POPULATION DYNAMICS OF SEWER RATS

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(With Plates 12 and 13 and 3 Figures in the Text)

The presence in sewers of rats, of the species *Rattus norvegicus* Berkenhout, has been known for many decades: it is mentioned in the Report of the Commission on the State of Large Towns and Populous Districts (Royal Commission, 1844), where reference is made to the invasion of dwellings by sewer rats. Until recently, however, little attention seems to have been paid to sewer rats, though in the period 1920–40 local authorities often did some casual poisoning of them by dropping baits down manholes. Before 1940 there had been no systematic study of the distribution or habits of sewer rats, and no information was available on their population dynamics.

The present study was undertaken in a London borough, and was designed to find out what happened to the sewer-rat population after it had been reduced in numbers by poisoning.

METHODS

(a) *The districts investigated*

Two districts of the borough were selected for the experiments, each of approximately 50 acres in area; they will be referred to as A and B respectively. The sewers of each district had few connexions with neighbouring parts of the sewage system. Initially there were 77 manholes in district A, and 79 in district B. During the investigation new manholes were built in both districts, and district A eventually had 85, and district B 86. The sewers were 6 in. or 12 in. pipes (Pl. 12, fig. 1), or brick barrels (tunnels egg-shaped in section), 3 ft. 9 in. by 2 ft. 6 in.

Both districts were residential; the property was for the most part poor, but there were no slums. Shops were few. There were several public houses in each district; district A had one school and district B had two. There was a large furniture depository in district B.

(b) *Estimation of rat populations*

Throughout the inquiry censuses were made in each district, usually at 6-weekly intervals. The method of census was based on that of Chitty & Shorten (1946). Weighted amounts of dry wheat grains were placed on the benching of each manhole, or on the floor of side entrances, or, if necessary, on a bait tray installed for the purpose (Pl. 12, fig. 2). The amount of wheat eaten was recorded on 5 successive days (Pl. 13). Quite often, on the first day, all the wheat put down was eaten at

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some points, but on the remaining days it was always possible to maintain a surplus. For each census the average daily take for the last 4 days was calculated, and this figure was taken as a measure of the rat population. For reasons fully discussed by Chitty (1954), and briefly mentioned by Barnett, Bathard & Spencer (1951), this figure does not give an accurate measure of the total number of rats, but it does provide an index of changes in the rat population.

Despite the limitation of bait points to the manholes there is evidence that it is easier to census sewer rats than surface rats. When a census is taken of surface rats the daily take usually rises from a relatively low figure, and levels off after about a week, at a figure representing the rat population (cf. Barnett *et al.* 1951). In the sewers this rise does not occur, and the amount of bait eaten on the second to fifth days shows no consistent rise or fall. This was found, not only during the work described here, but also in experiments done in other sewers and described by Perry (1954). It is possible that rats in sewers normally range widely during feeding, and show less hesitation than rats living elsewhere in accepting unfamiliar food.

(c) *Poison treatments*

Two methods of poison treatment were used. During the first part of the inquiry, in 1947 and 1948, the method used was the standard one described by Barnett (1946). This consists of prebaiting for 2 days with 120 g. plain bait in each manhole, followed on the third day by twice the amount of poison bait in each manhole. The materials used were damp sausage rusk with zinc phosphide at 2·5 %, and a bread and water mash with arsenious oxide at 10 %. These two baits were alternated in successive standard treatments. The other method of poison treatment was direct poisoning without prebaiting. This was done either with zinc phosphide at 2·5 or 5 %, or with the much more toxic sodium monofluoroacetate, '1080' (Barnett & Spencer, 1949), which was used at 1 %.

In 1950, in both districts, the two methods were combined in a double treatment: a direct poisoning with '1080' in soaked crushed barley was followed by a prebaiting and poisoning with 2·5 % zinc phosphide in damp rusk.

