Optimal Buffer Widths for Control of Possums in the Hauhungaroa Range : 1996 – Population Recovery and Tb Prevalence in Possums, Deer, and Pigs Two Years After Control

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Landcare Research Contract Report: LC9697/124

PREPARED FOR:
Animal Health Board, PO Box 3412, Wellington

DATE: August 1997

DOI: https://doi.org/10.7931/2ys2-7e76

Contents

1. Summary

1.1 Project and Client

Changes in possum and deer density and in the prevalence of bovine tuberculosis (Tb) in the possum, pig, and deer populations in parts of the Hauhungaroa Range are being monitored by Landcare Research for the Animal Health Board (AHB). This report presents results from assessments made in 1996 (22-32 months after the initial control operation).

1.2 Objectives

- To monitor the recovery of possum and deer populations in Tb buffers 1, 3, and 7 km wide and of possum populations along adjacent forest-pasture margins c. 2 years after aerial control.
- To determine the incidence of Tb in cattle on farms adjacent to each of the buffers, the prevalence of Tb in possum, deer, and pig populations in the 7-km buffer, and the prevalence of Tb in possum populations on forest-pasture margins managed under annual and bi-annual maintenance control operations.

1.3 Methods

- Changes in possum and deer densities c. 2 years after the aerial control using 1080 carrot bait were assessed for three buffer zones (1, 3, and 7 km) using faecal-pellet surveys, changes in hunting success rates for deer, and trap-catch data for possums.
- The incidence of Tb in cattle on farms adjacent to each of the buffers was assessed from annual herd testing data obtained from MAF for the 6 years from 1990/91.
- Tb-prevalence rates in possums were determined by examining possums taken from leg-hold trap lines set along the forest-pasture margin and cyanide-paste lines laid in the adjacent forest. Possums were necropsied and all major superficial and deep lymph nodes and major thoracic and abdominal organs were examined for Tb.
- Tb prevalence in deer and pigs was determined from animals shot by ground- and helicopter-based hunters in the 7-km buffer zone. These animals were necropsied at the Animal Health Laboratory, Ruakura.

1.4 Results

- Faecal-pellet indices of possum density have increased since 1995 by 120% in the 1-km buffer, 14% in the 3-km buffer, and 21% in the 7-km buffer, but none of these overall changes are statistically significant. However, there was a significant increase on one of the two 4-km long transects surveyed in the 1-km buffer.
- In the 1-km and 7-km buffers, the possum populations appear to be recovering more quickly at the "back" of the buffers where they adjoin areas not subjected to possum control. In the 3-km buffer, however, the possum population appears to be recovering most rapidly closest to the forest-pasture margin. Trap-catch rates along the forest-pasture margins of the 7-km buffer were below 4%, but were moderately high (16.4%) in the small parts of the 3-km buffer surveyed by trapping.
- Faecal-pellet indices of deer abundance have increased by 77% in the 1-km buffer and by 55% in the 7-km buffer since 1995, but only the latter result was statistically significant. There was no change in the index of deer abundance in the 3-km buffer.

- Overall, the incidence of Tb in 1995/96 in adjacent cattle herds had fallen to 0.35%, from 1.22 - 2.06% for the four years before winter 1994. Incidence rates in 1995/96 were lowest on farms adjacent to the 7-km buffer that were subject to annual maintenance possum control (0.06%) and highest on farms adjacent to the 3-km buffer (0.60%).
- No Tb was found in any of the 45 possums taken in or adjacent to the 7-km buffer, but two of the 89 taken from the 3-km buffer were infected. Eight (26%) of the 31 deer shot within the 7-km buffer were infected. The infected deer included four young males shot within 2 km of the central unpoisoned area. Combining data for all years, the prevalence of Tb in deer was significantly lower (13%) in those shot since 1994 in areas more than 2 km from unpoisoned areas than in those shot in the unpoisoned areas (37%).
- Thirteen (65%) of the 20 pigs shot in the 7-km buffer were infected. All of these pigs had been born since winter 1994, and some piglets <6 months old were infected.

1.5 Conclusions

- Approximately 2 years after poisoning, within-forest possum densities in the 3- and 7-km buffers remains low. In the 1-km buffer, however, the population now exceeds 40% of its pre-control density. For the 1-km and 7-km buffers, faster recovery at the back margin suggests immigration from adjacent unpoisoned deep forest. For the 3-km buffer, however, the more rapid recovery near the forest-pasture margin suggests less effective control of possums on adjacent farms than on farms adjacent to the 7-km buffer.
- Within 2 years of the 1994 poison operation indices of deer densities in the 7-km buffer have increased to near pre-control levels, but remain lower than pre-control levels in the 3-km buffer.
- The 1994 poisoning operation has helped reduce the incidence of Tb in cattle, particularly on the eastern side of the range.
- Tb prevalence in deer in areas more than 2 km from an uncontrolled possum population has declined since the poison operation. The most likely explanation is that possum control has reduced the frequency of transmission of Tb from possums to deer.
- The high prevalence of Tb in young pigs in the 7-km buffer is likely to reflect scavenging of infected deer carcasses.

