RECENT STATUS OF RAT INFESTATION IN THE SOUTHWEST COASTAL REGION OF SHIKOKU AND COMMENTS ON CENSUS TRAPPING OF RAT POPULATIONS

Ryo TANAKA

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General aspect of rat plague

Since the first outbreak of Norway rats (*Rattus norvegicus*) took place in 1949 on an islet (Tojima) of the southwest coastal region of Ehime prefecture, Shikoku, the region has not yet been completely free from infestation with the pest animals (Fig. 1). In the mean time, many control campaigns with good poisons, as well as by strong trapping, were

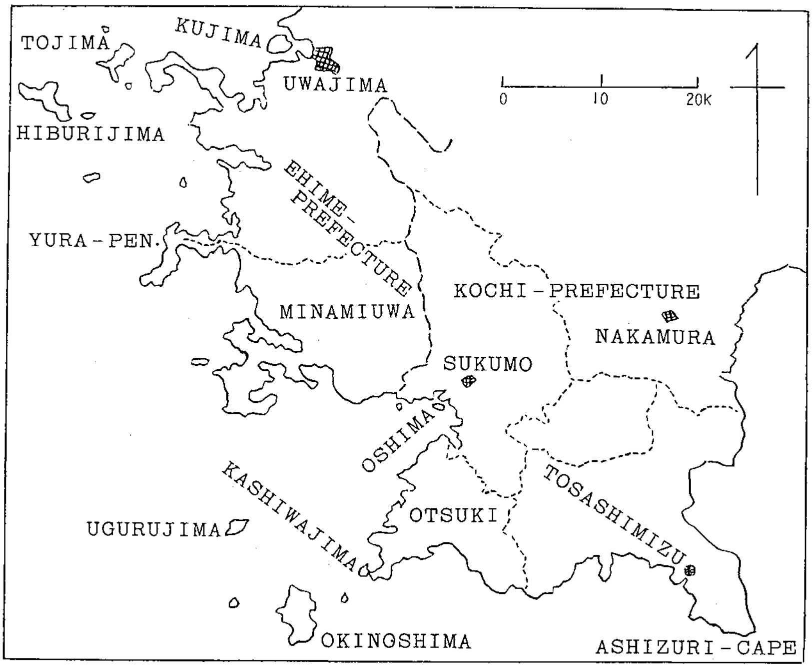

Fig. 1. A map showing the region of rat outbreaks, occurred during the time 1949—1963, in the southwest of Shikoku.

executed almost all over the region. Some rehabilitation has been done also and now is under way. Further, reinforcement of the predator pressure was attempted by introducing snakes, weasels, and domestic cats. The wild predators had been really so much reduced in number, especially on islets, by expansion of cultivated lands at the expense of their habitats. Many cats, dogs and wildlife were sacrificed in consequence of poisoning works.

For all the efforts, the rat-population density has not come down to such low levels as common in other rural regions of this country, and yet a very heavy infestation such as was supposedly realized in the incipient outbreaks no longer came into being. The rat plague appears to have fallen into a chronic state in terms of epidemics.

The infested territory extended year by year generally southeastward as far as the west coastal region of Kochi prefecture, where a peak density equivalent to an outbreak, was reached in 1962 (Fig. 1). The natural and human ecosystems(11) are almost the same throughout the plague areas in both prefectures, so these plagues may be looked upon as one associated phenomenon endemic to the southwest region of Shikoku.

The southeastern dissemination of the plague has been made showing a cyclic phase at intervals of 4－5 years. The outbreak, commenced in 1949, extended its area to the adjacent islet and coastal areas in Kitauwa county and Uwajima town, and its short slackness was seen in 1953, but the next year the populations were terribly enhanced causing the greatest damage all over the infested region; later the plague altogether tended to decline year after year.

In 1959, an outbreaking population was produced in Yura peninsula to the south of Uwajima. At that time, the farther, south county (Minamiuwa) was suffering from the similar infestation; this plague, which had been started as early as 1951 or '52, was made more and more intense up to its peak, attained in 1958 or so, in spite of natives' efforts in their independent control works.

The plague was spread further southeastward to the coastal region of Sukumo and Otsuki in Kochi prefecture, where the rat populations, beginning in about 1956, grew larger and larger up to the peak density, against native control works, in 1962. An islet, Oshima, near Sukumo town just to the southeast of the prefectural border was guessed on actual inquiry to have been suffering from the largest population among infested areas in Kochi prefecture.

