The Effect of Withdrawal of the Host on Populations of Trombiculid Mites

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SINCE MITE-TYPHUS (scrub-typhus) is transmitted by a mite normally parasitic on rats it is sometimes assumed that the removal of the rats will effect immediate control of the mites and hence of the disease. This is a fallacious assumption, because the number of free-living larvae depends not upon the present population of rats, but upon the population perhaps three months or more ago when the parents of the present generation were being returned to the soil as engorged larvae. The prevention of the establishment of rat populations is, of course, an important factor in the long-term prevention of the disease, but a number of the published recommendations do not make this distinction clear, so that it is probably not widely appreciated. Once an infested rat population is established the rats subserve the mopping up of the larvae as fast as they are hatched. Destruction of the rats will thus make a large number of larvae available for the infestation of such casual hosts as man, and will greatly increase the typhus risk. Warnings against the destruction of rats in controlling mite typhus have been given before this (e.g. Audy, 1949) but have been based on epidemiological observations. Some experimental support for the advice is given below.

The magnitude of this danger depends upon the precise relationship which exists between the mite-larvae, or "chiggers", and their hosts. The vectors of mite typhus, *Trombicula akamushi* and *T. deliensis*, exhibit a very wide range of possible hosts: thus Harrison and Audy (1951) summarize records from over 80 species of mammals and birds. Some hosts, however, are clearly of greater importance than others, in that the chiggers occur on in much greater numbers, even in the same locality. The chiggers seem ready to climb onto almost any warm-blooded animal, and the differences of infestation rates are clearly due to the different habits of the host, which may or may not bring it into contact with the chiggers. Those animals which are most efficient as hosts presumably encourage repeated self-infestation by returning engorged larvae to parts of their range whence there is good chance of their picking up larvae of the subsequent generation. Such hosts are, presumably, responsible for the formation of the characteristic "mite islands" of infestation.

These efficient hosts are always small ground dwelling mammals, although the actual species varies from country to country. Conditions in Malaya are illustrated in table 1 in which is shown the estimated population of a ten hectare area of scrubby grassland, and the average infestation rates (of vector chiggers) for those species. The mammal numbers, which are estimated from trapping, are probably reasonable estimates of relative rather than absolute numbers. The chiggers feed for about three days, so the product of number of mammals and infestation rate gives a measure of the turnover of chiggers per three day period, which multiplied by ten gives the turnover per month, i.e. the number of chiggers fed and returned to the soil per month.

TABLE 1

Estimated rat population of a 10 hectare area of grassland with scrub ("Pylon" area) showing the mean numbers of vector chiggers per rat and the estimated monthly turnover of the mites. About twelve other mammals are recorded from the area, but their populations and infestations are negligible*.

Species of rats	*Estimated number of individuals*	*Infestation rate T. akamushi and deliensis*	*Monthly turnover*
R. exulans	152	1	1,520
R. jalorensis	28	15	4,200
R. argentiventer	24	78	18,700
R. whiteheadi	20	0·6	120

It will be seen that, although *R. exulans* is the most numerous of the rats, *R. argentiventer* is responsible for feeding by far the largest number of chiggers. About a dozen other mammals occur in the area, but in small numbers and bearing very light infestations, so that their contribution to the turnover of chiggers may be neglected. *R. argentiventer* is clearly the major host in this area.

We wish to consider what would happen to these larvae if the major host were removed from the area; whether they would find alternative hosts, or would die. Clearly it is necessary to know how long the larvae will normally survive without finding a host. In the conditions of a laboratory culture they can be kept for up to four weeks after hatching before they are fed, after which they tend to refuse to feed. Kawamura & Ikeda (1936) say "they may live and retain their activity of biting for nearly one year" presumably over winter. Jenkins, 1948 says of the American species of *Eutrombicula* (which are common scrub-itch pests). "Unfed larvae can live under natural conditions without a host animal for over 1 month". These observations, however, do not necessarily apply to the surface of the soil under grass or scrub in Malaya. Direct observation of chiggers on the soil shows that they are active during the early morning, and apparently at night, but are no longer to be seen when the dew dries with the increasing heat of the day. We do not know if these same chiggers reappear with the evening dew, and if so in what numbers, and for how long they are capable of infesting a host.

The considerations outlined above provide material for a large research project. The object of this paper is to put on record some observations which throw light on this behaviour.