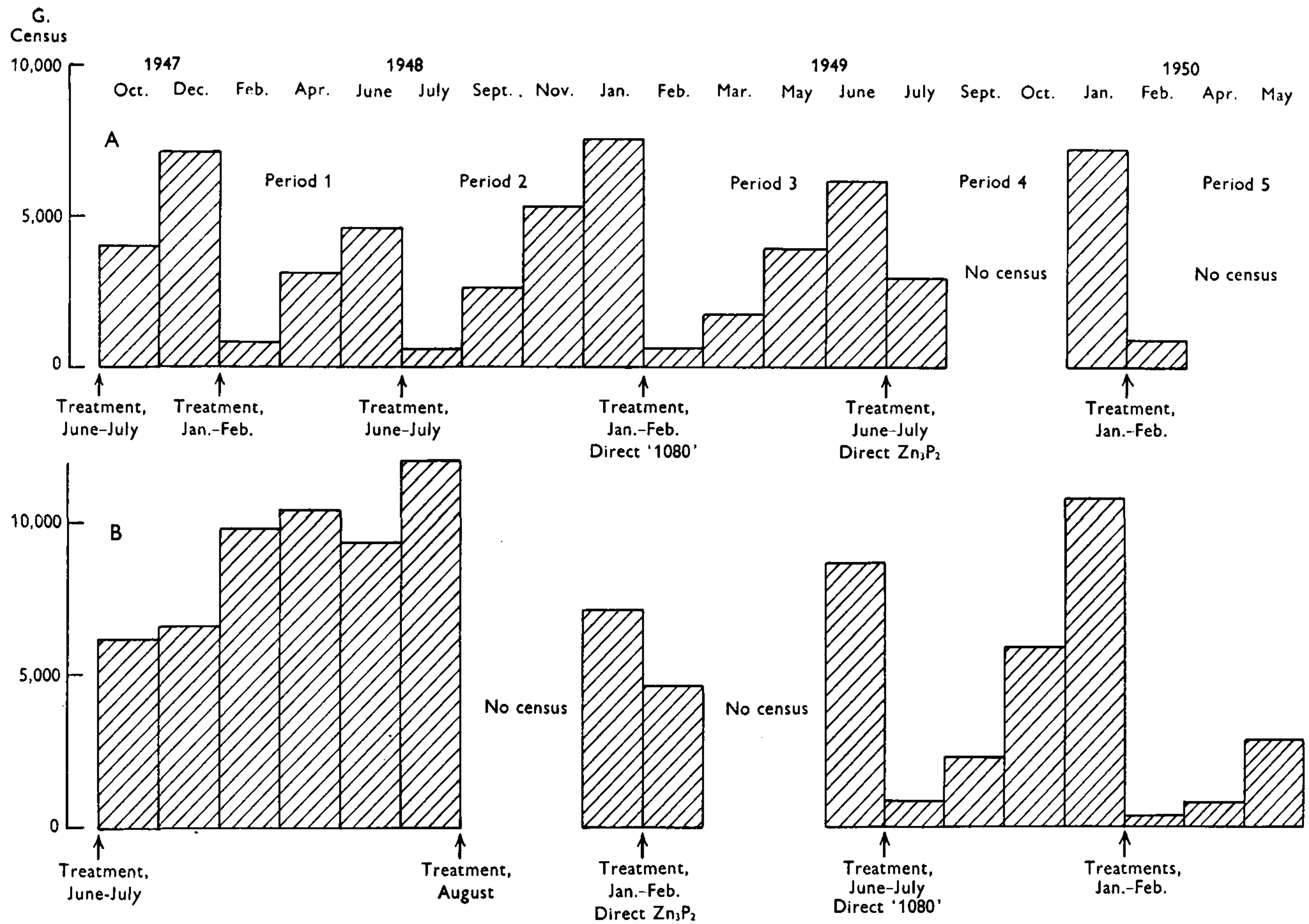
Whenever a poison treatment was done in either district, it formed part of a general treatment of the sewers of the whole borough (Barnett, 1947).

