A CHANGE IN OUTBREAKING POPULATIONS OF THE BROWN RAT UNDER PRESSURE OF FREQUENT POISONING OPERATIONS DURING ONE YEAR PERIOD

Ryo TANAKA

(*Received January 21, 1958*)

Several small islands and the adjacent coastal areas of Uwajima in the southwest of Shikoku, Japan, have been infested with outbreaking populations of the brown rat (*Rattus norvegicus*) since 1949 onward. The rat plague, originated in the islands, showed only a transient subsidence in 1953 and thereafter recurred as violently as before and spread to the adjoining peninsular villages and coastal districts of Uwajima City. It has lasted for an extraordinarily long period against the pressure of large-scale control campaigns conducted at frequent intervals under a good organization of residents and officials. Eventually, however, the pest populations are coming to calm down on the whole in the latest year (1957), although there still remains a population with unusual fecundity * and severe damage to crops occurs in restricted parts of the region. It will be a puzzle that the rat populations have so long a while been in the condition of outbreak if we take most examples of small mammal outbreaks in the world, which were of brief duration, followed by population crash under the influence of stress.

Since the onset of the outbreak, I have been concerned over the event, but it is after 1955 that I have had opportunity to give direct cooperation in the control campaign. I have inquired into the event to trace it back to its causes from the viewpoint of community ecology, and my views up to the present appeared in the foregoing papers.[10][12]

This paper explains the process of population shifts during a year period from April 1955 to March 1956; the result is mostly based on abundant data collected by residents and official leaders in every district as a consequence of the poisoning operations performed in the meanwhile throughout the region. Within this period, besides common poisoning, basic census work was exercised under my direction on numerous plots in diverse districts. The analysis of these data disclosed some characteristics of outbreaking populations. The maximum population density was estimated at as high as 200–300 per hectare; it must have produced an alarming crowding in winter when the majority of the population probably moved into residental areas from farm tracts. The average male percentage was as low as 34.6 in adult rats; this is evidence for unusual superiority of female over male number by reference to the value 43–44 % secured by Schein[9] and Leslie et al.[6] from rat populations in ordinary conditions. In respect of the age distribution, no feature of a rapidly growing type was indicated in any regional populations.

The mathematical analysis was made under kind guidance of Asst. Prof. H. Sugiyama, Statistical Laboratory, Medical Institute, Osaka City University, to whom I am deeply grateful.

---

* For instance, a pregnancy rate 0.73 was counted from 24 adult female rats in a village in March, 1957; this is unusually high as compared with the universal values presented by Davis etc.[2][3]

The present study was partly aided by the grant from the Scientific Expenditure, Education Ministry.

Basic census work

The basic census was done by the method of mark-and-release coupled with poisoning. A certain number of rats live-trapped in a day or two are marked and released, immediately after which the population of size N is exposed to poisons as strong and quick as possible. On the subsequent days, as many corpses as we can should be picked up. Be the number of corpses recovered R, m out of which may be previously marked. Then the maximum likelihood estimate $\hat{N}$ of the original population is given as $\hat{N}=RM/m$ from the hyper-geometric distribution. It has been verified[11] by me and some other students that marked and unmarked rats may differently response to live-traps, so the sample drawn from the population inclusive of marked should not be trapped animals, otherwise it would be biased. Nevertheless, the response to poison baits of marked and unmarked can be regarded as grossly homogeneous, hence the poisoned rats picked up must be a ramdom sample. The reliability of this method has been recognized by Chitty.[1]

The data of the census work are denoted in Table 1. Whether the corpse-recovery rate

Table 1. Results of basic census work by the method of mark-and-release followed by poisoning

Plot No.	1	2	3	4	5	6*	7	8	9	10	11	12	13
M	27	32	4	11	5	15	6	9	18	11	8	15	15
R	697	664	83	382	14	83	23	213	243	91	385	342	180
m	9	7	2	1	0	1	1	0	0	1	1	4	3
$\hat{N}$	2,019	3,035	166	4,202	—	1,245	138	—	—	1,001	3,080	870	909

Plot No.	14	15**	16	17	18*	19*	20*	21*	22*	23*	24*	25*	26
M	22	43	9	9	4	28	27	4	15	8	30	6	11
R	452	190	121	169	22	75	66	37	35	36	52	24	25
m	6	3	1	1	2	7	5	3	2	2	7	3	1
$\hat{N}$	1,657	2,723	1,089	1,521	44	300	343	49	263	144	223	48	275

M : number of marked and released; R : number of corpses picked up; m : number of previously marked out of R; $\hat{N}$: estimated size of original population.
* poisoned with phosphorus; ** with cumarin group; others with 1080.