Individual infestations

One of the effects of the repeated self-infestation postulated above would be that different individual rats inhabiting the same general area would consistently differ in the numbers or species of chiggers infesting them, but that successive infestations of the same individual would be very similar. This is well illustrated by two marked specimens of *R. jalorensis* from the same area of scrub which, during the seven months from December 1952 to June 1953 were trapped repeatedly and bore the following numbers of *Trombicula akamushi* (*a*) and *T. deliensis* (*d*).

rat No. SR12:—4a, 1d, 0, 0, 4a, 2d, 1d, 0, 2d, 0.

rat No. SR14:—56d, 29d, 0, (7a + 30d), 89d, 89d.

Clearly rat number SR14 usually bore large numbers of *T. deliensis*, but few or no *T. akamushi*, whereas SR12 bore very small numbers of each. Findings of this sort appear to be usual.

* These estimates are those quoted by Audy 1954 as "unpublished data, J. L. Harrison".

If this is a general phenomenon, the result will be that the number of *T. akamushi* or *T. deliensis* borne by a rat trapped on any occasion is closely correlated with the number borne on the previous occasion. To test this, coefficients of correlation were calculated between the numbers of chiggers at first capture and the number at second capture on each of fifty rats from each of two localities. Only rats retrapped after an interval of at least a week were considered. Species considered were *T. akamushi* on *Rattus exulans* from "Pylon" experimental area, and *T. deliensis* on *R. jalorensis* from "Spooner Rd." area (experimental areas as recorded by Audy & Harrison, 1954). The coefficients obtained were:—

T. akamushi on *R. exulans* .. .. r = 0·880

T. deliensis on *R. jalorensis* .. .. r = 0·827

Both of these values are highly significant, the probability that such differences from zero could be obtained by chance being less than one in a thousand million (Fisher & Yates, 1943). We can, therefore, safely allow for a positive correlation between the numbers of chiggers of these species on a rat at successive recaptures. This result is not necessarily valid for other species of mite—thus for *Walchia lewthwaitei* on the first fifty *R. exulans* from "Pylon" area the coefficient obtained was:—

W. lewthwaitei on *R. exulans* .. .. r = 0·178, P = 0·46.

That is, the coefficient does not depart significantly from zero. This mite usually occurs either in large numbers or not at all, irrespective of previous infestations.

The above results give us a basis for estimating the number of *T. akamushi* or *T. deliensis* to be "expected" on any individual (marked) rat, the standard being that number present at the first capture (or the last recapture, if that recapture had been after a long period of liberty).

Method of experiment

In the experiments from which the following data have been drawn, rats were trapped, marked, and released again, to be retrapped from time to time. At each trapping all chiggers were removed, identified, counted, and recorded. At the time of release the rat was, therefore, effectively free from infestation, and any chiggers found at a subsequent recapture must have attached in the interval following the time of release. The average feeding times of these chiggers are 2·8 days for *T. akamushi* and 3·0 days for *T. deliensis* (Harrison, 1954). For any rat captured within about three days of release the actual number of chiggers attaching could be estimated with fair accuracy; after three days the numbers completing their feed and then detaching become significant and the total attached is hard to estimate.

Since the number of chiggers attaching is correlated with the number on the rat at an earlier capture it is possible, by comparing rats which have received different treatment, to say if one treatment has increased or decreased the numbers of chiggers relative to the other. In this case the "treatment" was to detain the rat, after the first capture, for one or two days. Since it was not possible to predict whether an individual rat would be recaptured within three days of release, it was necessary to detain rats at random for various times in order to provide a suitable number of successful experiments. In fact convenience at the time determined the time of detention and provided a suitable and apparently unbiased assortment of detention times.

In the "Spooner Road" area, of fairly uniform scrub, some rats were released on the day of capture (i.e. "detained for 0 nights") and some were released next day (detained 1 night). All rats recaptured were inspected for mites, which were usually removed by hand for counting. Recoveries for up to six days after release (up to 6 days exposure) are recorded in table 3.

In the "Pylon" area, of grassland with some scrub, it was not practicable to return rats on the day of capture, so all rats were detained for one night, and a proportion for a second or subsequent night. Only detentions of one and two nights are sufficiently numerous to be considered for most rats in table 4, with the exception of *R. exulans*, where a wide scatter of detention periods made it advisable to consolidate the totals for two to five nights detentions. In this area all rats retrapped within two days of release (2 days exposure) were, if infested, kept over water for the timing of chigger feeds as described by Harrison (1954). This method of recovery gives a relatively poor return of numbers of chiggers, so that the estimates of infestation for these exposures are not directly comparable with those from rats recovered after the third day, which were estimated in the usual way. In table 4, therefore, exposure times of one and two days only are considered.