Thus the cyclic phase in the overall plague is revealed in that the peak years were 1949, '54, '58－'59 and '62, but it means only a seeming cycle, because the peak site was transferred from north to southeast. It is readily anticipated that the same plague will be spread along the coast toward Tosashimizu town and the cape of Ashizuri in 4 or 5 years.

The dynamics of rat populations in this region were discussed before;(10)(11)(12) a problem of social pressure expressed in terms of adrenal weight was attacked with samples taken out of them.(14)(16) The environmental capacity for rats can be supposed to have been fairly larger than elsewhere since formerly in view of climate, topography, and native mode of life proper to this region.(11) A record is found in classic literature that the coastal territory of Uwajima received a serious damage to crops by heavily haunted rats in 1795. The ecosystem would have been formed step by step from older times, and it was elaborately reformed to augment cultivation areas of food plants (sweet potatoe and wheat) toward the end of World War II, and after the reformation onward, nearly the same phase has perhaps been retained.

Therefore, the unusual capacity and characteristic composition of the ecosystem favorable for rat haunting will be ultimate causes of the trend for the populations to provoke frequent outbreaks and fall into a chronic state of plague lasting so long. However, it seems difficult to explain fully by any theories of natural control offered hereto why the first two abrupt and other gradational outbreaks took place at regular intervals in different sites. The apparent cycle could hardly be accounted for by the intrinsic mechanism theory, presented by me,(15) available for prolific vole-populations which may recurrently fluctuate going through stages of crash, upswing and peak in the same locality. No state of crash appears to have been actually encountered in any localities; the chief reason would be that all the populations were forced under pressure of artificial controls so that they could scarcely attain assymptotes in population growth. The adrenal analysis showed merely that some populations assumed to be of higher density had clearly larger adrenals than those of lower one, but no proof of deterioration in fecundity was found for those with augmented adrenal weights in discord with the theory of CHRISTIAN.[2]

When its upswing was going on, a population looked very tenaceous as if its biotic potential, so to speak, was kept strong enough to overcome every agency of natural or artificial controls, and it seems unlikely that the upswing was provoked by release of any suppression agents as suggested in SOLOMON's theory.[9]

In this region, the good poison 1080 was most often used. We used to be faced with the trouble that the repeated use of the poison decreased kill efficiency, it being much lower at the subsequent times than at the first one or two. The most likely reason may be the development of population shyness; its concerns were discussed by CHITTY[11] and TEVIS[8] for rats or mice. Some rats, on ingesting poison amounts below their lethal dose, will escape death, hence getting warier of the poisons, and others of innate shyness will avoid them at the first experience, and accordingly the survivors, which have been the more times exposed to poisons, will have the more shyness and invulnerability to them. In addition, their offspring may possibly inherit the trait of shyness, and eventually the population as a whole will intensify its invulnerability from generation to generation, the process being assumed as natural selection.

A second presumptive cause is the increase of population tolerance to the poison also through the natural selection. This problem with wild rats has as yet been neither approved nor disproved by any students so far as I know, but the individual variation in suscestibility to poisons in rats is really so wide that the same process as with the shyness would be probable, remaining room for a future research in the field of population genetics.

The geographical spread of plagues might be suspected to have been evoked by emmigration of outbreaking populations from the original place. We often heard natives speak of legends that a mass of rats could move swimming over a sea from land to land. Really in 1959 there was a fisherman who mentioned that he observed, on a dark night, something like a swimming band of rats about 400 m off the coast of Yura peninsula two months before the outbreak set in there, but no further fact was substantiated by him. The similar legends[5] of roof rats and Polynesian rats in Ponape were examined by means of swimming experiments by U. S. ecologists, who came to postulate that the possible mode of travel in the water was unlikely to have been important in the spread of rats across any sizable expanse of water. I consider such a postulation to be almost available for Norway rats, too, even if they are known to be more tolerant of water than roof rats. The fisherman's observation was not scientific at all so as to persuade us well. We have evidence that at the time of the earliest outbreak Norway rats had already been distributed everywhere in major parts of this region. In 1950 or so, a notable outbreak happened, but came to calm before long, in the islet Ugurujima lying at the southwest extremity of Fig. 1. Thus the suspicion of mass migration of outbreaking populations would be deniable.

Results of the latest surveys

In February, 1963 I jointed in the preliminary survey of the outbreaking population in Oshima shortly in advance of the general control work which was performed after a plan of official experts. Population features were sought from 147 specimens trapped in the survey.

