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ABSTRACT: Since 1984 pest control operatives in some inner-city areas in the U.K. have found that house mice have become increasingly difficult to control. Mice in these very localised areas have stopped taking rodenticide bait from bait containers, a phenomenon referred to here as behavioural resistance. We report here preliminary experiments designed to characterise the phenomenon more precisely by comparing West Midlands behaviourally resistant (WMBR) populations with non-resistant (BC) populations in Berkshire. We investigated three hypotheses, that compared with non-resistant populations, resistant mice 1) are less likely to enter conventional live-capture traps; 2) have unusual food preferences; and 3) avoid bait boxes. Longworth, Sherman and 'Tichy' traps were all less successful at resistant sites, the Longworth being ineffective and the Sherman almost so. WMBR mice also avoided Longworth traps more than BC mice in small-scale laboratory experiments designed to exclude environmental differences. A field trial showed that resistant mice much prefer peanut butter and Test Food 3 (which cannot be named for commercial confidentiality) to canary seed and Betalard (a proprietary rodenticide), but in this trial bait boxes were not avoided more than bait trays.

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INTRODUCTION

Rentokil's experience since 1986 has been that house mice in a number of separate urban areas have stopped taking rodenticide baits from bait containers. Labelled 'behavioural resistance', this phenomenon has occurred in very localised inner-city areas of London and Glasgow, but particularly in Birmingham (in the West Midlands of England). The extreme localisation of the problem in the West Midlands is shown in Figure 1.

To understand the development of the problem, it is necessary to go back to 1981 when, to achieve more effective control, Rentokil changed their bait base from grain to a cereal/oil mix named 'Non-Tox'. Formulated with the anticoagulant bromadiolone, Non-Tox gave a highly palatable bait named 'Bromard' and this was introduced into Birmingham city centre in 1981. Bromard gave efficient levels of control in the city centre for about 3 years, but then Rentokil service technicians noticed that although baits were still being removed from bait boxes, the levels of control achieved had decreased dramatically at some sites. Physiological resistance to Bromard was suspected and in 1984 Non-Tox formulated with the acute rodenticide alphachloralose and named 'Alphalard' was used instead of Bromard in WMBR sites. Alphalard was in turn replaced later in 1984 by a new formulation named 'Betalard', produced by mixing the rodenticide, reserpine, with the 'Non-Tox' bait base. Betalard gave good control in WMBR sites until 1986, when Rentokil service technicians reported that mouse infestations in the city centre were again increasing, apparently because the mice had stopped taking bait from bait boxes. In other parts of the country it was performing well. Other acute and chronic rodenticides, including brodifacoum, difenacoum, calciferol and bromethalin, were then tested in WMBR sites by Rentokil and other pest control contractors, and two rodenticides, calciferol and alphachloralose, were tested by Rentokil in a variety of bait bases including Non-Tox. The rodenticide baits were presented in a variety of bait containers, but none of these poisons appeared to reduce WMBR mouse populations significantly. Contact dusts, 'break-back' traps and live-capture traps also proved unsuccessful in reducing WMBR mice numbers, and the use of stickyboards appears to be the only effective method of control.

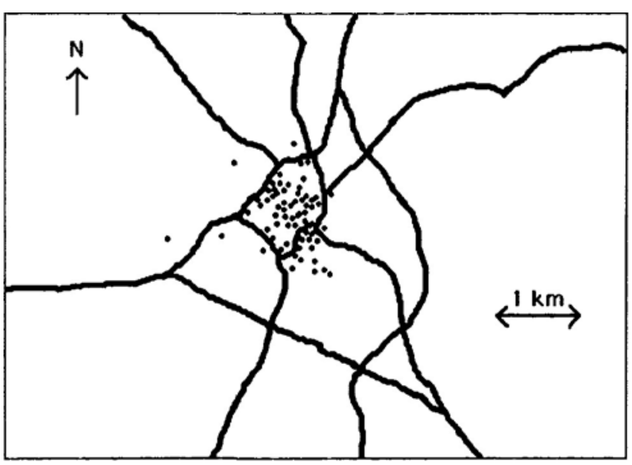

Figure 1. Distribution of behavioural resistance in house mouse sites in the West Midland connurbation in 1987, showing the extreme localisation of the problem sites relative to the extent of the urban area (about 600 km^2, only the portion in central Birmingham is shown here). From Rentokil's records.

As stated above behavioural resistance is identified in the field when house mice stop taking baits from bait containers, the continued existence of the mice being established from some or all of the following: fresh droppings, catches on stickyboards, time-lapse video recordings, damage to goods and structures, the presence of tracks and active burrows, and sightings of live and dead mice.