POPULATION CHANGES

(a) *The effects of poisoning*

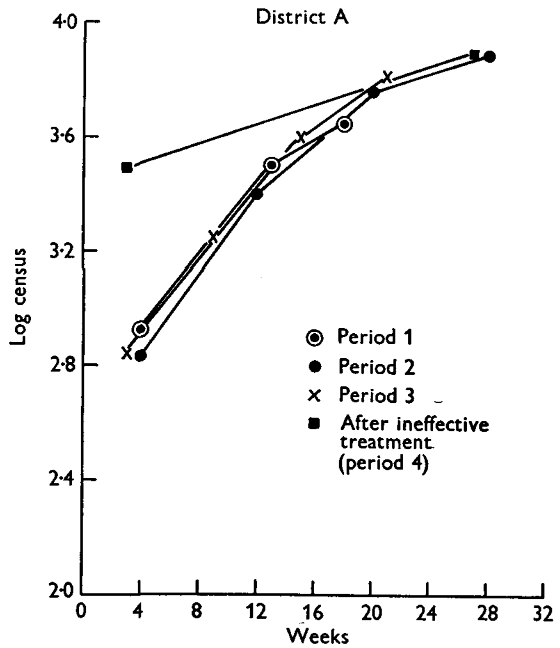
Text-fig. 1 summarizes census data and poison treatments in each of the two districts. In district A, standard treatments with prebaiting were carried out in January and February and in June and July 1948, and a census was made before and after each treatment. The censuses showed kills of 88 and 85 % respectively. During censuses made immediately after poison treatments, many small droppings, suggesting the presence of young rats, were seen near some bait points; often the wheat had been disturbed but no measurable amount had been taken.

Direct poisoning treatments were also used. In January and February 1949 a direct poisoning with '1080' in district A gave an estimated kill of 91 %,



Text-fig. 1. The sequence of events in the two districts. 'Treatment' alone signifies a standard prebaiting and poisoning. 'Direct' indicates that poisoning was done without prebaiting. 'Treatments' indicates that two poisonings were used, one after prebaiting (see text). Changes in size of the rat populations are shown in terms of amount of wheat eaten in a day. The first censuses were taken in October 1947, 3 months after a treatment, when the rat populations had already partly recovered.

a result closely similar to those of previous prebaiting treatments. But in district B, where the poison used was 2·5 % zinc phosphide, the kill was only 35 %. In June and July 1949, in district B, a direct poisoning with '1080' gave a recorded kill of 90 %; while in district A, which received a direct poisoning with zinc phosphide at 5 %, the estimated kill was 52 %.



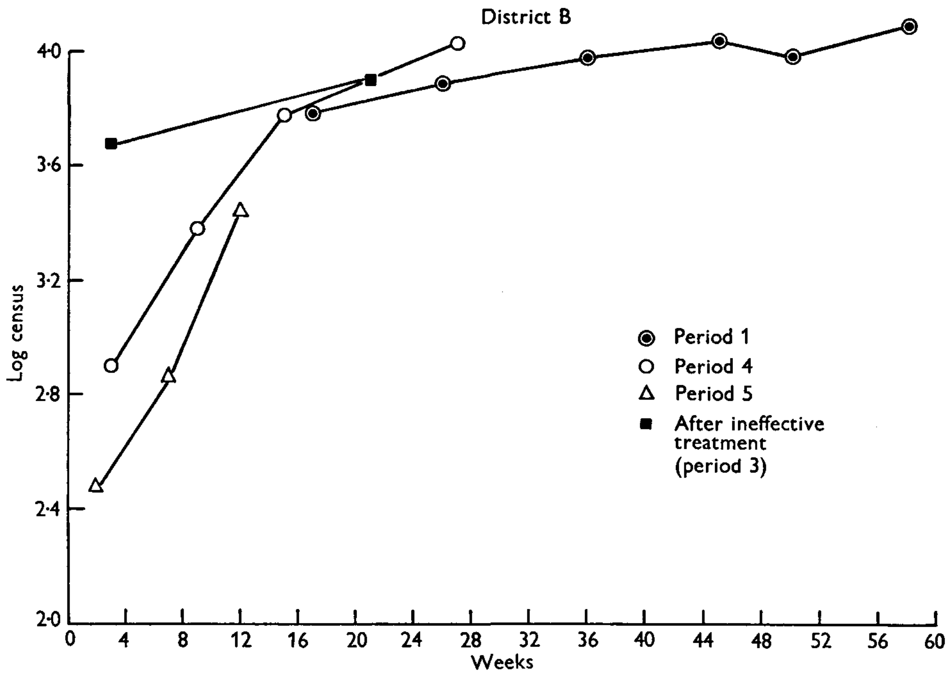
Text-fig. 2. District A: log of the census figure plotted against time elapsed since previous poison treatment, for each of the periods between treatments.