The sample consisted only of Norway rats, but two field mice (*Apodemus specisosus*) were taken besides, whereas every sample from Ehime populations contained roof rats in the ratio of 5−10%; that would suggest a great pressure of the Norway-rat population. Secondly, the body-weight structure (Fig. 3) shows a tendency for its population to be more prevalent in large classes over 350 g, as compared with any samples, which were otherwise treated

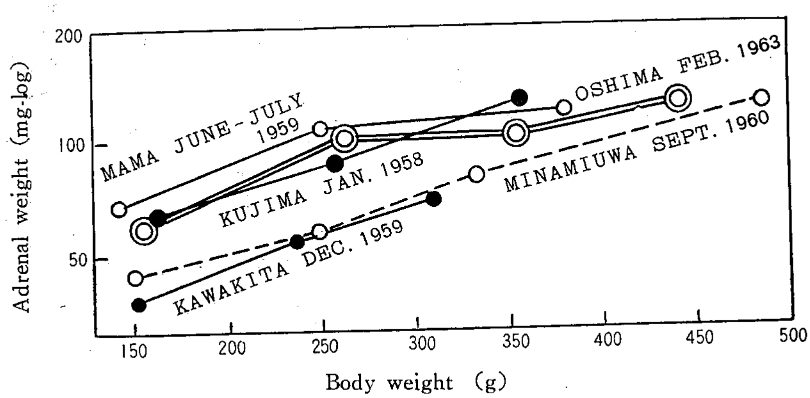

Fig. 2. Average adrenal weight of adult males in each body-weight class plotted on body weight for the comaparable populations of Norway rats.

before,[14][16] from various localities in both prefectures. The third feature consists in its level of adrenal weight (Fig. 2), assignable to the group of higher social pressure[14][16] among these populations. Thus, from these features, we are afraid that the population might be more harmful and uncontrollable than any of Ehime that have ever caused outbreaks. Fortunately, however, the first general control could result in a great success.

A gross census of the population (let it be N) at the time of the preliminary survey was attempted on the basis of numbers of corpses, picked up after poisoning, and catches with snap traps (Table 1) in the whole course of the control work.

Table 1. Numbers of trapped rats and corpses picked up after poisoning in residential area (247 houses) and its nearby fields of Oshima.

Date (1963)	5Ⅱ−7Ⅱ	14Ⅱ	15Ⅱ−17Ⅱ	18Ⅱ	21Ⅱ	22Ⅱ−25Ⅱ	Total
Catch	147	90	404	385	21	241	1288
Pick-up			362		23		385
Operation (Area)	Preliminary survey (partial)		General control (whole)		Post-control survey (whole)		

If we apply the corpse-recovery rate $(R/\hat{N})$,[12] which was 0.186 on the average as a result of count from the large sample gathered in Uwajima region, to the 'pick-up' size at the time of the general control operation, the population just before the time could somehow be estimated despite the awkward condition that poisoning and trapping ran side by side. Then, on the presumption that every trapped rat had no chance to collide with any poisons, the rest population N', exposed to those, would be estimated as N'=362×5=1810, and the total population N works out as N=1810+(147+90+404)=2451. Thus the density per house will be about 10, which is considered nearly tenfold as large as a common density of commensal rats in Japanese towns, for I could previously calculate the average density as 1 rat per house at most from several results by dint of the marking method.

The total kill, actually confirmed, is 1673, but the number (D) of all poisoned rats is difficult to assess. In the same paper,[12] D was estimated from the amount of poison consumed by rats, and the ratio D/R (ca. 2.5) was given. On applying this ratio, the total kill by both poisoning and trapping would be counted as (385×2.5)+1288=2251. Eventually the kill efficiency proves to have been as high as 92%. The great success was verified by a striking decrease of damage ensued from the control work, but a recruitment of the rat population, formed of small adults or youngs alone, was going on when I visited the islet again in September, 1963.

