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LARGE-SCALE POISONING OF SHIP RATS (*RATTUS RATTUS*) IN INDIGENOUS FORESTS OF THE NORTH ISLAND, NEW ZEALAND

Summary: This paper describes the impact of nine poison operations on ship rats in four areas (35 ha to 3200 ha) of North Island forest. Poisoning with 1080, brodifacoum, or pindone killed 87-100% of rats, based on trapping and tracking-tunnel indices. Rat populations took 4-5 months to recover. Operations to protect nesting birds should therefore coincide with the onset of nesting and be repeated each year, although not necessarily with the same methods. Population reduction declined each year at Mapara, King Country, during three annual 1080 operations which used the same lures and baits, but remained high at Kaharoa, Bay of Plenty, where poison toxicity was higher, non-toxic bait was pre-fed, and poisoning methods varied each year. Mouse tracking rates increased in poisoned forests 3-6 months after poisoning if the initial kill of rats exceeded 90%, peaked 7-9 months after poisoning, then declined to pre-poison levels.

Future research should focus on how prey and non-prey species within a forest community respond to a temporary reduction in rat numbers, and on methods to maintain low rat densities after initial knock-down.

Keywords: ship rats; *Rattus rattus*; mice; *Mus musculus*; indigenous forest; population control; poisoning; sodium monofluoroacetate; brodifacoum; pindone.

Introduction

The ship, roof, or black rat *Rattus rattus* (L.) was introduced into New Zealand last century, and is now a widespread pest in indigenous forests. Ship rats eat seeds and invertebrates (Beveridge, 1964; Best, 1969; Daniel, 1973; Innes, 1979; Gales, 1982; Meads, Walker and Elliott, 1984), lizards (Whitaker, 1978), and birds and their eggs (Atkinson, 1973, 1985; Innes, 1990), and perhaps compete with some native animals for food. The impact of their predation on mainland prey populations is little understood (Moors, 1983; King, 1984), but they are contributing directly to the demise of North Island kokako, *Callaeas cinerea wilsoni* (Bonaparte) (J.R. Hay, 1981, *unpubl. report*; J. Innes, *unpubl. data*) and perhaps other declining endemic bird species with low reproductive rates (Moors, 1983).

Previous attempts to control ship rats on the mainland have been confined to small areas of less than 5 ha, either to protect nesting birds or to eradicate animals coming ashore from fishing boats (Hickson, Moller and Garrick, 1986). Poisoning has, however, eradicated ship rats from five New Zealand islands, the biggest of them Somes Island at 32 ha (Veitch and Bell, 1990). Disincentives to more frequent or larger-scale control on the mainland have been the high cost, the rapid reinvasion (Innes and Skipworth, 1983) and a lack of clear conservation objectives for undertaking the control at all (Innes, 1990).

R. rattus is an important cosmopolitan commensal rodent pest, damaging crops both in the field and in storage throughout the temperate and tropical regions of the world (Prakash, 1988a). However it is widespread in indigenous forest only in New Zealand and on other islands which lack an indigenous rodent fauna. The control operations described here are unusual in a world setting in that they target ship rats as threats to other fauna, rather than to crops. Also, New Zealand is apparently the only country in which baits have been aerially distributed to kill this species; aerial bait distribution was used against mice in crops in Australia (Saunders, 1983).

This paper reports on the first large-scale control operations against ship rats in mainland forests, undertaken mainly to protect nesting North Island kokako. We also assess how aerial poisoning with 1080 (sodium monofluoroacetate) for control of brushtail possums *Trichosurus vulpecula* (Kerr) affects ship rat populations. This method of possum control has been widely used since the 1950s, and will continue in the foreseeable future. Ship rats are known to be killed by possum 1080 baits, since post-poisoning searches have recovered dead rats (E.B. Spurr, *pers. comm.*). Also, bait acceptance trials with "Mapua" cereal baits containing rhodamine dye showed 100% acceptance by rats in Northland forests (M.D. Thomas, *unpubl. data*). Finally, we examine the response of mice to the poisoning operations, since initial operations suggested that the density of mice, *Mus musculus,* increased after rat and possum poisoning.

Study areas

The four poisoned areas (Kaharoa Forest, Mapara, Pikiariki Ecological Area and Makino) and five non-treatment blocks are shown in Fig 1. All were in the central North Island and had similar vegetation. Tawa (*Beilschmiedia tawa)* was the dominant canopy tree. (Plant nomenclature follows Allan, 1961, and Connor and Edgar, 1987). The abundance of emergent podocarps such as rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*) and matai (*Prumnopitys taxifolia*) varied from high at Pikiariki Ecological Area (EA) in the Waikato to low at Mapara Wildlife Management Reserve (King Country). Other common canopy trees were kamahi (*Weinmannia racemosa*), rewarewa (*Knightia excelsa*) and hinau (*Eleaocarpus hookerianus*). The understorey vegetation at Moki and Makino (Taranaki) was severely depleted by goats (*Capra hircus* L.) and possums, but was diverse elsewhere. Common understorey or valley canopy species were mahoe (*Melicytus ramiflorus*), pigeonwood (*Hedycarya arborea*), supplejack (*Ripogonum scandens*), wineberry (*Aristotelia serrata*) and the treeferns *Dicksonia squarrosa*, *Cyathea smithii* and *C. dealbata.*

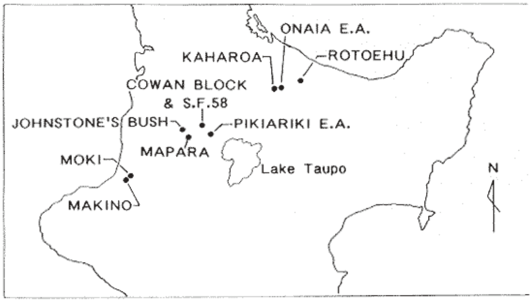

Figure 1: *Poison and non-treatment block study areas in central North Island.*

Mapara and Kaharoa Forest (Bay of Plenty) were both extensively logged for podocarps and some tawa, Mapara first before the second World War and again in the 1950s, and Kaharoa in the 1980s. However, forest structures at both places are largely intact, although the remains of old haulage tracks are still present as grassed logging roads.