1.6 Recommendations

- Because indices of possum densities in the 1-km buffer exceed 40% of pre-control levels further possum control should be undertaken there immediately. For the 3-km buffer, possum densities along the forest-pasture margin and on the adjacent farms should be regularly assessed to determine whether the apparently more rapid recovery along that margin reflects poor possum control on those farms.
- Possum and deer population recovery should be monitored within all three buffers in 1997, in the 3- and 7-km buffer in 1998, and along the eastern forest-pasture margin in both years. The annual assessment of Tb prevalence in livestock, possums, deer and pigs should also continue as planned.
- The AHB should extend the survey of Tb prevalence in deer and pigs to include the central unpoisoned area, and, ideally, some other unpoisoned area with deer, pigs, and infected possums present to provide more rigorous tests of our hypotheses about transmission between the different species.

2. Introduction

Changes in possum and deer density and in the prevalence of bovine tuberculosis (Tb) in the possum, deer, and pig populations in parts of the Hauhungaroa Range are being monitored by Landcare Research for the Animal Health Board (AHB). This report presents results from assessments made in 1996 (c. 2 years after the initial control operation).

3. Background

In 1994, a 5-year trial was established in the Hauhungaroa Range to compare the effectiveness of possum control over three different buffer widths (i.e., strips of forest adjacent to farmland) in limiting the rate at which the possum populations on the forest-pasture margins recover (Fraser *et al.* 1995; Coleman *et al.* 1996). The trial was prompted by anecdotal evidence that some possum populations on forest-pasture margins recover to near pre-control levels 1 - 2 years after initial control over 1 - 3 km wide buffers (P. Livingstone, AHB, pers. comm.). If this apparently rapid recovery does occur, there is little likelihood that control operations over such buffers will provide any sustained reduction in cattle reactor rates, or keep possum densities below the "40% of carrying capacity" threshold that Barlow's (1991) disease model indicates is required for elimination of Tb from possum populations.

Other ongoing aims of the trial are: (i) to determine whether there is any spatial variation in the rates of possum population recovery within the buffers; (ii) to compare the effectiveness of annual and bi-annual maintenance (ground-based) control on possum numbers at the forest-pasture margin of the largest buffer; and (iii) to assess the effect of possum and deer control on the prevalence of Tb in deer, possums, and pigs and on the incidence of Tb in cattle on adjacent farms.

Following the aerial 1080 poison operation in winter 1994 in which carrot baits were distributed over forest buffers of 1, 3, and 7 km, we recorded possum kills of 78 - 92%, deer kills of up to 42%, and overall Tb prevalence rates of 0.9% for possums and 37% for deer (Fraser *et al.* 1995). One year after control, possum densities remained low in all three buffers and were not related to distance from the forest-pasture margin (Coleman *et al.* 1996). Highest possum densities were recorded in the 1-km buffer, and although trap-catch rates along the forest margin of the 7-km buffer had doubled they were still low. Deer densities remained close to post-control levels. Overall Tb prevalence had changed little from pre poison levels, with no Tb found in 29 possums necropsied but with about one third of the deer being infected. However none of the eight deer born since late 1993 and shot within the poisoned area were infected.

Tb reactor rates in the stock farms adjacent to the 3-km buffer had not declined as much or as fast as for the 7-km buffer, so in 1996/97 we extended our trapping to include the 3-km buffer by reassessing possum density (and Tb prevalence) along trap lines established in 1994 by

Department of Conservation (DoC) and Manawatu/Wanganui Regional Council staff. Our aim was to supplement data from faecal-pellet counts within the 3-km buffer with trap-catch and Tb prevalence data.

4. Objectives

- To monitor the recovery of possum and deer populations in Tb buffers 1, 3, and 7 km wide and of possum populations along adjacent forest-pasture margins c. 2 years after aerial control.
- To determine the incidence of Tb in cattle on farms adjacent to each of the buffers, the prevalence of Tb in possum, deer, and pig populations in the 7-km buffer, and the prevalence of Tb in possum populations on forest-pasture margins managed under annual and biannual maintenance control operations.