Rentokil service technicians have suggested that behaviourally resistant mice also avoid walls, baits and/or bait boxes and conventional live-capture traps. Here we investigate these hypotheses by comparing the behaviours of West Midlands behaviourally resistant (WMBR) mice with those of non-resistant (BC) mice in Berkshire. Each hypothesis is first examined in replicated field trials, and then in laboratory trials designed to exclude the effects of environmental differences such as must occur in the field.

TRAP AVOIDANCE

Differences in trappability between WMBR and BC populations became apparent when we started to collect mice for laboratory study. Here we present an overview of the success of the different types of trap we used.

Methods

Twelve types of trap were used at WMBR sites and three at BC sites, as shown in Table 1. Traps were placed randomly, approximately every lm, in areas of recent mouse activity as judged from droppings, tracks, sightings and subsequent capture on stickyboards. WMBR traps were baited with either Test Food 3 or cereals and BC traps with canary seed, Test Food 3 and canary seed being found to be highly palatable to WMBR and BC mice respectively in the food preference trials described below. Trapping was carried out in 40 WMBR and 7 BC sites from February 1988 to March 1990.

Results and Discussion

The three types of trap employed in both populations (Longworth, 'Tichy', and Sherman) were all less successful in WMBR sites than in BC sites (Table 1, chi-square tests, $P < 0.001$). Despite being one of the most widely used live-capture traps in the U.K. (Gurnell and Flowerdew 1982), and despite their success at BC sites, Longworth traps were ineffective in catching WMBR mice, and Sherman traps achieved a success of less than 3%. Only 'Tichy' traps showed a modest success in catching WMBR mice, but still only achieved a quarter of their success catching BC mice.

Table 1. Trap success (animals/trap night) of various types of live capture trap in WMBR and BC sites.

	WMBR		BC	
Type of Trap	No. of trap nights	% trap success	No of trap nights	% trap success
Longworth	2114	0.2	270	26.7
Tichy[a]	546	7.3	84	27.4
Sherman	758	2.6	454	9.5
Trip-trap	473	0.4	—	—
Anderson	16	0	—	—
Kindhart	9	0	—	—
Havahart	31	0	—	—
Tincat (multi-catch)	18	0	—	—
Ketch-All (multi–catch)	14	0	—	—
Reading University Homemade multi-catch trap	24	0	—	—
Fuller Mouse Box	26	0	—	—
Milk Bottle	72	0	—	—

[a]A wooden trap of German origin introduced to us by Dr. H. Tichy.

Figure 2 shows that Longworth and 'Tichy' trap success did not change with time in simultaneous trials carried out March-September 1991 at 16 WMBR sites, at which traps were baited with Test Food 3 and 7 BC sites, at which traps

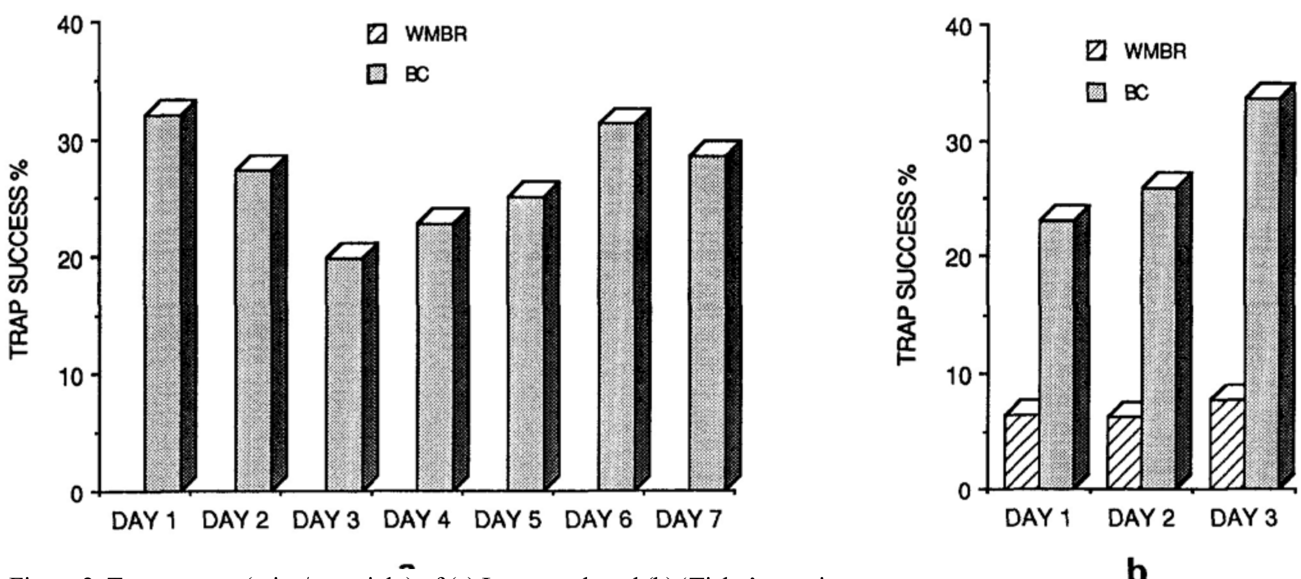

Figure 2. Trap success (mice/trap night) of (a) Longworth and (b) 'Tichy' traps in field trials.