Untreated areas in which rat numbers were monitored to determine natural abundance changes during the period of poisoning were usually in forests adjacent to the poisoned areas (Table 1). These were always chosen so that vegetation and topography were similar to that in the poisoned blocks, and were sufficiently distant or isolated by pasture or river gorges that rat movement between blocks was very unlikely.

Methods

The operations described here span a decade, and involve a range of control and monitoring methods. Techniques were often changed from one operation to the next, in an effort to increase kill success, standardise monitoring procedures and to reduce costs. Table 1 lists for each poisoning operation (clustered by location) the area covered, sowing method, toxin and its concentration, bait, monitoring methods and untreated block location. Rat and mouse populations were mostly monitored by kill-trapping or tracking in paired poisoned and non-treatment blocks to derive indices of abundance. We assumed that these indices directly reflected actual population densities. Footprint-tracking indices in each pair of blocks were always taken simultaneously to allow for the effects of weather and other variables on rat activity, although ship rats are active even on wet nights (Innes and Skipworth, 1983; S. Hooker and J. Innes, *unpubl. data*).

Some poisoning operations described in this paper were deliberately targeted at either ship rats or possums, while others targeted both species together. When both were controlled to protect nesting kokako, operations were undertaken later in the year (September-October) than is usual for possum control alone (June-August). This timing shift was so that control coincided with the onset of kokako breeding in November.

Ground poisoning, Pikiariki EA, 1982-83

Talon 50 WB (ICI Crop Care, Nelson, New Zealand) poison baits were placed in 40 cm long cardboard 'A-frame' tunnels which were wired to the ground to prevent disturbance by possums. Mean distance between tunnels was 31 m. Three hundred and thirty-nine tunnels were placed in the 35 ha poison block, laid out in 22 parallel lines with 10-18 tunnels per line. One bait was put in a tensioned wire holder in each tunnel on 24 January 1983. Baits were checked and, if necessary, replaced on seven occasions at about 5 day intervals (range 3-8 days); the last bait replacement was on 22 March 1983.

Relative rat numbers were monitored with tracking tunnels in the poison block and an untreated

Table 1: *Locality, date, area, poisoning method, toxin, bait, monitoring method and non-treatment block of nine poisoning operations monitored since 1982. The pindone aerially distributed at Kaharoa in 1991/92 was applied under an Experimental User's Permit.*

Treatment locality	Operation date	Area (ha)	Method	Toxin (conc.)	Bait and rate	Monitoring method	Untreated block
Pikiariki EA (Pureora)	25 Jan. to 22 Mar. 1983	35	ground-stations, 31 m spacing	brodifacoum (50 ppm by weight)	Talon 50WB	footprint-tracking, Fenn traps	Pikiariki EA (Pureora)
Makino (North Taranaki)	Aug. 1989	3200	aerial, by helicopter	1080 (0.15%)	Wanganui No.7 cinnamon-lured green-dyed, 9kg ha^{-1}	snap traps	Moki Forest
Mapara (10 grids)	17 Oct. 1989 to 18 Apr. 1990	12.25 per grid	ground-stations, 50 m spacing	brodifacoum (50 ppm by weight)	Talon 50WB	poison bait take, tracking, Fenn traps	Mapara
Mapara 1990-91	10 Sept. 1990	1432	aerial by helicopter	1080 (0.08%)	Wanganui, No.7 cinnamon-lured green-dyed, 8kg ha^{-1}	footprint-tracking, Fenn traps	Johnstone's Bush
Mapara 1991-92 (incl. some private land)	19 Oct. 1991	1700	aerial, by helicopter and hand-sowing near road	1080 (0.08%)	Wanganui, No.7 cinnamon-lured green-dyed, 8kg ha^{-1}	footprint-tracking Fenn traps	Cowan Block and S.F. 58
Mapara 1992-93	19 Oct. 1992	1400	aerial, by helicopter and hand-sowing near road	1080 (0.08%)	Wanganui, No.7 cinnamon-lured green-dyed, 8kg ha^{-1}	footprint-tracking Fenn traps	Cowan Block and S.F. 58
Kaharoa 1990-91	30 Oct. 1990	630	aerial, by helicopter	1080 (0.15%)	Wanganui, No.7 cinnamon-lured green-dyed, 18kg ha^{-1}. Pre-fed non-toxic Wanganui baits 2kg ha^{-1} on 9 Oct. 1990	footprint-tracking Fenn traps	Onaia Ecological Area
Kaharoa 1991-92	24 Oct. 1991	381	aerial, by helicopter	pindone (50 ppm by weight)	Mapua cinnamon-lured green-dyed, 10kg ha^{-1}	footprint-tracking Fenn traps	Rotoehu Forest
Kaharoa 1992-93	28 Oct. 1992	440	aerial, by helicopter	1080, surface coated (0.13%)	Wanganui, No.7 cinnamon-lured green-dyed, 6kg ha^{-1}. Pre-fed non-toxic Wanganui baits, 4kg ha^{-1} on 4 Oct. 1992	footprint-tracking Fenn traps	Rotoehu Forest

block 1.1 km away before and after the poison operation, and incidentally by Fenn-trapping during the poisoning. Forty unbaited tracking tunnels (King and Edgar, 1977) were placed at 100 m spacing on lines 100 m apart on the ground, and a further twenty were put on flat surfaces up trees (mean height 10 m; maximum height 22 m) in each of the poison and untreated blocks. Tracking papers were collected monthly from March 1982 to July 1983. Few rats were tracked up trees, so data from ground tunnels only are presented. An index of rat abundance was calculated as $1000N\ (D \times T)^{-1}$, where N = no. of tunnels with rat tracks, D = no. of days the tunnels have been set and T = no. of tunnels. Disturbed or unusable tunnels were removed from the calculation. Data were not subject to statistical analysis since there was no replication of lines within each block. Thirty-three Fenn traps baited with tinned catfood were set at *c*. 100 m spacing on tracks throughout the poison block for the duration of the trial to catch mustelids, but they also trapped ship rats.