5. Methods

5.1 Recovery of animal populations

Faecal-pellet indices

Faecal-pellet surveys for possums and deer in the 1, 3, and 7-km buffers were carried out in October and November 1996. Each of the buffers had between 800 and 1100 circular faecal-pellet plots spaced at 10-m intervals along 0.5-km transects (except for the narrow 1-km buffer where two 4-km transects were used instead; Fig. 1). The same plot centres were used to search for pellets of both species. Searchers recorded the number of identifiable possum pellets within 0.8 m of the plot centre and the number of intact deer pellet groups within 2.5 m of the plot centre. Indices of abundance were derived from the mean numbers of possum faecal pellets and deer pellet groups found per transect. The percentage change in the abundance indices for each species in each buffer was determined by comparing these results with those from the pre- and post-control faecal-pellet surveys conducted in 1994 and with the first annual assessment in 1995.

Area-wide changes between years in possum and deer faecal-pellet disappearance rates (and possibly also in defecation rates), were adjusted for by using data from two nearby non-treatment areas. Results from the central non-treatment area (650 plots) were used to calibrate faecal-pellet counts for the 3-km buffer, while those from the southern non-treatment area (400 plots) were similarly used for the 1-km and 7-km buffers.

The lack of precision of the faecal-pellet data collected for pigs in previous surveys meant there was little value in continuing to monitor this species using faecal-pellet indices (Coleman *et al.* 1996).

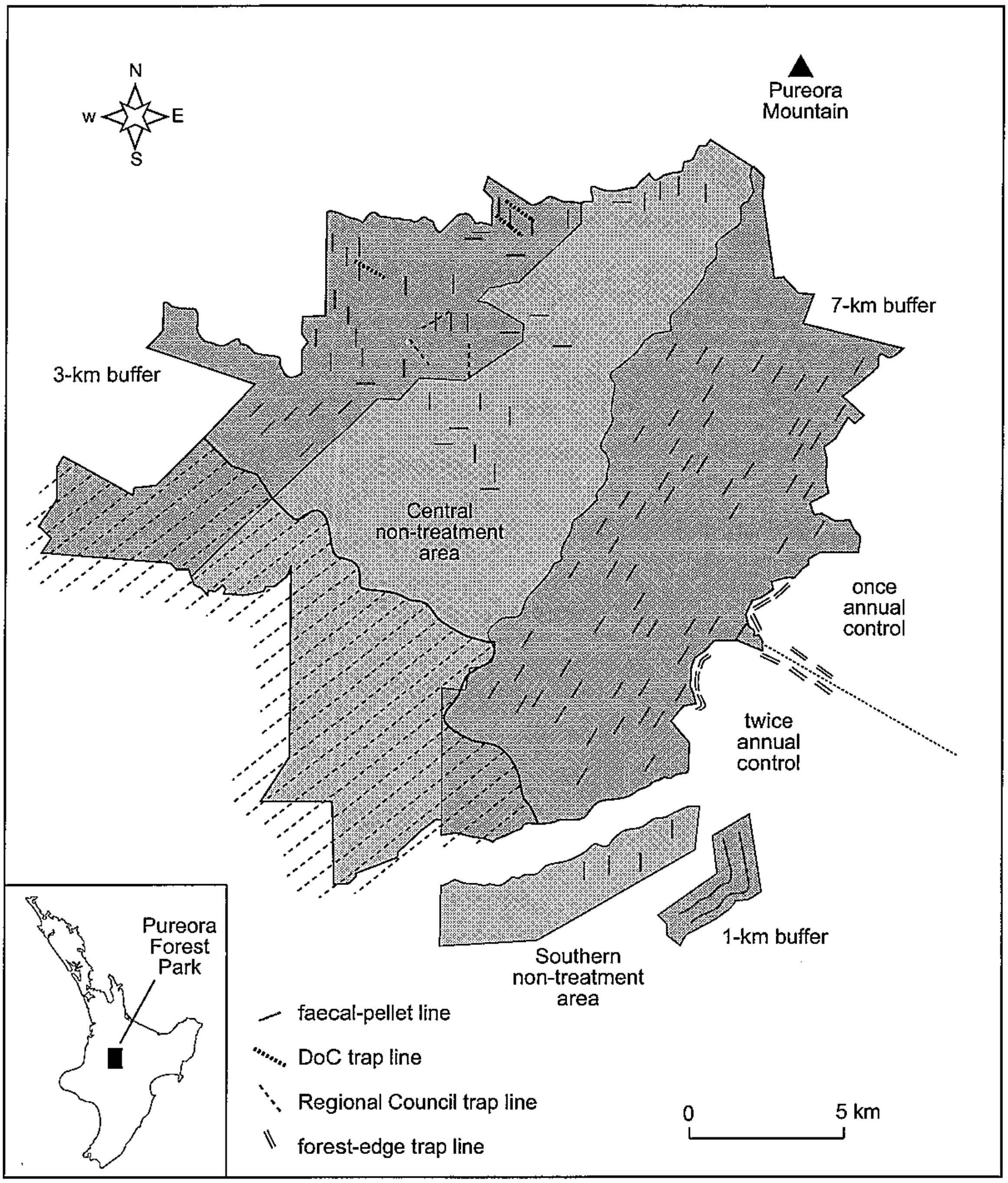

Fig. 1 Locations of the three buffer zones poisoned in winter 1994, the south-western area poisoned in winter 1995, the central and southern non-treatment zones, and the sections of the forest-pasture margin of the 7-km buffer subject to once- and twice-annual control. Also shown are the locations of the faecal-pellet count transects and the various trap lines.