Finally, in January and February 1950, direct poisoning with '1080' was followed in both districts by a prebaiting treatment with 2·5 % zinc phosphide. In district A, the estimated kill of 87 % was no higher than the results of previous single treatments; however, heavy rain fell during the second poisoning and washed away the baits, making this poisoning ineffective. In district B, on the other hand, the census after the double treatment indicated that the rat population had been reduced to 2·9 % of its previous level.

(*b*) *Size and growth of the rat populations*

The growth of the rat populations after poison treatments is shown in Text-figs. 2 and 3. Text-fig. 2 shows what happened in four periods between treatments in district A. In periods 1–3 the populations started at a level represented by a census of about 900 g., and the population size, plotted logarithmically, rises steeply at first but more slowly later. The census figure which each curve approaches is approximately 10,000 g. This figure was approached also in period 4, after the relatively ineffective direct poisoning with zinc phosphide: thus after 6 months the rat population was about the same size whether the starting-point was over 3000 g. or less than 1000 g.

Text-fig. 3 shows that in district B the rat population behaved in much the same way. The curve for period 1, an extended period without a poison treatment, shows clearly the increase to a maximum which was again about 10,000 g. The similarity in the sizes of the rat populations in the two districts was a convenient accident. The curve for period 4 in district B is similar to those for periods 1–3 in district A. After the ineffective direct poisoning (period 3) the tendency was again for the rat population to approach the asymptote after a few months.



Text-fig. 3. District B: as Text-fig. 2.

The most important censuses in district B were those of period 5, made after the very successful double treatment. These censuses show an exceedingly rapid rate of increase in the number of rats, which within 3 months brought the population to a point near the curve for period 4.

There was considerable variation, in both districts, in the persistence of infestation and rat population density recorded at different manholes. In district A no bait was taken from seven manholes throughout the inquiry; in district B the number was six. Only one manhole showed evidence of the presence of rats in every census in district A, while five did so in district B. The highest census figure for one manhole in district A was 537 g.; on the basis of the known mean daily consumption of wheat by *R. norvegicus*, this represents a probable minimum number of 21 rats (Leslie, 1954). In district B the highest census figure in period 1 was 885 g. (at least 35 rats), in other periods 557 g.

When the records for small groups of manholes in subdistricts within each district were examined, it was found that the population growth nearly always took a form similar to that of the districts as a whole. The subdistricts of greatest interest were those which had no bait taken during the first census of a period between treatments. In two of them, both in district A, the apparent total obliteration of the rat population was followed 6 weeks later by a census indicating that the population was now restored to the level to be expected had only 90 % of the rats been killed. However, after the double treatment of district B in January and February 1950, one subdistrict had its apparent rat population reduced to zero; and it remained at zero for both subsequent censuses, that is, for 12 weeks after the end of the treatment.

(c) *Weights of rats picked up after poisoning*

In January 1950, after the direct poisonings with '1080', rat bodies were collected from both districts and were sexed and weighed. In district A, 27 males were found with a mean weight of 304 g. (S.D. = 122), and 36 females, with a mean weight of 251 g. (S.D. = 96). For district B the corresponding figures were: 36 males with a mean weight of 323 g. (S.D. = 111); and 41 females with a mean weight of 307 g. (S.D. = 78). Of the total of 77 females collected, 21 (27·3 %) were pregnant, although January is one of the months at which the breeding of surface-living rats is at its lowest (Leslie, Venables & Venables, 1952).

BEHAVIOUR OF THE RATS

During the censuses objects were sometimes brought to the benches on which the wheat was laid. They included pieces of fish, bread, bones, raw meat, cheese, cakes of soap and cherry and plum stones. Sometimes these objects were found on the wheat.

The rats reached the bait points either along the sewers, or through the walls of the sewers. Rats have been seen running along the cement pointing between the bricks, above sewage level; the fur of these rats was dry. Faulty brickwork and broken joints round drain connexions were often seen, and at some of these points rats had dug out the earth; the heavily trampled heaps of spoil which resulted became obstacles to the flow of sewage. After poison treatments dead rats were found in these openings.

The re-laying of a length of sewer, and the building of new inspection chambers, did not drive the rats away. In one infested length three additional inspection chambers were built. Rats were seen every day by the men digging the trench, and when the work was completed the next census showed that rats were still present.