Aerial poisoning, Makino, 1989

Rat abundance was monitored with kill traps before (2-14 August 1989) and after (19-30 September 1989) aerial poisoning. Eight lines of 40 Supreme Eziset rat kill-traps were set for 3 nights in each of Makino (poison block) and Moki (untreated block) Forests. Traps were baited with peanut butter and rolled oats. Wire cages were placed over the traps and either staked to the ground or held firm with logs or rocks to exclude possums and birds. All lines were run concurrently in each block so that any changes in weather affected the rat catch in both blocks equally. The estimate of rat kill was determined by two methods. The first used an index of abundance based on the catch per 100 trap-nights. Half a trap-night was deducted for each sprung trap (Nelson and Clark, 1973). The difference between the estimated post-poison index, calculated from the untreated block, and the actual post-poison index gave the estimated percent kill. The second method used the rate of decline in the rat catch over the 3 nights to estimate the size of the population number which was in the effective area of the lines (Seber, 1982).

Ground poisoning, Mapara, 1989-90

Talon 50 WB poison baits were placed in ‘Novapipe’ (Marley Company, Auckland, N.Z.) plastic drainage pipe tunnels laid out in a square 12.25 ha grid. Each grid consisted of 64 tunnels on an 8 x 8 arrangement, with 50 m spacing between tunnels, located on the territory of at least one kokako pair. There were 10 grids in the South Block of the Mapara Wildlife Management Reserve.

Baits were replaced weekly for 5 weeks and monthly thereafter. The number of baits laid was three per tunnel when replacements were weekly and generally six thereafter. There was always some bait in each tunnel, except briefly at the beginning of the programme when bait-take was very high. As possums were suspected of raiding tunnels for baits, cyanide poison and traps were laid in some grids in December to kill any possums interfering with the tunnels.

Population reduction was assessed by three methods: bait-take, footprint tracking and Fenn-trapping. Bait-take (percentage baits taken) provided a cumulative index of activity during the week or month before baits were replaced. Footprint-tracking rates (pre- and post-poison in poison and untreated blocks) were recorded as indices, using baited tracking tunnels and the chemical tracking method of King and Edgar (1977). Fifty-six tracking tunnels were placed on each of four poisoned grids, midway between poison tunnels, at 50 m spacing. Tunnels were baited with peanut butter and ‘set’ for one night each 6 weeks for the duration of poisoning. Two identical grids of tracking tunnels were put in untreated areas of the Central Block at Mapara. All data were expressed as percent available tunnels with rat tracks, and *t*-tests were used to examine differences between blocks.

Fenn traps (King and Edgar, 1977) set in tunnels for mustelids provided a third indexing method. There were 37 traps in South Block and 66 in total in North and Central blocks, set at roughly 200 m intervals on tracks and ridges. Traps were baited with sardines for the last 2 weeks of October and with rabbit liver for the first 2 weeks of November but were subsequently set unbaited.

Aerial poisoning, Mapara, 1990-91

Rat and mouse abundance was assessed before and after aerial poisoning with three grids of 56 tracking tunnels each, at 50 m spacing in an 8 x 7 arrangement. An untreated block was chosen at Johnstone’s Bush, 8 km away, after checks that its forest composition and rat abundance were similar to those at Mapara. The 56 tunnels at Johnstone’s Bush were set at 50 m intervals in a large circle rather than a grid. All tunnels were baited with peanut butter and ‘set’ for one night each 6 weeks from August 1990 to May 1991. Indices were taken from the poison and untreated blocks on the same night, and *t*-tests were used to examine differences between tracking rates in poison blocks and the untreated block.

Unbaited Fenn traps (King and Edgar, 1977) provided a second abundance index. About 140 traps were set at approx. 200 m intervals along tracks and ridges throughout the entire study area for most of the period spanned by tracking, and results are expressed as rats trapped per month of trapping effort.

Aerial poisoning, Kaharoa, 1990-91

Ship rat numbers were monitored with tracking tunnels and Fenn traps, and mouse numbers with tracking tunnels, before and after aerial 1080 poisoning. Seventy-two tracking tunnels were put 50 m apart in lines in the poison block and 36 were set in the nearby Onaia EA (Fig. 1). As at Mapara, these were 'set' baited with peanut butter every 5-6 weeks, but for two consecutive nights rather than one, since initial trials showed a lower tracking rate at Kaharoa than at Mapara. Data were expressed as the proportion of tunnels with tracks, but differences between blocks were not subjected to statistical analysis since lines were not replicated within blocks.

Seventy-one Fenn traps baited with 'beef and gravy' flavoured catfood were set at 150 m intervals on roads and tracks throughout the study area until late March. Rat abundance was expressed as rats trapped per month.

Aerial poisoning, Kaharoa, 1991-92 and 1992-93

Four lines with at least 25 tracking tunnels each were established in the poison block (Kaharoa) and also in an untreated block (Rotoehu Forest). Tunnels 50 m apart were baited with peanut butter for one night every 6 weeks, on the same night in the two blocks. The index of rat and mouse abundance used was the mean (n = 4) proportion of tunnels per line with tracks. *T*-tests were used to examine differences between tracking rates in poison and untreated blocks.

Also, 71 Fenn traps were set at roughly 150 m intervals throughout the poison block, and results were expressed as rats trapped per month. Thirty six traps were baited with hen eggs as part of a mustelid baiting trial and the remainder were unbaited.

Aerial poisoning, Mapara, 1991-92 and 1992-93

Ship rats and mice were monitored before and after aerial poisoning in 1991-92 and 1992-93 with the method described above for Kaharoa and its non-treatment block, including data analysis. One line of tracking tunnels was in the North Block of Mapara, one was in the Central Block and two were in South Block. The untreated area was in the Cowan Block, adjacent to the North Block of Pureora Forest Park.