(proportion of pick-up size to original population) $\gamma=R/\hat{N}=m/M$ is stable or not, i.e. the characteristic has a normal sampling distribution or not, can be inspected by means of the 3σ method.[5] For the test, control lines for the rate are constructed above and below the standard rate or the weighted mean $\bar{\gamma}=0.186$ (Figure 1).

The figure shows that the observed γ-values are all within control lines, thus the rate must be considered as stable in despite of different kinds of poison used and of other different circumstances in each district. It will, therefore, be logically allowed to apply the standard rate also to results of common poisoning work, if its process is run as elaborately as in the basic census, for the population before a treatment to be estimated from the number of corpses picked up. From the value of $\bar{\gamma}$, $\hat{N}=5.368R$

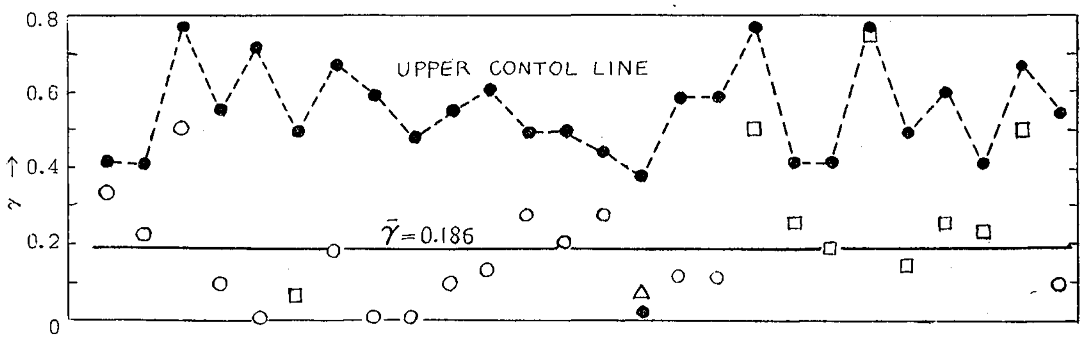

Figure 1. Control chart of the corpse-recovery rate; lower control line is on zero in all cases but one; ○ with 1080, □ with phosphorus, △ with cumarin group.

is induced; it means that the population is some fivefold as large as the number picked up.

The number recovered after poisoning is habitually quoted as a measure of a control success, but this may be useless if applied without reflection. However, its usefulness seems to have unduly been disregarded by population ecologists. According to Chitty,[1] while this proves a certain minimum mortality and a big psychological value, no information is given about the residual population and little about the original one; therefore in the absence of other data, little importance can be attached to the size of the pick-up, which varies at least with population size, kind of poison, and nature of habitat. Indeed, his data (Table 3, p. 166)[1] exhibit clearly that the pick-up is unrelated either to the total kill or to the original population estimated. One may suppose the discrepance between his data and ours to be attributed to a notable difference in sample size, his numbers picked up being only 5 or less in most cases.

According to our result, however, the number recovered, if it is large enough, may be proportional to the original population size; it is proved also by making a regression chart of R against $\hat{N}$, where a nearly linear relation is produced. If R is approximately related to total kill size, the efficiency of kill can be inferred to have been grossly invariable throughout the census work. The effects of shyness[1] to poison baits among survivors of the population may well be neglected by reason that the census has been done in different plots in almost all the cases.

