, but factors influencing dispersal within its environment are unknown.

Although *R. assimilis* has a wide distribution (McDougall, 1944b) the author has not taken this rat in the Mackay district. It is not concluded that the species does not exist in this district, but rather that, though trapping has been intensive in the correct habitat, years of very low densities have been encountered.

Melomys littoralis Lonn.

There is little fundamental information available for either this species or *M. cervinipes.* The author, with the facilities available, did not find it practicable to cover these species as well as ground rats in a systematic manner during normal years.

In cane, and to a slight extent elsewhere to an experienced field man, the presence of *M. littoralis* may be indicated by bites, but there are few other traces or signs such as are left by ground rats. Even in moderate population densities the finding of nests, which may be uninhabited, is mostly fortuitous. This means a considerable amount of difficult trapping, most of which yields very small numbers of rats. In cane, where the rows apparently have some directional influence on movements, more rats are taken between stools in the rows than on trapping sites between rows. This, however, does not help to any appreciable extent when endeavouring to work this species. If ground rats are also present, and dependant on relative densities and movements, the presence of the semi-arboreal *M. littoralis* may be masked so far as ground trap catches are concerned (note Tables 3 and 21). This is so even in a low ground cover such as Poona pea (Table 21, Grid 2). In June, 1938, 257 *R. conatus* were taken from $1\frac{1}{4}$ acres of cane without recording one *M. littoralis,* though obviously this rat was attacking the crop. In several instances when working contiguous grids covering some acres *Melomys* damage has been noted in small parts of the grids but the species was not recorded during tagging.

It is concluded that attempts to work this species should be on a three-dimensional basis with the ground surface as a favoured plane only. Accordingly a trap as shown in Plate 3 has been designed. This works on the same basic principle as the Bureau trap*; light piano wire (Nos. 6–8) should be used for the springs and very light setting is required.

Examples of densities of this species encountered by ground trapping only which is considered as comparable to line-trapping for *R. conatus* and therefore without detailed knowledge of movement, are given in Tables 2 and 21. During 1935, 148 and 79 nests of *M. littoralis* were counted in two approximately one-acre patches of blady grass.

---

* During 1946, instead of wire door lock and door lock guides as figured for the Bureau trap (McDougall, 1944) spring steel clips larger but otherwise similar to those for the *Melomys* trap (Plate 3) were used. This improvement rectified the most serious mechanical defect of the original type trap.

Plate 1.
A type of rat-infested country at Habana, Mackay district.

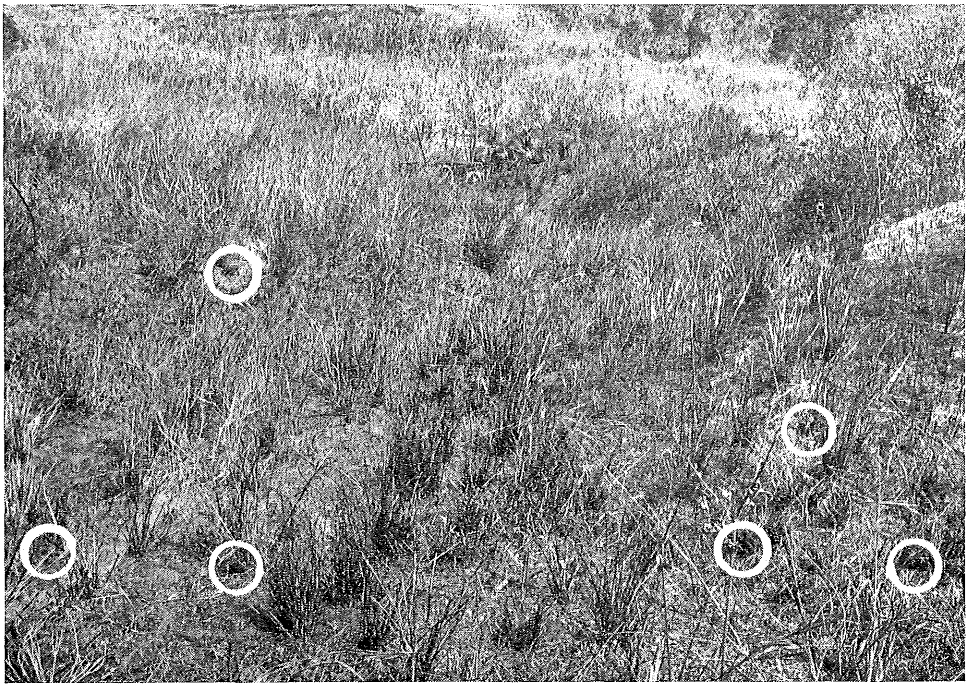


Plate 2.
Rat-infested country at Habana after burning of ground cover in October, 1936.
Burrow openings are ringed.