The most important problem of sewer rats' movements is that of the connexion with surface premises. The records of the borough health department were examined for notifications of rat infestations. Table 1 gives the figures for infestations reported in the two experimental districts and the number in which defective drains were held responsible. In district A, over the whole period, the drains were implicated in 13·7 % of infestations; in district B, 27·8 %. There was no evident trend up or down in the proportion during the period covered, nor was there evidence of a decline in the total number of infestations. The positions of reported surface infestations were plotted on maps of the two districts and considered in relation to the known points of heaviest sewer infestation. No relationship could be established. According to the borough engineer's department many infestations reported as due to sewer rats were in fact due to entry by rats from burrows in the surrounding earth, and were unconnected with the sewers.

Table 1. *Rat infestations of dwellings*

			Drains implicated	
		Total	No.	%
District A	1947 (Aug.–Dec.)	35	6	17·1
	1948 (Jan.–Dec.)	26	3	11·5
	1949 (Jan.–Dec.)	25	3	12·0
	1950 (Jan.–June)	16	·2	12·5
	Total	102	14	13·7
District B	1947 (Aug.–Dec.)	13	3	23·1
	1948 (Jan.–Dec.)	49	19	38·8
	1949 (Jan.–Dec.)	37	7	18·9
	1950 (Jan.–June)	16	3	18·7
	Total	115	32	27·8

DISCUSSION

(*a*) *Form of population growth curve*

Text-figs. 2 and 3 show that in both districts the maximum rat population is that represented by a census figure of about 10,000 g. Calculated from the known average daily consumption of wheat by *R. norvegicus* in Britain, this corresponds to a probable minimum population of 400 rats (Leslie, 1954). In district A this level was never quite reached, but in district B it was reached, and was maintained for 22 weeks in period 1. Whenever the population was reduced to less than 10% of this maximum the rate of increase was initially high, but tended to flatten 16–20 weeks after the poison treatment. This sequence of events was observed on three occasions in district A, for each of which the curves are remarkably similar, and on one occasion in district B.

These results suggest that the growth curve of the populations studied is of the S-shaped or logistic type. If this is so, it should be possible so to reduce the rat population that the rate of increase would initially be much lower than the maximum; the level of infestation would then remain low for a considerable period. This sort of effect has been reported for urban habitats by Emlen, Stokes & Winsor (1948), and for rural areas by Barnett *et al.* (1951). It was thought that the double poison treatments done in 1950 might so reduce the rat populations of the experimental districts that these populations too would only slowly be restored to the maximum. As it was, in the one district which received an effective double treatment, the initial rate of increase was the highest recorded.

(*b*) *Source of population increase*

Whether the rapid increase of the rat population is due solely to breeding, or whether invasion from outside the sewers plays a major part, is therefore an important question. The high proportion of pregnant females found in January, and the absence of fluctuation in population growth with the seasons, suggest that sewer rats breed steadily throughout the year. If so, this may be due to the relatively uniform temperature of their environment. Leslie (1945) gives a figure for the reproductive capacity of *R. norvegicus*. The inherent rate of natural increase is 0·1040 per week per head. Up to February 1950, the highest rate of increase indicated by census results was 0·0732; this was in district A during 8 weeks in July to August 1948. The highest rate recorded in district B was 0·0726, in July to September 1949. For these rates of increase there was no need to assume that anything but breeding was contributing to the population increase.

This, however, does not apply to the population growth recorded in district B after the double poisoning of January and February 1950. For the sixth to the tenth week after this treatment the weekly rate of increase was 0·1158, a rate which, on Leslie's figures, cannot be accounted for merely by breeding. The need for more information on the character and extent of rat movements between sewers and other infested sites is, therefore, very obvious. Especially is this so since, as we have shown, no clear relationship could be established between surface infestations and rat population density in the sewers, in either of the experimental districts. Unfortunately, it was not possible to make an estimate of the surface rat population from which the sewer populations might be receiving additions.

Two other observations have a bearing on the population increase. First, the frequent presence of small droppings on census bait after a poison treatment suggests that many of the survivors are young, perhaps just weaned. Secondly, the weights of rats picked up after poisoning are nevertheless quite high, and indicate that the rat population at the time of poisoning was by no means a predominantly young one. Taken together these facts tend to confirm the likelihood of invasion from the surface. Further inquiry is needed to determine the true relationships of rat populations feeding in sewers with those outside.