One hundred and forty-two Fenn traps were set unbaited in tunnels throughout the Reserve; the index used was rats trapped per month.

Results

Impact of ground poisoning on ship rats

Pikiariki EA, Pureora, 1982-83

Tracking indices generally declined in both the poison and non-treatment blocks in the 12 months prior to poisoning. However the poison block index dropped suddenly compared to the non-treatment block index immediately after poisoning (Fig. 2). A percent kill can be roughly estimated using the mean ratio of poison block to untreated block indices prior to the operation, and assuming that the tracking rate relates directly to rat abundance. The mean ratio of indices was 1.8 (S.D.=0.84, n=11). The first post-poison index in the poisoned block in March 1983 was 4.8, rather than 17.8 if the pre-poison ratio between blocks had been maintained, suggesting a 73% decline in tracking. Ship rats were trapped in Fenn traps from 25 January to 7 February 1983 (for 2 weeks after poisoning started on January 25) but none thereafter, consistent with effective poisoning. Rat numbers were reduced for at most 2 months, since indices were similar in the two blocks according to the second post-poison index taken during April.

Mapara, 1989-90

Bait-take declined from near 100% to 32% at Mapara in 3 weeks, then increased. Possums were probably responsible for some of the increase, since bait-take declined after possums were poisoned in the tenth week.

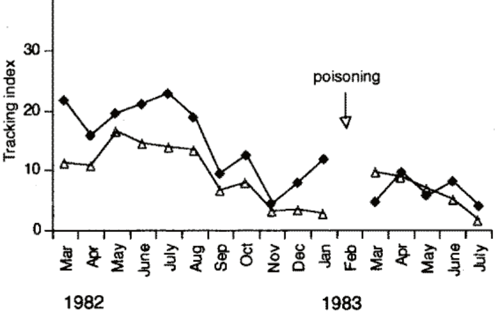

Figure 2: *Tracking indices of rat abundance in poison (solid diamond) and untreated (hollow triangle) blocks before and after ground poisoning with brodifacoum at Pikiariki EA, Pureora, 1982-83.*

Tracking indices indicated an average reduction in rat activity throughout the poisoning programme (October 1989 to April 1990) of 91%. Rat tracking rates were highly significantly lower in poisoned grids than in untreated grids throughout the poisoning operation and significantly lower for at least 3 months afterwards (Fig. 3).

Fenn traps set throughout the South Block (where poison grids were) rapidly caught fewer rats as the operation continued. Only three rats were trapped in December and one in January, suggesting that the impact of poisoning extended beyond the grids. Fenn trap-catch also declined after 3 months in North and Central Blocks where there was no poisoning (Fig. 3).

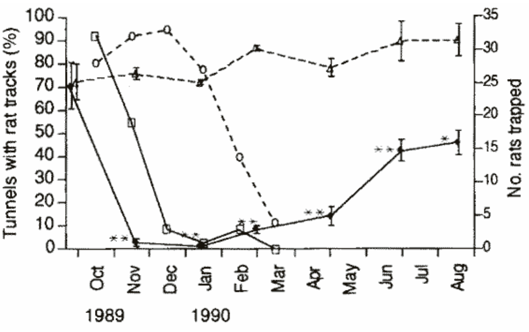

Figure 3: *Tracking frequencies of rats in poison (solid diamond) and untreated (hollow triangle) blocks before and after ground poisoning with brodifacoum at Mapara, 1989-90. Bars are standard errors, and asterisks indicate significant difference (** =* P<0.01*; * =* P<0.05*) between poison and untreated blocks. Hollow squares and circles show number of rats Fenn-trapped per month in South Block (poisoned) and North and Central Blocks (combined; untreated) respectively. Poisoning was from 17 October 1989 to 18 April 1990.*

Impact of aerial poisoning on ship rats

Makino, August 1989

The corrected capture index gave an estimated mean kill of 92.1% (95% C.L. = 83.8-100%), a little higher than that estimated from the decrease in rat abundance over 3 nights (87.5%; 95% C.L. = 75-100%). Possums were responsible for most sprung but unsuccessful traps; the number of sprung traps decreased in the post-poison trial in the poison block (Table 2).

Mapara, 1990-91, 1991-92, 1992-93

Aerial poisoning with 1080 at Mapara reduced rat tracking to zero in 1990-91, but was less effective in the two subsequent seasons (Fig. 4). In 1990-91, mean tracking rates in poisoned blocks were significantly lower than in untreated blocks at least 4.5 months after poisoning, but significant reductions lasted only half this time in 1991-92 and 1992-93.

Fenn trapping gave similar results. On average, 3.5 rats per month were trapped from October 1990 to January 1991 inclusive, whereas 20-45 rats per month were trapped in the 3 months after poisoning in October 1991 and October 1992 (Fig. 4).

Rats trapped during the week following the unsuccessful 1992-93 Mapara operation had not eaten baits, but rats ate baits for the next 9 weeks (Table 3).

Kaharoa, 1990-91, 1991-92, 1992-93

Tracking declined from 49% to zero immediately after aerial 1080 poisoning in 1990, and was only 4% by 15 February 1991, 4 months later. Similar results were achieved with pindone in 1991 and again with 1080 in 1992 (Fig. 5). Tracking was highly significantly reduced in poison blocks for at least 4 months in 1991-92 and at least 3 months in 1992-93. Fenn-trapping catches were also very low after poisoning (Fig. 5).