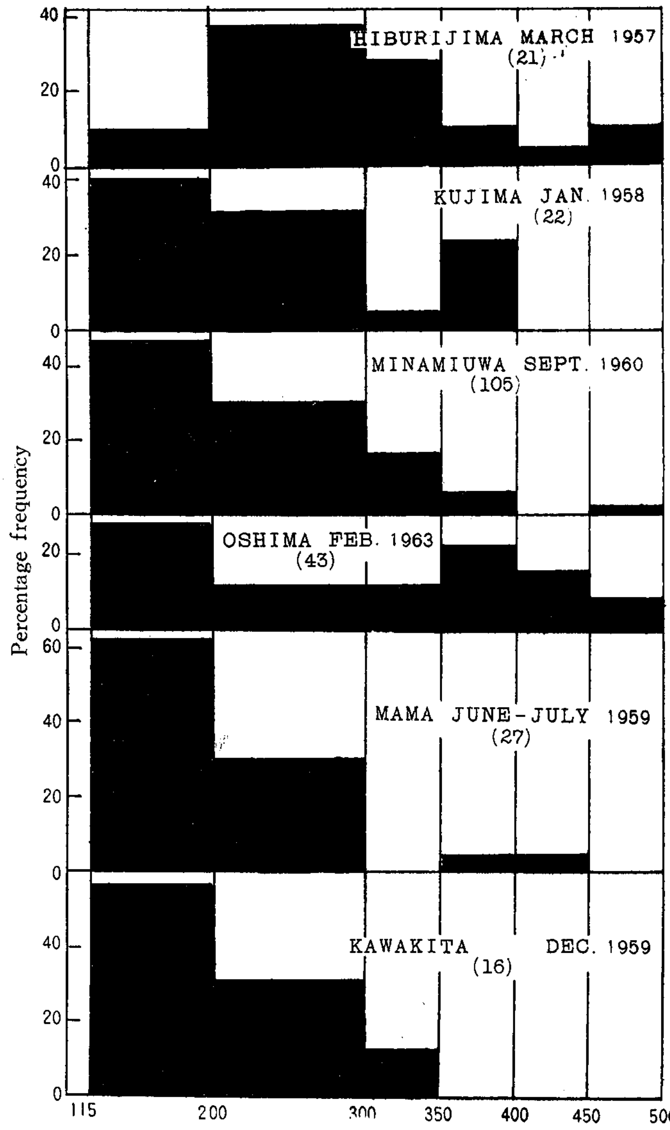

Fig. 3. Body-weight structure in samples from Norway-rat populations in Oshima and other localities, the figures in parentheses being sample size.

MORIKAWA[6] and ITO[4], Biological Institute, Ehime University, made actual surveys on the rat infestation in Ehime prefecture in the period between August, 1962 and April, '63 and informed us of their census results in several areas.

According to their reports, a stressed work of control was planned and carried out nearly all over the plague region of the prefecture under the supervision of the prefectural rat-control committee, created in 1961, with the aim of rat eradication in a year's duration ending in the spring of 1962. The poison as dangerous as Ca-cyanate also was employed in fields. The annual expense amounted to 12.5 million yen.

The very condition that such a strong control was still required will surely account for the chronic state of the plague.

Since their survey was started a few months after the thorough control, it was natural that they found, by census trapping, generally low levels in rat density which was, however, something far above zero. After all, we can not yet warrant any sanguine expectations about the coming phase of the plague. Further they disclosed that field mice (*Apodemus*) were exclusively prevalent in the fields around two hamlets in Minamiuwa, while Norway rats alone were trapped even in the fields as far as those near woods in Kujima islet of Uwajima. The hamlets (designated as A and B), which are each isolated from the others by fields and woods, were infested with rats of low density in A but of very high one in B; the latter had not been subjected to the thorough control. Why the field in B also was occupied by field mice looks to be a perplex in view of the idea that field mice may be predominant in fields when a rat population weakens in pressure so much as not to disperse into fields.

ITO has offered a critique of the routine census formula by feeling unreliable about that in application to rats in consequence of his practical census and subsequent survey of kill in these hamlets.

A problem on rat census

The results of census trapping, and the numbers of trapped rats and recovered poisoned ones in the after survey in hamlets A and B were given by ITO[4] (Table 2). For the census, snap traps were used, the mean number set per house being 7.8 in A (180 houses) and 10.5 in B (74 houses), and the formula $C_n=(N-S_{n-1})p$ was applied to each set of the

Table 2. Numbers of trapped rats and corpses picked up after poisoning in hamlets A and B (reformed from ITO[4])

	Date (1963)	27X 28X 29X	30X − 4XI	5 XI	6XI−8XI	9 XI	Total
A	Catch	85 54 34 (census trapping)		12		6	277
	Pick-up		32		54		

	Date (1963−'64)	28XII 29XII 30XII	31XII	1 I − 11 I	Total
B	Catch	221 123 62 (census trapping)	35		540(+85*)
	Pick-up			99(+85*)	