SUMMARY

1. The effects of poison treatments on the rat populations of two sample districts of heavily infested sewers in a London borough were studied.

2. Each district had a maximum rat population represented by a census figure of about 10,000 g. wheat eaten per day, corresponding to at least 400 rats.

3. Poison treatments after prebaiting, at intervals of 6 months, reduced the rat population of each district to less than 10 % of the maximum. A rapid restoration of the population followed, and the level reached in 6 months was near the maximum.

4. In both areas, direct poisoning with sodium monofluoroacetate '1080' was as effective as a prebaiting treatment. Direct poisoning with zinc phosphide was relatively unsuccessful.

5. When both areas received double treatments, consisting of direct poisoning with sodium monofluoroacetate followed by a prebaiting treatment, the estimated population of one district was reduced to about 3 % of the maximum. In the other area, rain made the second poisoning ineffective.

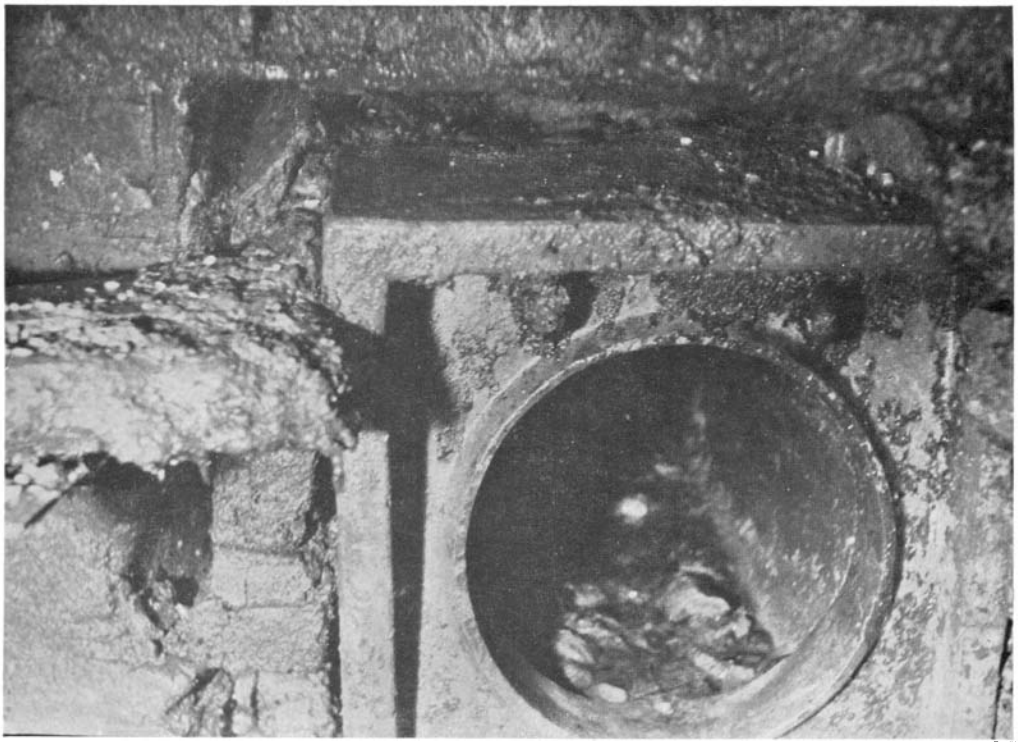


Fig. 1.