Table 2: *Rat and mouse captures, with percent of total trap nights in brackets and corrected percent kill, based on snap-back trapping before and after an aerial 1080 operation in Makino, 1989.*

		Pre-poison	Post poison	Corrected Percent kill (±95% C.L.)
Poison block	Trap nights	941	962	
	Rats trapped	71 (7.5)	9 (0.9)	92.1 ±7.1
	Mice trapped	11 (1.2)	2 (0.2)	87.0 ± 21.0
	Sprung traps	238 (25.3)	48 (4.9)	
Non-treatment	Trap nights	939	944	
	Rats trapped	111 (11.8)	157 (16.6)	
	Mice trapped	11 (1.8)	15 (1.6)	
	Sprung traps	435 (46.3)	415 (43.9)	

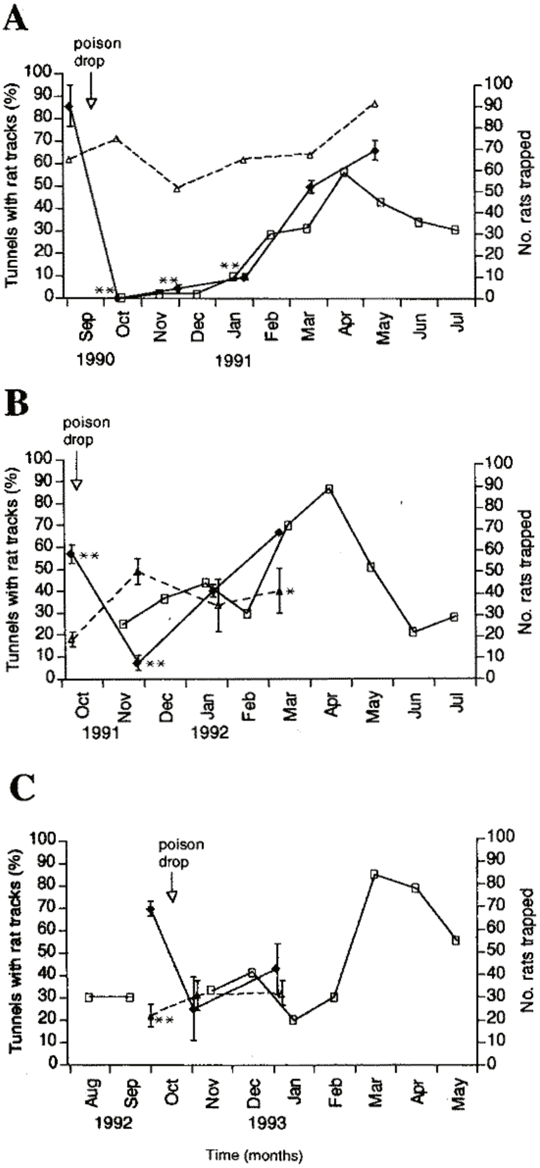

Figure 4 (column above): *Tracking frequencies of rats in poison (solid diamond) and untreated (hollow triangle) blocks before and after aerial 1080 poisoning, Mapara, 1990-91 (A), 1991-92 (B) and 1992-93 (C). Bars are standard errors, and asterisks indicate significant difference (** =* P*<0.01; * =* P*<0.05) between poison and untreated blocks. Hollow squares show rats Fenn-trapped per month in the poison block.*

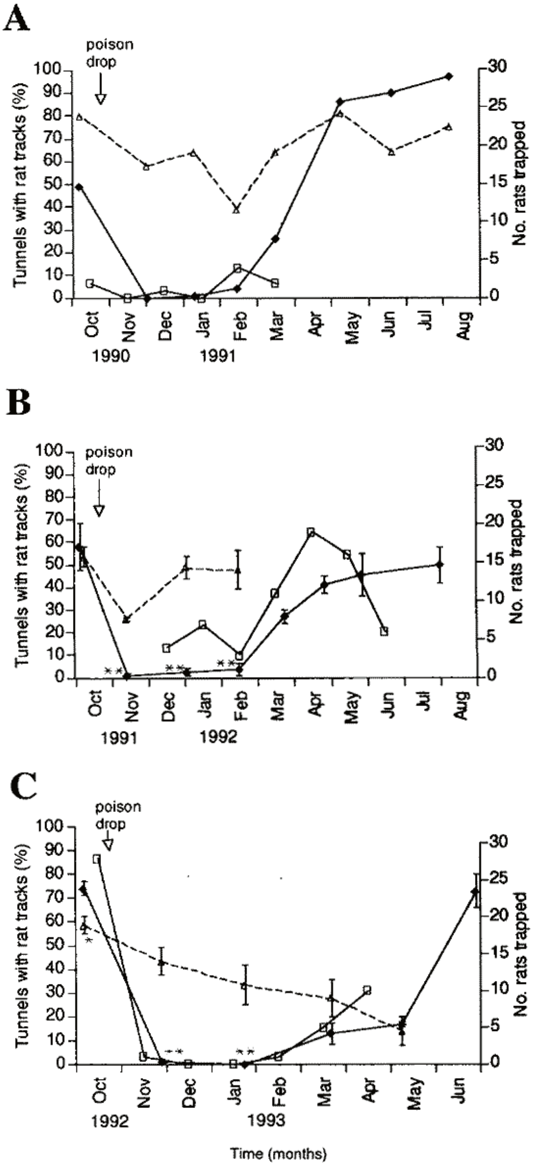

Figure 5 (column above): *Tracking frequencies of rats in poison (solid diamond) and untreated (hollow triangle) blocks before and after aerial 1080 poisoning, Kaharoa, 1990-91 (A), 1992-93 (C) and aerial pindone poisoning 1991-92 (B). Bars are standard errors, and asterisks indicate significant difference (** =* P*<0.01; * =* P*<0.05) between poison and untreated blocks. Data in Fig. 5A were not subjected to statistical analysis, since lines of tracking tunnels were not replicated within blocks. Hollow squares show rats Fenn-trapped per month in the poison block.*