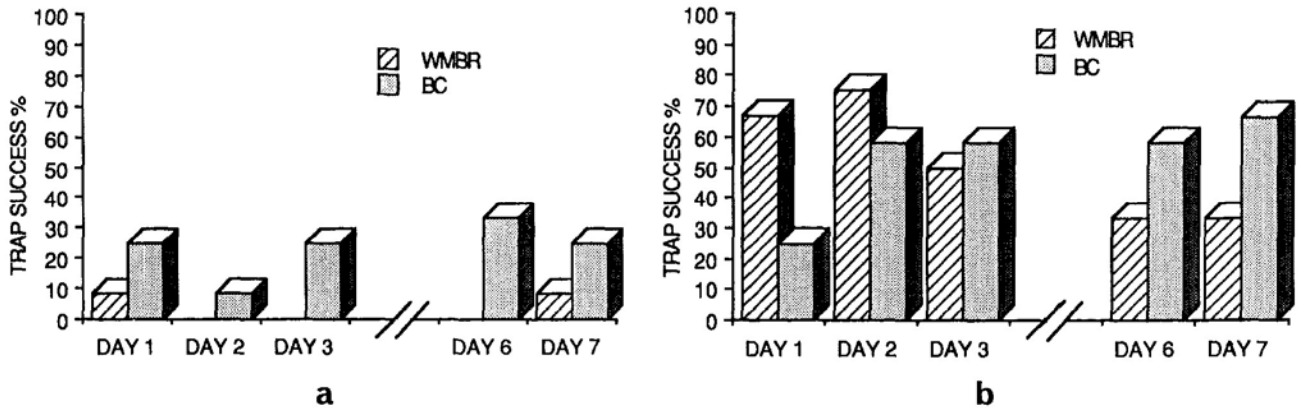

Figure 3. Trap success (mice/trap night) of (a) Longworth and (b) 'Tichy' traps in pen trials.

were baited with canary seed. Note that during the period of this trial no WMBR mice were caught in Longworth traps.

Because the differences seen in the field might be due to the different environments in which the mice lived (e.g. variety and abundance of alternative foods, frequency of exposure to new objects such as traps and availability of refuges) or to differences between the populations (e.g. in density) pen trials were carried out to further investigate trap responses and trap successes under controlled environmental conditions.

Methods

The subjects were adults (> 14g) obtained from the trapping programme described above, and tested in pairs consisting of one male and one female. Each pair was housed for three weeks in a pen measuring 2m x 2m x lm containing sawdust on the floor, 2 mouse boxes with bedding, 2 food trays and a water container. Two 'Tichy' and two Longworth traps were then introduced along the back walls of the pen, 60cm apart, and checked daily for seven days. Each trap contained bedding but was unbaited. Six replicates were performed for WMBR and six for BC mice.

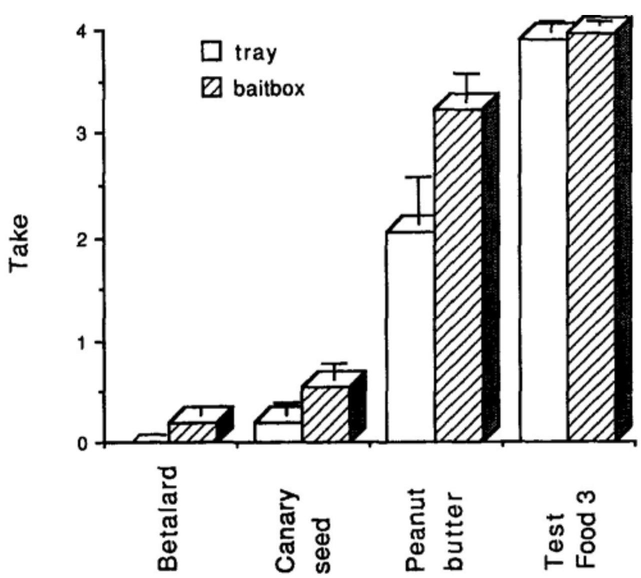

Figure 4. Average bait take on a 5-point scale (see text) of four foods in field trials at WMBR sites. Bars indicate standard

Results

As in the field trials, Longworth traps were less successful catching WMBR than BC mice, with overall catch rates of 2/60 and 14/60 respectively (%i^2 = 10.4, P < 0.05), but there were no differences in the catch rates of 'Tichy' traps (31/60 vs 32/60, Xi^2 = 0.03, n.s.). Note, however, that since these trials only involved 12 WMBR and 12 BC mice, some were caught more than once. Longworth were less successful than 'Tichy' traps, (Xi^2 = 35.2, P< 0.05 for WMBR mice, *%i*^{2}= 11.4, P< 0.05 for BC mice), as occurred in the field trials at WMBR sites (though not at BC sites).