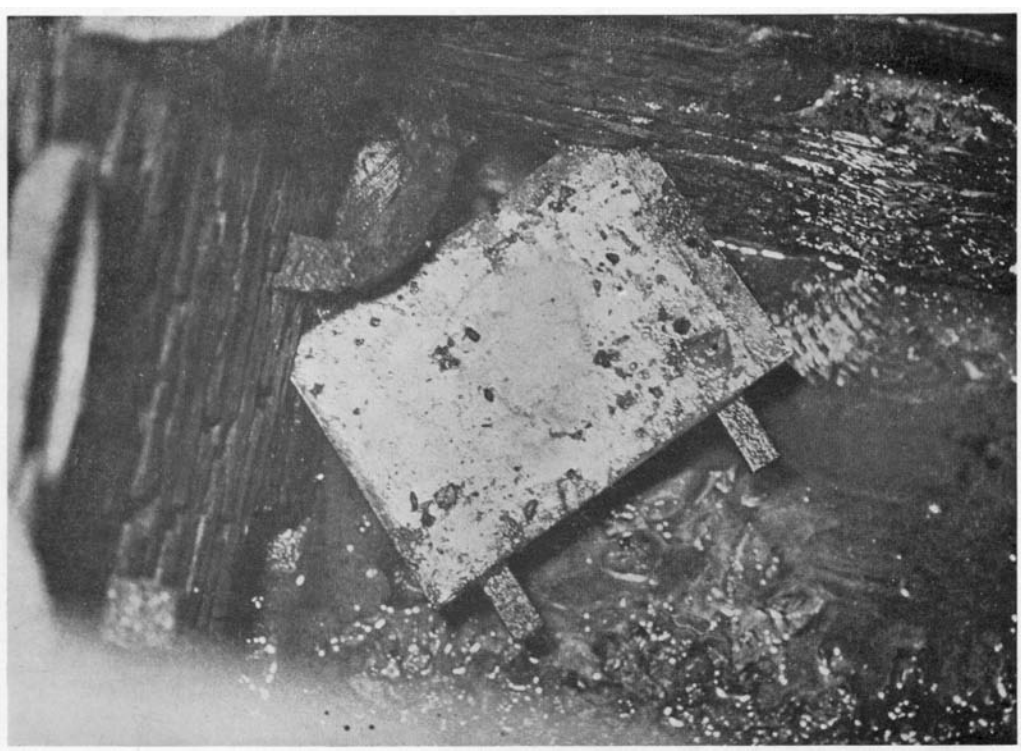


Fig. 2.

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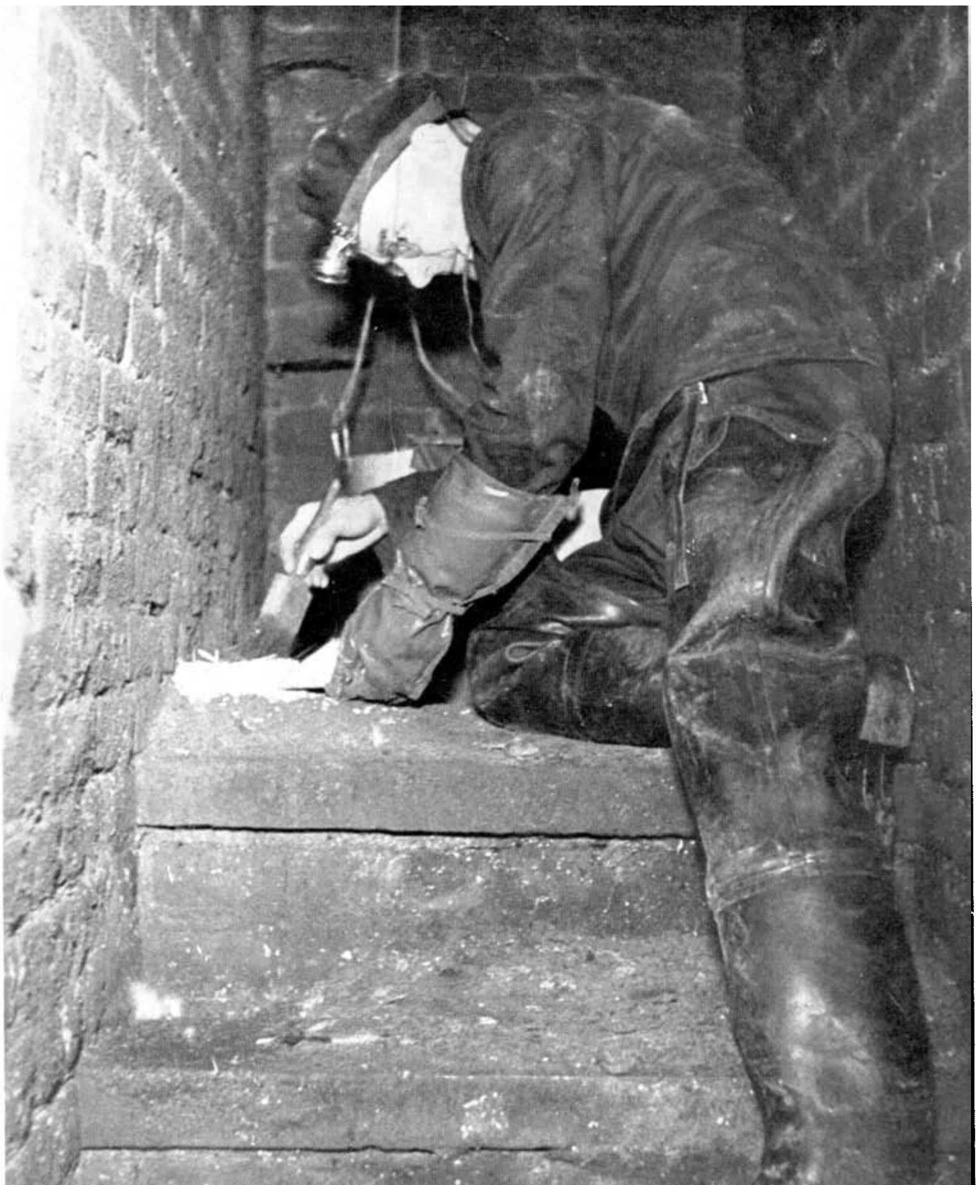