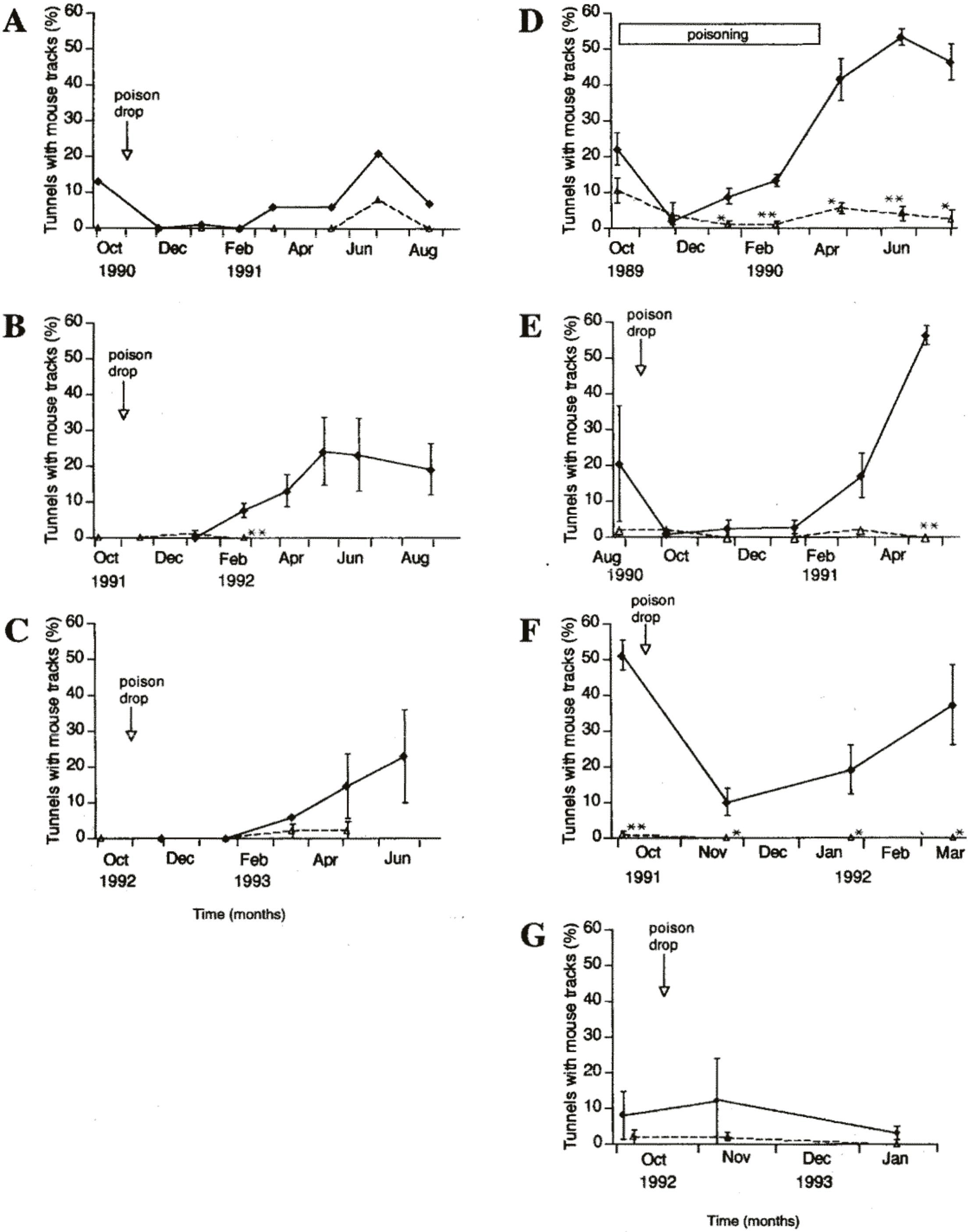

Figure 6: *Tracking frequencies of mice before and after poisoning at Kaharoa, 1990-91 (A), 1991-92 (B) and 1992-93 (C), and Mapara, 1989-90 (D), 1990-91 (E), 1991-92 (F) and 1992-93 (G). Bars are standard errors, and asterisks indicate significant difference (** =* P*<0.01; * =* P*<0.05) between poison and untreated blocks.*

Table 3: *Rats trapped at Mapara before and after the the 19 October 1992 aerial 1080 operation and the number which ingested bait as revealed by lissamine green dye.*

Date trapped	Week after aerial drop	No. of rats examined	No. with green dye
Before 19.10.92	Prior	18	0
20-26.10.92	1	4	0
27.10-2.11.92	2	4	2
3-9.11.92	3	5	5
10-16.11.92	4	8	8
17-23.11.92	5	1	1
24-30.11.92	6	12	12
31-7.12.92	7	4	4
8-14.12.92	8	5	3
15-21.12.92	9	5	3
After 22.12.92	10, onwards	30	0

Impact of poisoning on mice

Fewer mice were trapped or tracked after poisoning in at least five operations, four by aerial 1080 (Makino in 1989, Kaharoa 1990-91, Mapara 1990-91, and Mapara 1991-92) and one by ground poisoning with Talon (Mapara 1989-90) (Table 2; Fig. 6). The 1080 drop at Mapara in 1992-93 did not affect mouse tracking rates.

The initial declines were, however, followed by marked increases 3-6 months after poisoning. In the only ground operation for which data are available (Mapara 1989-90), the increase started within 3 months of the commencement of poisoning and escalated while Talon poison was still available in tunnels (Fig. 6d). The increases were significant or highly significant at Mapara in 1989-90 and 1990-91, and the same trend was obvious at Kaharoa. Comparison of Fig. 6 with Figs. 3, 4 and 5 shows that the increase was pronounced after operations in which the first post-poisoning rat-tracking index was 1% or less (Mapara 1989-90, 1990-91; all Kaharoa operations), weaker at Mapara 1991-92 when the first post-poisoning index was 7%, and non-existent at Mapara in 1992-93 (post-poisoning index 25%). Mice increased at the same time as rats increased after poisoning, so that in poisoned blocks both species coexisted in high numbers. This was never the case in untreated blocks, where mouse tracking rates rarely exceeded 5%. Post-poison mouse numbers exceeded pre-poison numbers at Mapara in 1989-90 and 1990-91 and at Kaharoa in 1990-91, the only operations for which pre-treatment mouse data are available.