Plate 3.

Traps for use off the ground when working *M. littoralis*; also a feeding tray. (Note: The damage to the cane shown was not caused by *Melomys* spp.)

Full data on the comparative survival, breeding and activity of *M. littoralis* and *R. conatus* are not available, but McDougall (1946, p. 42) should be noted. Earlier (McDougall, 1944b) it was stated that in some years *M. littoralis* is responsible for most of the rat attacks on cane in many Queensland cane districts, when the greater proportion of the effect is of the nuisance order only. During the past few years some extension workers have expressed the opinion, that, with the tendency to convert a nuisance into economic loss through increased harvesting costs of rat-damaged cane, this species may eventually prove the most important rat pest of cane.

In seasons associated with plagues all species follow the broad outline of population trends and may be taken in numbers in their respective habitats. A tentative hypothesis concerning *M. littoralis* attacks on cane in more normal years, based on detailed work with *R. conatus* and some sampling of *Melomys* populations, is put forward here. This species shows greater response than does *R. conatus* to short-time changes in climatic conditions which is exhibited by more congregating, possibly greater survival and activity and by noticeable attacks on cane. In 1944 and 1945 (Table 19) *M. littoralis* was troublesome in some parts of the northern cane districts. The usually accepted version of these occurrences was that rapid multiplication of this rat was aided by the protection of the prolific growth of grass and weeds during the early and prolonged wet seasons. It was generally admitted that controls were either inefficient or difficult. The author considers this version rather superficial. For a beginning, rapid multiplication by breeding under the stated conditions is more than doubtful. It is suggested that for a short time climatic conditions favoured *Melomys* survival in the wetter northern areas and during general population movements in early summer controls were either inefficient or difficult.

Melomys cervinipes Gould.

As with *R. assimilis* little is known about the behaviour of this species within rain-forest. This heavier *Melomys* species, though an excellent climber, seems to find cane an unnatural habitat and there may be handled satisfactorily with ground traps.

Grid No. 7, Table 21, one of a series of grids in a settled population mostly of medium age, yielded 22 specimens. A further indication of population density is given by figures obtained during 1936, when 123 younger *M. cervinipes* were taken from an acre of badly damaged cane near "scrub" in the Mackay district. Little was known of population movement at the time.

REFERENCES.

ALDOUS, S. E. 1946. Live trapping and tagging muskrats. J. Wildlife Mangt. 10 (1) : 42-4.

BLAIR, W. F. 1941. Techniques for the study of mammal populations. J. Mammal. 22 : 148.

——————. 1942. Size of home range and notes on the life history of the woodland deermouse and eastern chipmunk in northern Michigan. J. Mammal. 23 : 27.

BUCHANAN, G. 1927. Spirochaetal jaundice. Spec. Rept. Ser. 113, Med. Res. Counc. Lond.

CHITTY, D. 1936. Bureau of Animal Population, University of Oxford, Annual Report 1935-36.

——————. 1937. A ringing technique for small mammals. J. Ani. Ecol. 6 (1) : 36-53.

——————. 1942. A relative census method for brown rats (*Rattus norvegicus*). Nature 150 : 59.

CILENTO, R. 1942. Tropical Diseases in Australia. Brisbane: W. R. Smith and Paterson.

DICE, L. R. 1931. Methods of indicating the abundance of mammals. J. Mammal. 12 : 376-81.

——————. 1941. Methods of estimating populations of mammals. J. Wildlife Mangt. 5 (4) : 398-407.

DOTY, R. E. 1938. The pre-baited feeding-station method of rat control. Hawaii Plant. Rec. 42 : 39-76.

——————. 1945. Rat control on Hawaiian sugar cane plantations. Hawaii Plant. Rec. 49 (2) : 71-239.

ELTON, C. 1935. Animal Ecology. London: Sidgwick and Jackson Ltd.

——————. 1942. Voles, Mice and Lemmings: Problems in Population Dynamics. Oxford: Clarendon Press.

——————, DAVIS, D. H. S., and FINDLAY, G. M. 1935. An epidemic among voles (*Microtus agrestis*) on the Scottish Border in spring of 1934. J. Ani. Ecol. 4 (2) : 277-88.