* Additional number recognized after the report was published.

observed values, which were well on a regression line in either set; as a result, $\hat{N}_A=234\pm24.1$ and $\hat{N}_B=483\pm21.3$ were counted by the ZIPPIN's method.[17] For comparison, the

LINCOLN index method also was employed in B; out of 34 rats previously marked, 7 were recaptured in 3 days of the census trapping, resulting in $\hat{N}=1971$ after the index model. It will later be seen that the value is an undue overestimate explicable by the bias-making trend of $\pi<p$ which may be revealed even in a process with snap traps.[13]

He thought well the agents corresponding with 'dilution factor' of LESLIE (1952) to have been almost negligible through the census and after survey because of absence of rats from field areas of the isolated hamlets and of the survey period as short as two weeks or so.

The upper fiducial limits (282 and 526 at 95 % level) of the maximum likelihood estimates ($\hat{N}_A$ and $\hat{N}_B$) approximate the total numbers (277 and 540) of rats either trapped or picked up, respectively. However, unknown numbers larger than the pick-up size must have surely been poisoned, then he guessed, on no statistical grounds, the recovery efficiency (R/D) to be 25 and 20 % at most under various circumstances in each hamlet.

Thus, on relying upon the guessed ratios, he has concluded that the estimated sizes (535 and 936) of the total kill respectively amouns to nearly twice the upper limits of $\hat{N}$, the discrepancy being important. If my feasible efficiency 40 % (the reciprocal of D/R value above quoted) is adopted, instead, the total kill will be 406 for A and 689 for B, but that of B by making allowance for the pick-up later added will be as large as 901. Furthermore, there was no evidence that the rat populations had been exhaustively killed by the procedures.

At any rate, we ought to approve that the census method produced so great underestimates that the kill estimates were by 40 % (A) or 70 (B) over the upper limits of $\hat{N}$; then the degree of underestimation was higher in B than in A.

The incomplete exposure of populations to traps will be only a way to furnish an explication for the underestimation for the present. ITO also tried to explain from the point of view by conjecturing that many young rats were unexposed at least with B, for there the numerical ratio of young to adult in the catch was much lower than that in the pick-up. As another reason, he mentioned of the probable existence of very trap-shy rats. Nevertheless, we should clearly distinguish the phenomenon of shyness from that of unexposure in view of probabilitity of capture.

The population density per house works out at 2.3 for A and 12.2 for B; the latter is high enough to deserve to be called one at outbreaking times. Hence the mean trap number, alloted to each animal, could be about 3 and 0.9 respectively. The fewer alloted traps might be responsible for the higher degree of underestimation in B.

DAVIS and EMLEN[3] proved that large rats were markedly more trappable than small ones in the first third of the trapping period. We can thus interpret that large rats will come to traps in advance of small ones. Thence the unexposure of small rats to traps will be possible for a time as short as 3 days. But the trend for large rats to go ahead seems not to occur as a rule, because I have at hand unpublished data quite inconsistent with that.

Anyhow, a sufficient number of traps to be reasonably distributed in and around each house must be necessary to have a whole population exposed to those and make the census formula to work to the point. Here is adduced a good example suggesting a complete exposure. A census[7] was taken with an animal-shed population of rats by the marking method with 50 traps; the work of 8 days' duration gave 41 for $\hat{N}$ by the same equation as above, even the first 3 days' observed points lying close to the regression line, and the new captures aggregated to 41, too. The after trapping for ca. 25 days demonstrated none of new captures in the first third of the period.

Therefore, in such complicated ecosystems with densely conggregated houses as these rural hamlets, the entire exposure of rat populations to traps would seem to require the trap number per house as large as 5 times or more the rat density per house. As well, deliberate consideration must be given to the trap arrangement inasmuch as the passages utilized by rats for foraging are known to be never of random distribution.

Summary

The Norway-rat plague in the southwest coastal region of Shikoku has lasted long since 1949, looking to be in a chronic state at present and not yet allowing any sanguine expectations about its coming phase. It was spread southeastwards from year to year, causing a seeming cycle at intervals of 4−5 years with different peaks in different sites. Some features in outbreaking populations were discussed, but a full explanation for their dynamics was sought in vain.

Remarkable underestimates were resulted from the latest census-surveys on two hamlet populations in this region by means of the routine census formula. Only a conceivable reason for the underestimation will be incomplete exposure of those to traps mainly on account of insufficient trap numbers against the population density per house.

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