Results

Table 3 summarises the results from "Spooner Rd." and table 4 from "Pylon" areas. Since, as noted above, different methods of estimating numbers of chiggers were used for the two areas, the results are not directly comparable.

TABLE 2

Detailed infestations of 22 *R. jalorensis* bearing *T. akamushi*, from "Pylon" area, recovered within 1 day of release, to illustrate the construction of tables 3 & 4. For each rat is shown the numbers of chiggers at the first and second captures.

Number of chiggers (*T. akamushi* only) on:—

	Rats released after 1 night's detention		*Rats released after 2 nights' detention*	
	at first capture	*at second capture*	*at first capture*	*at second capture*
	1	4	10	0
	61	0	63	0
	70	0	65	0
	59	0	47	0
	58	3	34	0
	68	0	43	8
	49	1	43	0
	34	0	26	0
	111	0	45	33
	18	0	81	0
	6	0	5	0
Totals ..	535	8	462	41
	8/535 = 1·50%		41/426 = 8·88%	

The construction of these tables is illustrated in table 2 which shows details of the 22 *R. jalorensis* bearing *T. akamushi* in Pylon area, summarised in the fourth row of table 4. Since the numbers of chiggers on the same rat at different times are correlated, the numbers present after a "treatment" can be expressed as a percentage of those present before treatment for purpose of comparison between groups. In fact the numbers which have been used for this purpose are the totals on all the group receiving the treatment. In tables 3 and 4 the left hand column shows the period of exposure of the rats, i.e. the time before it was recaptured. The next two columns show the numbers of rats involved in the two "treatments", which are detention for 0 night and 1 night (table 3) or 1 night and 2 nights (table 4). The next two columns show the actual numbers of chiggers recovered after treatment, corresponding to the second and fourth columns of table 2. The last two columns show these numbers expressed as percentages of the numbers before treatment. The latter numbers are not shown, with the exception of groups for which no mites were recovered.

TABLE 3

Numbers and proportions of mites at recapture on *R. jalorensis* in "Spooner Rd."

Numbers are shown separately for 0 and 1 nights detention before release and for 1 to 6 days exposure before recapture. For each class is shown the number of rats involved, the total number of mites on them after recapture, and this number as a percentage of the number at first capture. The number of mites at first capture is not shown except where the number at recapture is zero, when it is shown in parenthesis.

Exposure	*Recovered after 0 night's detention and release*			*Recovered after 1 night's detention and release*		
	Rats	*Mites*	*Mites as % total at first capture*	*Rats*	*Mites*	*Mites as % total at first capture*
Trombicula akamushi						
1 day	5	0/(12)	0%	12	32	35%
Trombicula deliensis						
1 day	9	0/(178)	0%	36	171	21%
2 days	2	0/(7)	0%	23	175	22%
3 days	2	8	67%	6	168	78%
4 days	0	—	—	6	98	85%
5 days	5	85	82%	1	46	(460%)
6 days	2	47	115%	4	30	120%

TABLE 4

Numbers and proportions of mites on rats in "Pylon" area.

Numbers are shown for 1 or 2 nights detention, and for 1 or 2 days exposure as in Table 3. For *R. exulans*, rats detained for more than 2 nights (up to 5) are consolidated with those for 2 nights.

Exposure	*No. of rats recovered*		*Total number of mites on them*		*Mites as percentages of totals on the rats at first capture*	
	1 night	*2 nights*	*1 night*	*2 nights*	*1 night*	*2 nights*
T. akamushi on *R. exulans*						
1 day	11	17	11	14	10·5%	16%
2 days	6	13	5	28	8%	22%
T. akamushi on *R. argentiventer*						
1 day	3	2	2	14	1·2%	7·3%
T. akamushi on *R. jalorensis*						
1 day	11	11	8	41	1·5%	8·9%
T. deliensis on all three spp. of rat.						
1 day	11	5	1	4	1%	29%
2 days	2	2	1	1	17%	33%

It will be seen that, with every group, the proportion recovered after the longer period of detention is greater than that after the shorter period. Some of the actual differences are statistically significant, others are too small for significance, but the chance of getting twelve increases out of twelve trials by chance fluctuations (supposing increase and decrease equally likely) is less than one in four thousand. Clearly increased detention leads to an increase in the number of chiggers attaching after release.