EVANS, F. C. 1942. Studies of a small mammal population in Bagley Wood, Berkshire. J. Ani. Ecol. 11 (2) : 182-97.

GARD, K. R. 1935. The rat pest in cane areas. Int. Soc. Sugar Cane Tech. Proc. 5th Congr. 1935: 594-603.

——————. 1936. The Macknade Pest Destruction Board: Report of the Technical Adviser for the year 1935. (Unpublished.)

GILMOUR, D., WATERHOUSE, D. F., and MCINTYRE, G. A. 1946. An account of experiments undertaken to determine the natural population density of the sheep blowfly, *Lucilia cuprina* Wied. Counc. Sci. Ind. Res. Aust. Bull. 195.

GREEN, R. G., and LARSON, C. L. 1938. A description of shock disease in the snowshoe hare. Amer. J. Hygiene 28 : 190-212.

HACKER, H. P., and PEARSON, H. S. 1944. The growth, survival, wandering and variation of the long-tailed field mouse, *Apodemus sylvaticus*. Biometrika. 33 (2) : 136-62.

——————————. 1946. The growth, survival, wandering and variation of the long-tailed field mouse, *Apodemus sylvaticus*. Biometrika. 34 (2) : 333-61.

HAMILTON, W. J., Jnr. 1937. The biology of microtine cycles. J. Agric. Res. 54 (10) : 779-90.

JACKSON, C. H. N. 1932. On the true density of tsetse flies. J. Ani. Ecol. 2 : 204.

——————. 1941. The analysis of a tsetse fly population. Ann. Eugen. Lond. 10 : 332.

KALABUKHOV, N. I. 1935. On the causes of fluctuations in numbers of mouse-like rodents. Zool. Zhurnal 14 : 209-42. (Trans. from Bureau of Animal Population, Oxford University.)

KING, R. T. 1932. The saving of vanishing data. Canadian Field Naturalist. 46 : 108-111.

LESLIE, P. H., and DAVIS, D. H. S. 1939. An attempt to determine the absolute numbers of rats on a given area. J. Ani. Ecol. 8 (1) : 94-113.

MCDOUGALL, W. A. 1944a. An investigation of the rat pest problem in Queensland canefields: 1. Economic aspects. Qld. J. Agric. Sci. 1 (2) : 32-47.

————————. 1944b. An investigation of the rat pest problem in Queensland canefields: 2. Species and general habits. Qld. J. Agric. Sci. 1 (2) : 48-78.

————————. 1944c. An investigation of the rat pest problem in Queensland canefields: 3. Laboratory experiments on food intake and toxicity. Qld. J. Agric. Sci. 1 (3) : 1-32.

————————. 1946. An investigation of the rat pest problem in Queensland canefields: 4. Breeding and life histories. Qld. J. Agric. Sci. 3 (1) : 1-43.

OSBORN, W. A. 1932. Mice plagues in Australia. Nature. 129 : 755.

PEMBERTON, C. E. 1925. The field rat in Hawaii and its control. Expt. Sta. Hawaii. Sugar Plant Ass. Entom. Ser. Bull. 17.

ROEBUCK, A., BAKER, F. T., and WHITE, J. H. 1944. The grazing of winter cereals by the wood-mouse (*Apodemus sylvaticus*). J. Ani. Ecol. 13 (2) : 105-9.

STORER, T. L., EVANS, F. C., and PALMER, F. G. 1944. Some rodent populations in the Sierra Nevada of California. Ecol. Monogr. 14 : 165-92.

SAWERS, W. C. 1938. Some aspects of the leptospirosis problem in Australia. Med. J. Aust. June 25, 1938: 1089-96.

TRIPPENSEE, R. E. 1933-1934. Cottontail in Relation to Cover. American Game. Sept.-Oct., Nov.-Dec., 1933, and Jan.,-Feb., 1934.

TROUGHTON, ELLIS. 1943. Furred Animals of Australia. Sydney: Angus and Robertson.

WINTERBOTTOM, D. C. 1922. Weevil in wheat and storage of grain in bags: a record of Australian experience during the war period (1915-1919). Adelaide: Government Printer.