Discussion

Most ground-based and aerial poisoning operations reduced indices of ship rat abundance by at least 90%. Because the six aerial 1080 operations also killed possums, they simultaneously reduced populations of the two pests most damaging to nesting kokako (J. Innes, *unpubl. data*). However, rat numbers were reduced for only one breeding season, because the rat populations recovered within 2-5 months.

The impact of poisoning on rodent populations was monitored with activity indices rather than absolute population estimates because managers did not have the time and resources to undertake the latter repeatedly as populations recovered. Tracking was preferred to kill-trapping because repeated indices were required in poison and non-treatment blocks, and we did not want to kill rats in the latter, especially if the blocks were small as this would increase the impact of a trapline on the population. Tracking tunnels did not have to be moved to new sites between samples in poison blocks as kill-traps did (at Makino), saving labour. Footprint-tracking is one of several standard population-indexing techniques for murid rodents (Moors, 1978: Kaukeinen, 1979; Spaulding and Jackson, 1983). We suggest that single night tracking indices enable managers to efficiently obtain a satisfactorily precise index for the objective of determining ship rat and mouse abundance before and after poisoning operations. At Kaharoa and Mapara, tracking indices provided repeatable (between blocks) and intuitively coherent accounts of ship rat population changes in the absence of poisoning in non-treatment blocks and after poisoning in poisoned blocks. We also suggest that 1-night tracking indices are more informative than monthly indices (as used at Pikiariki EA) for monitoring poisoning impact. A high index recorded over a month may misleadingly reflect increased tracking on the final few nights after many nights with no tracking at all. Kill-trapping has the advantage of eliminating contagion effects, where one animal visits many devices, but brief (1-night) tracking indices reduce the chance of contagion occurring. Contagion could be studied by toe-clipping rats during routine tracking to see if rats visited several tunnels on the same night. Kaukeinen (1979) recommends that a minimum of two independant census techniques be used in each evaluation to ensure that adequate data are generated.

It is implausible that index declines in poisoned blocks at the time of poisoning were accidents of changing rodent activity, especially when population trends indicated by tracking were shown also in the numbers of rats killed in Fenn traps (Figs. 3-5). In 1991-92 and 1992-93 at Mapara, Fenn traps continued to catch moderate numbers of rats after poisoning, confirming tracking results of unsatisfactory kills. Catches declined during January-May in six of the seven operations we monitored with Fenn traps, sometimes contrary to the trends shown by tracking (Figs. 3, 4a, 5a, 5b). We suggest that this reflects the cessation of dispersal by young rats at the end of each breeding season. That is, catches declined at that time of year because the permanent traplines killed resident animals which were not replaced, although tracking rates did not decline because no rats died due to tracking.

Research to investigate the relationships between such indices and actual population density is badly needed for all rodent-indexing techniques in New Zealand. A 9 ha extinction trapping study in 1993 at Kaharoa by Kerry Brown (Otago University, *unpubl. data*) showed a strong correlation between ship rat density and tracking frequency, using the tracking tunnels and spacing described for these operations.

Ship rats which have eaten a fatal dose of brodifacoum poison range normally for 3-5 days, then die (S. Hooker and J. Innes, *unpubl. data*). Therefore anticoagulants such as brodifacoum may be too slow-acting to immediately stop predation at known bird nests, in which case acute poisons or traps are more appropriate tools for that objective. Cox and Smith (1992) found that feeding declined rapidly in anticoagulant-treated *Rattus norvegicus*; research on wild New Zealand murids is needed to verify this in the New Zealand situation.

These poison operations show that rats readily accepted green-dyed, cinnamon-flavoured 1080 cereal baits, since kill rates were very high at Makino, Kaharoa and initially at Mapara. Neophobia (the avoidance of an unfamiliar object in a familiar environment; Barnett, 1988) did not prevent the rats from eating the baits, although just sampling them may have been enough for a fatal dose to be ingested. The LD 100 (the amount of poison per kg of animal required to kill 100% of individuals in a population) of the ship rat is 1.2 mg kg^{-1} (Hone and Mulligen, 1982). The amount of 1080 in an average 6 g cereal bait is 4.8 mg if 0.08% 1080 is used, and 8 mg if 0.15% 1080 is used. A ship rat of average weight (140 g) therefore has to consume only a small fraction of a bait (3.4% of a 0.08% bait; 1.9% of a 0.15% bait) to receive an LD 100 dose, and smaller rats need consume even less. While this may be excessive dosage for ship rats alone, co-targeting of the larger (2.8 kg) possums and the rapid leaching of 1080 by rainfall both suggest that higher-toxicity baits are preferable provided that bait acceptance remains high. The three aerial 1080 operations we monitored where the 1080 content was 0.13-0.15% by weight all obtained excellent kills. These toxicities are lower than those used overseas. Lund (1988) recommends that for rats 1080 be used at 0.25% by weight in dry baits.

Acute poisons which rapidly cause illness in rats (e.g., 30-90 minutes for 1080; Lund, 1988) are well known to cause poison aversion, which may generalise to bait shyness lasting weeks or months (Prakash, 1988b). This may explain why the effectiveness of aerial poisoning declined each successive year at Mapara, where 0.08% 1080 in green-dyed, cinnamon-lured cereal baits was used without pre-feeding for all operations, although few ship rats live more than a year in the wild (Daniel, 1972; Innes, 1990). In contrast, effectiveness did not decline at Kaharoa, where 1080 content was 0.13-0.15%; the two aerial 1080 operations were pre-fed with non-toxic baits, and the run of 1080 operations was broken by using the anticoagulant pindone in the second year. Field evidence of declining kills at Mapara suggests that learned bait aversion (including bait flavour and texture and lure flavour aversion) increased each year. This is consistent with the suggestion that at Mapara in 1992-93 the baits were acceptable to rats only after rainfall had leached the 1080 out of them; further research is needed to verify this. Bait shyness may be mitigated by pre-feeding, by using second-generation anticoagulants such as brodifacoum which do not need pre-feeding (Prakash, 1988b), or by altering bait flavour (Naheed and Khan, 1989).