6. The rate at which the population was restored from the 3 % level was even higher than the rates previously observed, and was probably too high to be accounted for solely by breeding. Evidently, invasion from the surface played a part.

7. No relationship could be established between the estimated sewer rat population densities within each district, and the known sites of surface infestation.

We are grateful to the Council and officers of the Borough in which the work was done, for unstinted help throughout the inquiry. We also owe thanks to H. V. Thompson for help in the early stages; to him and to Miss M. D. A. Lawrence for discussing the work during its progress; to Miss M. M. Spencer for help in the analysis of the records and in checking calculations; and to A. G. Jenson for mapping the districts and for drawing the figures.

REFERENCES

Barnett, S. A. (1946). *Infestation Control: Rats and Mice*. London: H.M.S.O.

Barnett, S. A. (1947). Rodent control in towns. *Ann. appl. Biol.* **34**, 297.

Barnett, S. A., Bathard, A. H. & Spencer, M. M. (1951). Rat populations and control in two English villages. *Ann. appl. Biol.* **38**, 444.

Barnett, S. A. & Spencer, M. M. (1949). Sodium fluoracetate as a rat poison. *J. Hyg., Camb.*, **47**, 426.

Chitty, D. (1954). *The Control of Rats and Mice. Vols. I and II: Rats.* Oxford.

Chitty, D. & Shorten, M. (1946). Techniques for the study of the Norway rat (*Rattus norvegicus*). *J. Mammal.* **27**, 63.

Emlen, J. T., Stokes, A. W. & Winsor, C. P. (1948). The rate of recovery of decimated populations of brown rats in nature. *Ecology*, **29**, 133.

Leslie, P. H. (1945). On the use of matrices in certain population mathematics. *Biometrika*, **33**, 183.

Leslie, P. H. (1954). In Chitty, D. (ed.) *The Control of Rats and Mice. Vols. I and II: Rats.* Oxford.

Leslie, P. H., Venables, U. M. & Venables, L. S. V. (1952). The fertility and population structure of the Brown Rat (*Rattus norvegicus*) in corn-ricks and some other habitats. *Proc. zool. Soc., Lond.*, **122**, 187.

Perry, J. S. (1954). In Chitty, D. (ed.) *The Control of Rats and Mice. Vols. I and II: Rats.* Oxford.

Royal Commission (1844). First Report of the Commissioners for Enquiring into the State of Large Towns and Populous Districts. *Parliamentary Papers*, **17**. London: H.M.S.O.

EXPLANATION OF PLATES 12 AND 13

Plate 12

Fig. 1. Opening of 12 in. pipe in inspection chamber. Above it is a gap in the brick wall; rats were seen coming from this gap, to feed on bait laid on benching on the left.

Fig. 2. A bait tray, from above, in a flooded side entrance, during prebaiting before poisoning. All the bait has been eaten, and rat dung can be seen on the tray.

Plate 13

Sweeping up census bait (wheat) at the bottom of a side entrance.

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