Interpretation

These results must be interpreted with caution, as suggested above. The "Pylon" mites were recovered by keeping the rat over a water tray, and since this method is less efficient than the normal method of hand removal, something less than half the number of mites being recovered, the percentages will be much too small. For this reason tables 3 and 4 are not directly comparable. The days of exposure are also likely to be misleading; the final "day" is in fact the night on which the rat was trapped. If the trapping took place early in the night (as is likely to happen with these rats accustomed to traps) the actual exposure to mites will be minimal.

Taking the feeding time of the two mites as about three days, the expected rate of attachments of the mites is about 33 per cent per day (36 per cent for *T. akamushi* with a slightly shorter feeding time). On this count we would expect an almost zero attachment after 1 day (for the reason given above) 33 per cent after 2 days, 67 per cent after 3 days, nearly 100 per cent after 4 days (there will be a few detaching), and 100 per cent for 5 days and onward. It will be seen that this is very nearly realized in the first percentage column of table 3 (the zero for 2 days being out of seven only). In the second column, after a detention of 1 night, the proportions are consistently higher. The amount is, however, variable and it is difficult to draw any conclusion of value as to its magnitude. It is, however, consistent with the assumption that most of the mites not picked up by the end of the morning are still available in the evening. The fact that these mites were present and active at the onset of darkness and dew would explain the comparatively high pick up on the rats exposed for "1 day" only. In normal circumstances the "1 day" rats would, during their short evening exposure, meet very few mites, most of which would hatch later in the night. A detention of one day, however, would provide a full supply of mites waiting to attach at the beginning of the evening.

Interpretation of table 4 will differ in that the minimum detention is 1 night, instead of zero, and therefore corresponds to the right hand column of table 3. The efficiency of recovery is much less so that percentages are an indeterminate amount smaller, and only exposures of one and two days are available. By the previous hypothesis, that most of the infestation on rats detained for 1 night and exposed for 1 day come from the previous day's supply of mites, it would be expected that the infestations on rats detained for 2 nights and exposed for 1 day would average twice as much as those detained for 1 night. The numbers here are too small for statistical tests, but they are not inconsistent with the hypothesis.

Conclusion

There seems no doubt that when a rat, normally infested with one of the typhus-vector species of mite, is absent from its range for one or two nights, the mites, which it would normally have picked up during this period, wait and are picked up when the rat returns to its range; to produce an unusually large infestation on the rat.

The results demonstrate the phenomenon over two nights, so that such unattached mites must, clearly, remain capable of infesting a host for at least three nights. These figures, however, give no indication of how long they may persist, and other evidence suggests that they may remain available for considerably more than three days.

Mite-typhus is the result of a chance infestation by mites which would normally infest a rat. Removal of the rats will, therefore increase the chance of infestation and infection at least threefold, probably much more than three (if the mites will accumulate over longer periods). Moreover, since infection is normally acquired in the presence of the rats, when most of the mites are being picked up by them, the mere removal of the rats will immediately increase the chance of infestation, even without any build-up of populations. This conclusion seems inevitable, although it has not been tested by controlled experiment on infection rates. It does, however, explain observations, summarized by Audy & Harrison (1956) of very high infection rates following the removal of rats.

Summary

1. It is sometimes assumed that the removal of rats from an area infected with mite-typhus (scrub-typhus) will help to control the disease. Since the number of chiggers (mite-larvae) available depends upon the number of rats three months or more before, this seems unlikely.

2. A serious possibility, however, is that removal of rats may actually increase the risk by increasing the unattached chiggers available.

3. To test this, marked rats, frequently retrapped, were detained before release for one or two nights, and their infestations compared with those released the same day, or detained for only one night.

4. The numbers of *Trombiculia akamushi* or *deliensis* on a rat are positively correlated with the number on the same rat at an earlier recapture. This fact is used as a standard against which to measure the number of chiggers found. The total numbers on all the rats undergoing any one treatment are expressed as a percentage of the number at first capture. When like conditions are compared, the numbers on rats detained are greater than the numbers on rats which had not been detained, and the numbers on rats detained for two days are at least twice as great as the numbers on rats detained for one day only.

5. The explanation proposed is that a rat, by repeatedly returning engorged chiggers to its own range, establishes a self-infestation. If the rat is not in its usual haunts the chiggers which hatch out in its absence, accumulate on or near the surface of the soil until either the rat returns, or a chance host (possibly a man) appears.

6. The mere removal of rats from a typhus-infected locality will, therefore, produce an immediate increase in the risk of typhus. The longer the life of a free-living unfed chigger in field conditions, the greater will this increase become.

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