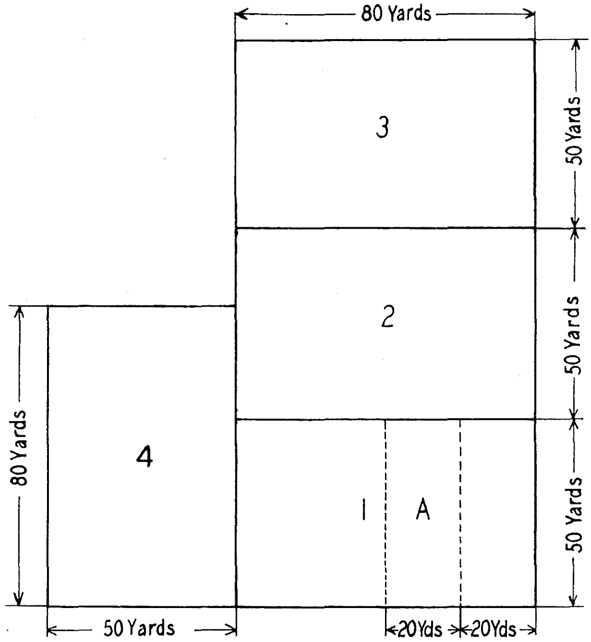
WOOD JONES, F. 1923. The Mammals of South Australia. Pt. III. Adelaide: Govt. Printer.

APPENDIX A.

Illustrating a poor experimental lay-out.

Farm B. Field of P.O.J. 2714 ratoons; crop harvested Nov., 1937.

Lay out of grids:



All grids 8 x 5 with 10-yd. intervals.

Grid No.	Date.	A.P.	No. of Rats Tagged.	No. of Rats Killed while Tagging.	Trap-out.	Remarks.
1	6–8 Apr., 1938	32	24	1 (1 tag)	See below (grids 1–3)	
2	9–12 Apr.	40	28	5 (inc. 1 tag)		5 tags from grid 1 in this grid.
3	21–23 Apr.	26	23	..	..	3 tags from grid 2 in this grid
4	29–30 Apr.	..	..	..	27 (no tags)	

Rats breeding: some very young rats tagged.

Take-up of tagged rats on each grid was as follows:—

Grid 1. 19 females, 5 males; 13 adults, 2 sub-adults and 9 immatures.
Grid 2. 17 females, 11 males; 13 adults, 3 sub-adults and 12 immatures.
Grid 3. 12 females, 9 males; 7 adults, 10 sub-adults and 4 immatures.
Grid 4. 16 females, 11 males; 12 adults, 8 sub-adults and 7 immatures.

From April 10-12 placed a 5 x 2 Feeding Stations grid on area A, grid 1. First night intake of wheat was 41·5 g.; this dropped to 26 g. on the second night, when slight movement in populations was discernible in grid 2. On April 21 counts of rat-damaged stalks were made with the following results:—Grids 1, 2, 4, nil; grid 3, 7·2 per cent. On May 8, grids 2 and 3 were baited with 160 (2 a place) 1 : 500 thallous sulphate treated wheat baits. 15 were nibbled and 20 disappeared. One rat was taken during a check trap-out of these grids on May 11.

On May 12-14 grid 1 was trapped out, yielding 15 rats, only three of which were tagged. One of the tagged rats was new to the field and was originally tagged three miles away during Nov. 1937. Further trapping during this period on grid 4 yielded another 15 rats (no tags).

During July, 1937, 15 rats were taken from this field with 20 traps set for one night.

APPENDIX B.

SUMMARY OF A SAMPLE OF WEIGHT/AGE DATA, WITH ANALYSIS BY P. B. McGOVERN.

Wt. Class.	No. of Observations.	Mean Age in Weeks.	Range of Age in Weeks.	Variance.	Mean Variance.
5–	38	1·0	0–2	·07	
10–	58	2·0	1–3	·11	·13
15–	27	2·7	2–4	·26	
20–	23	3·5	3–5	·35	
25–	20	4·1	3–5	·22	·32
30–	14	5·3	4–6	·40	
35–	23	5·6	4–10	1·6	
40–	21	6·6	6–10	1·0	1·3
45–	10	7·8	6–10	1·3	
50–	20	9·0	7–12	2·2	
55–	16	9·2	7–12	1·4	1·9
60–	12	10·2	8–13	2·4	
65–	14	11·8	9–14	1·7	
70–	13	11·8	10–14	2·0	2·8
75–	8	12·6	8–15	6·0	
80–	19	14·9	10–21	6·9	
85–	16	17·0	13–24	11·2	10·3
90–	14	18·3	14–29	13·8	
95–	5	16·0	11–23	20·0	
100–	9	19·6	15–24	6·8	24·9
105–	6	24·7	16–36	57·9	
110–	10	31·2	16–58	234	
115–	17	35·9	11–120	1,072	515
120–	18	29·4	14–65	140	
125–	14	39·0	26–105	451	
130–	12	33·3	22–49	81	418
135–	17	40·7	17–120	622	
140–	19	40·8	17–92	431	
145–	11	38·9	26–64	96	222
150–	26	39·9	17–72	122	
155–	20	45·4	21–81	215	
160–	10	54·2	38–96	494	259
165–	21	45·4	26–96	195	

APPENDIX B.—continued.