Common poisoning work

Most of the common poisoning operations were carried out with the powerful poison 1080 on farm tracts, and the present results are all based on treatments with this poison. In each work, the rats killed were recovered by every possible effort and the consumed amount of poison baits examined carefully enough after a treatment, and yet, since they were run over much more extensive areas than the basic censuses, the corpse-recovery rate must have inevitably been inclined to be somewhat smaller, accordingly the populations have presumably been underestimated in some measure.

The take of poison is counted from that of poison baits, in which the quantity of poison contained is known, and the size of total kill is assessed theoretically from poison take divided by a lethal dose of poison. In practice, the estimation under such a design is difficult because some uncontrollable factors may be introduced in the phenomenon. Thus this method has by no means been adopted as a reliable one for kill evaluation.

Certain kinds of poison baits are carried away by rats[1] and some of them are stocked in a nest or harborage. However strong the poison may be, individual rats are subject to a wide range of variation in the way of response[13] to poison baits and in resistance to its toxicity. Some rats may take much more doses of poison than a lethal one before paralysed by its intake. For these reasons, the determination of a lethal dose best qualified for count of kill in natural populations is very difficult. Even with 1080, lethal doses for the rat (mg. per kg. body weight) are given very differently by different authors as follows: $LD_{50}=0.22-0.01$;[4] $LD_{50}=4$, $LD_{90}=6$ (Pests, 1947);[8] $LD_{50}=0.1-10.0$, $LD_{100}=3$;[7] $LD=0.3-3.0$ (Steinger).[7] From these, the unit amount of the disappeared poison competent for killing a rat of 200−300 g. in average weight has been determined as 5 mg. by taking account of consumption caused by various factors other than direct intake by a rat. This amount is equivalent to kill of several rats by reference to $LD_{90}=6$, whereas it might be too large an estimate according to $LD_{50}=0.1$ or 0.22.

Thus the estimate of total kill has been obtained from the amount of poison baits, disappeared, divided by 5 mg. The numbers of corpses recovered and the total kill estimated in the common poisoning operations are shown in Table 2, in which a fraction of the data in the basic census is included. These figures are partially illustrated in the chart (Figure 2).

Table 2. Number (R) of corpses picked up and estimated size (D) of total kill in each of the common poisoning operations.

Time			Uwajima R	Uwajima D	Yusu R	Yusu D	Tojma R	Tojma D	Hiburi R	Hiburi D	Komobuchi R	Komobuchi D	Shitaba R	Shitaba D
1955	April	B*	—	—	—	—	275	2,600	484	1,700	424	9,000	—	—
		M	—	—	—	—	—	—	—	—	—	—	—	—
		E	—	—	3,900	7,200	—	—	—	—	—	—	—	—
	May	B	—	—	—	—	—	—	—	—	—	—	—	—
		M	—	—	—	—	766	4,000	—	—	—	—	—	—
		E	—	—	1,141	4,800	—	—	—	—	—	—	—	—
	June	B	—	—	—	—	1,084	4,000	—	—	150	3,000	—	—
		M	30,500	61,350	—	—	—	—	—	—	—	—	—	—
		E	—	—	—	—	—	—	1,277	3,000	—	—	—	—
	July	B	—	—	—	—	—	—	—	—	—	—	—	—
		M	—	—	—	—	1,602	4,640	560	1,800	355	5,000	—	—
		E	—	—	6,310	7,200	—	—	—	—	—	—	—	—
	Aug.	B	31,200	70,200	—	—	614	3,200	452	1,600	—	—	—	—
		M	—	—	—	—	—	—	—	—	—	—	—	—
		E	—	—	532	2,400	—	—	460	1,400	—	—	—	—
	Sept.	B	—	—	—	—	—	—	—	—	—	—	—	—
		M	12,100	49,920	—	—	780	2,400	—	—	—	—	—	—
		E	—	—	—	—	—	—	—	—	—	—	—	—
	Oct.	B	—	—	—	—	—	—	—	—	—	—	—	—
		M	—	—	—	—	—	—	—	—	—	—	—	—
		E	—	—	—	—	—	—	—	—	—	—	—	—