Why did mouse tracking increase after successful poisoning? The increases occurred regardless of poisoning method or toxin and were greater when ship rat control was most effective. This may reflect increased tracking (increased mouse activity or increased use of tracking tunnels) by an unchanged number of mice, or an increase in the number of mice. The first is unlikely; it is hard to envisage a behaviour change which is first apparent 3-6 months after poisoning. This delay also seems to rule out a competitive interaction between ship rats and mice at the tracking tunnels themselves, since in most operations ship rats declined dramatically within 2-3 weeks of poisoning. Also, mouse tracking increased after poisoning at the same time as rat tracking also increased. It also seems unlikely that the increases were due to real abundance changes unrelated to poisoning. Significant increases occurred only in poisoned blocks (but even then, only when rat poisoning was effective), or in those parts of a block which were poisoned (Mapara 1989-90; Fig. 6d). Finally, quarterly trapping of mice in podocarp-tawa forest at Pureora from 1982 to 1987 (C.M. King, J.G. Innes, M. Flux, *unpubl. data*, summarised in Murphy, 1990) and irregular trapping at Rotoehu (Bay of Plenty) between January 1991 and February 1994 (J.G. Innes, *unpubl. data*) yielded very low maximum indices of 3.7 and 3.4 mice per 100 trap-nights (100 TN) respectively, and in both areas the traplines often caught no mice at all. These data suggest that in the absence of any pest management, mice in mature central North Island podocarp-tawa forest have very low, stable populations. Choate (1965) also trapped no mice in podocarp-kamahi forest in a single trapping session at Jackson Bay, South Westland. Mouse capture rates in podocarp-tawa forest have never neared the 20-73 mice per 100 TN recorded from beech (*Nothofagus* sp.) forests, the 26-47 mice per 100 TN from young pines and other areas of dense cover on the mainland, or the up to 130 mice per 100 TN on islands (data summarised by Murphy, 1990). At Rotoehu, footprint-tracking indices were 0-3.5 % in 13 tracking sessions between January 1991 and February 1994 (J.G. Innes, *unpubl. data*) ; i.e., concurrent trapping and tracking both suggested that mice were rare. The frequent and significant increases (to 21-56 %) in the mouse tracking rate which we observed in podocarp-tawa forest after poisoning suggest that there were large increases in mouse numbers or distribution or both caused by the poisoning operations.

The increase may have been due to improved food supply for mice, as postulated to explain mouse increases after heavy flowering in South Island *Nothofagus* forest (Fitzgerald, 1978; King, 1982, 1983; Murphy, 1992). Alternatively, it may indicate release from predation or harrassment by ship rats, stoats (*Mustela erminea*) or cats (*Felis catus*), all of which may have been reduced after poisoning. Mice in native forest at Pureora were largely confined to areas of dense cover in the presence of these predators (C. M. King *et al.*, *unpubl. data*). However, 18 stoats trapped at Mapara between 15 October 1990 and 15 April 1991 had no mice in their guts (Murphy and Bradfield, 1992) despite the increasing abundance of mice after January 1991. The reason(s) for the general and temporary increase in mouse numbers after poisoning could be explored with enclosure studies of interactions between mice and the other mammals, and with age and diet studies of mice, ship rats, cats and stoats before and after poisoning.

Ground-based poisoning in kokako territories is much more costly per hectare than aerial poisoning, although it targets only nesting areas. Both methods probably give the same protection from rats. Ground-based poisoning with Talon at Mapara in 1989-90 targeted rats alone and cost in total $22 000 in 10 kokako territories (144 ha; $153 ha^{-1}), mostly attributed to the labour cost (130 person-days @ $120 = $15 600) of setting up tunnel grids and replacing baits. In contrast, the 1990 aerial 1080 operation at Mapara cost $34 000 for 1432 ha ($23.70 ha^{-1}), and killed possums and rats (P. Thomson, *pers. comm.*). Pre-feeding non-toxic bait and increasing sowing rates at Kaharoa increased aerial 1080 operation costs to $39 ha^{-1} and $47 ha^{-1} in 1990 and 1992 respectively, and in 1991 the aerial pindone operation cost $49 ha^{-1} (M. Wilke, *unpubl. data*).

Ship rats and mice were undoubtedly killed in huge areas of New Zealand forests during aerial 1080 operations targeted at possums in the last four decades. Benefits to wildlife from such operations may include some relief from rat and mouse predation as well as improvement of vegetation after reduced possum browsing. Positive responses by bird populations to predator and competitor reductions have been reported from islands (T. Lovegrove, 1986, *unpubl. report*; Miller and Anderson, 1992).

Future research should examine which elements of the native flora and fauna benefit from a large but temporary reduction in ship rat numbers. Improvements in control efficiency, including maintenance of low rat numbers after initial knockdown, are badly needed to reduce the cost of sustained control. Unexpected ecological repercussions of large-scale poisoning in North Island New Zealand forests may include a functional change (diet) by stoats (Murphy and Bradfield, 1992) and a numerical change (increase) by mice. Assessment of the costs and benefits of large-scale poisoning must allow for these and other repercussions of community perturbation.

Acknowledgements

We thank Mark Kimberley, Graham Hickling and Chris Frampton for help with statistics; Colleen Pakes for word-processing; many Department of

Conservation staff members for assisting with monitoring the poisoning operations; John McLennan, Elaine Murphy, Eric Spurr, an anonymous referee, Cleveland Duval and Gillian Rapson for helpful comment on ms drafts; Harry Bunn and Tony Beveridge (ex Forest Research Institute, New Zealand Forest Service) for encouragement to trial mainland ship rat control for kokako conservation in the early 1980s. The research was funded by the Department of Conservation (Contracts 5020/191, S7005/562, P579) and the Foundation for Research, Science and Technology (Contract C0 9232).

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