SUMMARY OF A SAMPLE OF WEIGHT/AGE DATA, WITH ANALYSIS, BY P. B. McGOVERN—*continued*.

Wt. Class.	No. of Observations.	Mean Age in Weeks.	Range of Age in Weeks.	Variance.	Mean Variance.
170–	15	43·1	22–88	346	
175–	26	58·5	25–135	759	737
180–	18	72·6	30–124	1,028	
185–	17	53·9	30–140	861	
190–	11	68·2	37–97	346	590
195–	12	63·5	38–91	416	
200–	9	85·9	46–155	1,047	
205–	5	76·2	48–150	1,779	941
210–	10	72·9	53–96	153	
215–	3	67·7	47–81	329	
220–	..	..	..	..	
225–	2	61·5	..	..	
230–	2	69·5	..	..	
235–	4	74·5	54–98	392	
240–	1	75·0	..	..	
245–	7	93·6	60–128	625	
250–	1	87·0	..	..	
255–	4	88·0	69–106	249	
260–	..	..	..	..	
265–	2	78·5	..	..	

If from a fitted curve an estimated age (y) is obtained for a rat of given weight, then this estimate in 95 per cent. of cases lies within the range y $\pm$ 2 Variance. Thus from the data above any age determination based on weight alone would be subject to, as mentioned in the text, the following limitations:—

1. Up to a weight of 100 g. the age can be predicted to within $\pm$ 10 weeks, the limits being smaller for the younger age groups.
2. Above a weight of approx. 100 g. the age can be predicted to within $\pm$ 44 weeks and the limits do not show much variation at different weights.

An examination of weight-age data for female caged rats yields the same type of result.

APPENDIX C.

Lay-outs and grid combinations used purely for population studies.

3 x 7, 10-yd. interval: trapped out on a 3 x 7, 10-yd. interval, bb. Examples: Table 6, grids 1 and 3, and Fig. 1.

4 x 5, 10-yd. interval: trapped out on a 4 x 5, 10-yd. interval bb. Examples: Table 6, grids 2, 4, 6, 7, 8, 9 and 10, and Fig. 2.

4 x 5, 10-yd. interval: trapped out on a superimposed and overlapping 9 x 8, 10-yd. interval, bb. Example: Table 7.

8 x 5 or 3 x 13 (Table 6, grid 5), 10-yd. interval: trapped out on grid areas, or on grid areas plus adjacent environment, with bb. traps at either 10-yd. or 5-yd. intervals.

8 x 5 or 4 x 5, 20 yd. x 10 yd. or 10 yd. x 5 yd.; trapped out by bb. grids of 20 yd. x 10 yd., 10 yd. x 5 yd., or of 20-yd., 10-yd. or 5-yd. intervals.

4 x 5, 20-yd. interval: followed by a centrally placed 4 x 5, 10-yd. interval: followed by a centrally placed 4 x 5, 5-yd. interval: trapped out on the largest grid area with bb. traps at 10-yd. or 5-yd. intervals.

4 x 5, 10-yd. interval: followed by a centrally placed 4 x 5, 5-yd. interval: trapped out on a 4 x 5, 10-yd. interval, bb. Example: Table 8, grid 2, and Fig. 5.

4 x 5, 10-yd. interval: followed by a 4 x 5, 5-yd. interval: trapped out on a 4 x 5, 5-yd. interval. Example: Table 8, grid 3, and Fig. 5.

Series of grids, sometimes with different grid intervals, and used for a number of purposes. Example: Fig. 3.

Series of grids, with varying intervals, set out continuously over areas up to 12 acres: trapped out over the whole area or on selected parts with bb. grids of 10-yd. or 5-yd. intervals. Fig. 6 (see also Table 9) is an example of continuous and contiguous grids with 10-yd. intervals, eventually trapped out within an area of 2·84 acre.

Partial overlapping of grid areas: trapped out by various methods. Fig. 4 is an example of a one-third overlap of two 3 x 7, 10-yd. interval grids.

Partial or complete surrounding of grids with trap cordons, single lines or parallel series of lines, at distances up to 100 yd. from grid perimeters.