Time		Locality	Uwajima		Yusu		Tojima		Hiburi		Komobuchi		Shitaba	
			R	D	R	D	R	D	R	D	R	D	R	D
1955	Nov.	B	—	—	—	—	—	—	1,350	3,720	—	—	—	—
		M	—	—	—	—	275	1,600	—	—	—	—	—	—
		E	—	—	643	3,800	—	—	—	—	—	—	—	—
	Dec.	B	—	—	—	—	—	—	—	—	—	—	—	—
		M	—	—	—	—	—	—	—	—	—	—	—	—
		E	37,600	81,600	—	—	643	5,600	985	6,400	—	—	—	—
1956	Jan.	B	—	—	—	—	—	—	970	4,000	—	—	—	—
		M	—	—	—	—	314	1,600	—	—	—	—	—	—
		E	—	—	—	—	—	—	—	—	—	—	—	—
	Feb.	B	—	—	352	31,920	—	—	344	3,200	554	7,200	150	4,800
		M	25,200	83,160	—	—	—	—	—	—	—	—	—	—
		E	—	—	—	—	—	—	—	—	383	6,000	—	—
	Mar.	B	—	—	—	—	540	3,200	—	—	—	—	204	4,800
		M	—	—	1,523	30,400	—	—	—	—	—	—	—	—
		E	32,400	100,300	—	—	—	—	864	3,000	682	12,000	210	2,420

* B: at the beginning; M: at the middle; E: at the end.

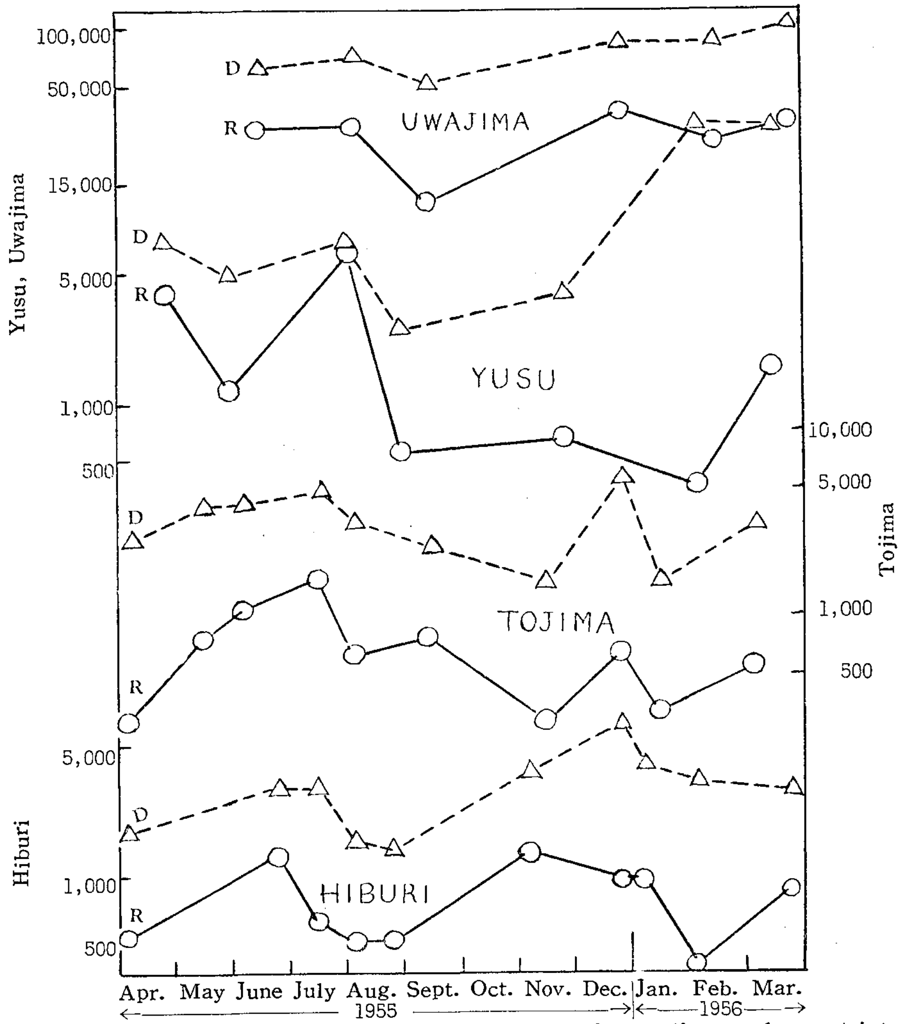

Figure 2. A change in R and D of the succesive control operations at frequent intervals during a year period; R and D are indicated in logarithm.