Figure 3 shows that as in the field there were no systematic changes in trap success with time, as expected since house mice are thought to show no marked neophobia towards new objects (Barnett 1990, Wolfe 1969).

FOOD PREFERENCES AND AVOIDANCE OF BAIT BOXES BY WMBR MICE

The relative success of traps baited with Test Food 3 in pilot studies at WMBR sites suggested that these resistant mice might have abnormal food preferences - mice generally prefer cereals (Rowe et al. 1974, Meehan 1984, Ahmad et al. 1985). In addition service technicians had suggested that WMBR populations tended to avoid bait boxes. As a preliminary investigation of these suggestions, we set up field trials to compare take from boxes and trays using a 'cafeteria' experimental design.

Methods

In June 1990 41 study sites were selected within the WMBR area (Fig. 1) in commercial premises with a history of mouse infestation. 3-5g of Betalard, canary seed, peanut butter and Test Food 3 were individually placed in bait boxes and, where safe, on bait trays. Bait stations were sited along wall-floor junctions. Each container was reweighed after six or seven days and bait take was scored as follows

0 - no bait disturbance
1 - minimal disturbance of bait, e.g. toothmark
2-<50%baittake
3 - 50% < bait take < 100%
4 - complete take of bait

Results and Discussion

Peanut butter and Test Food 3 were markedly preferred to Betalard and canary seed irrespective of whether bait was presented on trays or in boxes (Fig. 4, preferences tested using Wilcoxon matched-pairs tests, E < .05). Take was similar from trays and boxes, but significantly more peanut butter was taken from boxes (Fig. 4, Mann-Whitney tests for tray-box comparisons, $P < .05$ for peanut butter). There was therefore no indication in this experiment of bait-box avoidance as suggested by service technicians, although comparisons with BC populations are also needed (see below).

The food preferences shown in Figure 4 are surprising since canary seed and Non-Tox (Betalard's bait base) are considered highly palatable foods for house mice. To demonstrate that WMBR mice are unusual, however, it is necessary to show that other populations behave differently, preferably in simultaneous trials which exclude environmental differences, including maternal effects. As a first step to achieving this we extended the above design so that WMBR and BC populations were assayed simultaneously. Preliminary results of field trials indicate that WMBR mice do have distinctive long-lasting food preferences, as judged from a 'cafeteria' test now offering a choice of nine foods (i.e. Test Foods 1,2, 3, peanut butter, canary seed, cat stars, wheat, PCD (MOD) laboratory diet and Non-Tox). To remove immediate environmental effects, we are conducting a series of pen trials with wild-caught adult animals. The distinctive food preferences shown in the field trials appear to remain intact in these controlled environmental conditions, and to persist into the next generation in individuals matured with their parents. Further work will be needed to establish whether the differences have a genetic basis, however, since it is still possible that the preferences are learnt from the mother.

WALL AND BAIT-BOX AVOIDANCE

In a further set of trials, wall and bait-box avoidance are being studied simultaneously. In pilot field trials, both phenomena were studied by analysing time-lapse video recordings made in WMBR sites. These showed WMBR mice were active in wall areas but avoided bait boxes containing the rodenticide Betalard.

Further investigations have systematically compared dropping distributions around regularly spaced empty bait boxes in WMBR and BC populations. Preliminary analysis of the results has failed to show any differences between the populations either in the use of empty bait boxes, or in wall avoidance.

These trials, therefore, do not appear to support the suggestions of service technicians that wall and bait-box avoidance are linked to behavioural resistance.

GENERAL DISCUSSION

It seems on the basis of the experimental and preliminary results presented here that behaviourally-resistant populations differ from non-resistant populations in food preferences and Longworth-trap avoidance, but not in empty bait-box or wall avoidance. If response to bait boxes really does differ from response to traps, this is puzzling, since to the mouse both presumably appear as safe harbourage, at least prior to entry.

To find differences in two apparently independent characters (food preferences and trap avoidance) is surprising, even though both make the mice harder to control/catch by conventional methods. Both behaviours may be considered adaptive responses to the same selection pressure (rodent control by man). Whether the responses are genetically based or acquired by learning is the subject of ongoing research.

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