As shown in the figure, D varies approximately in parallel with R in nearly all the cases notwithstanding that both values were secured quite independently of each other. Then a regression chart of D against R is constructed, it proving that the regression is linear where the coefficient $b=2.44\pm0.106$. Thence we get $D=2.44R$, i.e. about a half of the total kill has been recovered in average.

If the corpse-recovery rate, above offered, is applied to R in the present result on the presumption that the kill efficiency is constant in every operation, the populations before treatments each time are seen from this figure to have been kept in almost the same level of density, even if there occurred some fluctuations probably due to vernal or autumnal rise in fecundity or to absence of control pressure for a few months. Here, the efficiency proves to have been about 50 % in average because $\hat{N}=5.38R$ and $D=2.44R$ hence $\hat{N}\fallingdotseq 2D$. If the effects of shyness had developed more intensely at the later than at the earlier time during the period, we are led to suppose that the density level would have been advanced toward the end, but this supposition seems very unlikely in view of the actual circumstances such as the amount of crop damage and direct evidence of rat infestation. Therefore, it may be inferred that no general trend to refuse poison baits under the effects of shyness had increased in the later populations at least during the period.

The control success of 50 % is very slight contrary to our expectation, but it is in some degree comprehensible from the wide individual variation in the shyness to poisons or baits and the resistance to toxicity. A possibility of not a few survivors of poisoning campaigns, with the strongest poisons, is pertinently explained by Tevis.[13] After all, it reveals that a poisoning efficiency is unexpectedly low in successive operations against natural populations in the outbreak, no matter how powerful poison used may be.

Conclusion

In the successive poisoning operations against the outbreaking populations of the brown rat, carried out with 1080 at brief intervals from 20 days to 3 months during a year period from April 1955 to March 1956, about 50 % success was calculated in average, and the population level had been kept nearly the same in general in the meantime. The number of corpses (R) recovered and the amount of poison baits disappeared after treatments have proved to be sufficiently available for estimation of the original population (N) and the total kill (D), hence the efficiency when a large population is dealt with. From the basic census and common poisoning, $\hat{N}=5.38R$ and $D=2.44R$ were induced respectively, a combination of both resulting in 50 % success.

Reference

(1) CHITTY, D. 1954 Control of rats and mice, Vol. I: 160—305. (2) DAVIS, E. D. 1953 Quart. Rev. Biol., 28: 373—401. (3) —— & O. HALL 1951 Physiol. Zool., 24: 9—20. (4) DIEK, S. H. & C. P. RICHTER 1946 Pub. Health Rep., 61: 673—679. (5) DIXON, J. W. & F. J. MASSEY, JR. 1951 Introduction to statistical analysis. (6) LESLIE, P. H., U. M. VENABLES & L. S. V. VENABLES 1957 P. Z. S. London, 122, Pt. I: 187—238. (7)* MISAKA, K. 1956 Hoppo Ringyo, 8: 246—248. (8)* SASA, M. & T. SUZUKI 1952 Insecticides and rodenticides. (9) SCHEIN, M. W. 1950 Amer. Nat., 84: 487—496. (10) TANAKA, R. 1955 Bull. Kochi Wom. Coll., 4: 23—32. (11) —— 1956 Annot. Zool. Jap., 29: 44—51. (12) —— 1957 Bull. Wom. Univ., 5, Ser. Nat. Sci., 1: 20—30. (13) TEVIS, L. JR. 1956 J. Mamm., 37: 358—370.

* in Japanese only.

(Zoological Laboratory, Kochi Women's University, Kochi, Japan)