Hunting statistics

The hunting success rates of recreational hunters before the 1994 control operation and in 1995 and 1996 were compared using data from hunting diaries sent to the Department of Conservation (see Fraser 1996 for methodology).

Spatial patterns of recovery

Variation in the rate of recovery of possum populations in the 3- and 7-km buffers in relation to distance from the forest-pasture margin and from adjacent uncontrolled forest areas was determined by surveying twenty nine 50-plot faecal pellet transects in the 3-km buffer and 62 in the 7-km buffer. These transects included those used to assess population recovery, and most were aligned parallel to the forest-pasture margin. They were established at c. 0.25 km, c. 0.75 km, c. 1.5 km, and then at c. 1-km intervals from the forest-pasture margin. The irregular shape and topography of the 3-km buffer meant that some faecal-pellet transects could not be aligned parallel to the forest-pasture margin. For the 1-km buffer spatial variation was assessed on two 4-km transects which were parallel to, and 0.25 and 0.75 km respectively from, the forest-pasture margin. A search radius of 1.14 m was used, with the percentage of plots per transect on which pellets were found used as the index of possum abundance (i.e., presence/absence or % frequency).

Trap catch

The effectiveness of the once-annual or twice-annual maintenance control programmes in keeping possum populations low on the forest-pasture margin of the 7-km buffer was determined using the trap-catch procedures described in our first report (Fraser *et al.* 1995). Six trap lines were established in April 1994 on the margin of the 7-km buffer area and 5 trap lines were established on the margin of the nearby Lakeside Reserves. These lines were trapped again in September 1994, May 1995, and May 1996.

In 1996, six additional lines were monitored within the 3-km buffer. They included three "Regional Council" trap lines with origins located within 1 km of the forest-pasture margin and monitored in May and July 1994 by the Manawatu/Wanganui Regional Council, and three "DoC" trap lines established in a small 600 ha area (the Rata-nu-nui Reserve) in the middle of the buffer and monitored in April and August 1994 by DoC Waikato (Fig. 1).

All lines in each area were trapped for three consecutive fine nights, and all animals captured were humanely killed.

5.2 Tb prevalence

Cattle

Tb test data for the period 1990/91 to 1995/96 for cattle herds located immediately adjacent to the 1-, 3-, and 7-km buffers were provided by MAF Quality Management, Taumaranui. The data included the number of cattle tuberculin-tested each year, the number reacting to the test (reactors), and the number of lesioned (Tb) cattle identified at slaughter (from both reactor and culled animals).

Possums

The prevalence of Tb in possums on the forest-pasture margins was checked by necropsy (by JDC). The prevalence of Tb in possums in the forest was determined from possums killed using cyanide baits. One hundred cyanide-paste baits were set for two nights at 20-m intervals along each of seven parallel transects spaced at 1-km intervals across the 7-km buffer (beginning c. 0.5 km from the forest edge). Each transect ran parallel to the forest-pasture margin and was located in the same place as in our previous surveys (see Fig. 2 in Fraser *et al.* 1995).

All major superficial (axillary and inguinal) and deep (axillary, mesenteric, hepatic, and mediastinal) lymph nodes, all major thoracic and abdominal organs (lungs, liver, kidney, and spleen), and the adrenal glands were checked for gross lesions indicative of bovine Tb. All visible suspect lesions were excised and frozen before being forwarded to MAF Quality Management (Lincoln) for culture to confirm field diagnoses.

The sex, age class, body weight, reproductive status, and physical condition (mesenteric fat weight) of all necropsied possums were recorded, and two molar teeth (M2 and M3) were collected from the lower jaw for age determination from cementum annuli (Clout 1982).

The presence or absence of Tb in nine ferrets, one rabbit, one stoat, and one cat incidentally trapped on forest pasture margin was also checked by necropsy.

Deer and pigs

The prevalence of Tb in deer and pigs within the 7-km buffer was also determined by necropsy survey in 1996/97. Animals were obtained in a variety of ways. A few were shot by research staff involved in other work and some were purchased from a commercial helicopter operator in September and October 1996. However, most were shot by three ground-based hunters serviced by a lightweight helicopter in November 1996, and the remainder were shot from a helicopter by Environment Waikato staff in early 1997. Unlike 1995, no animals were obtained from west of the Hauhungaroa Range crest (i.e., the central unpoisoned area). Some ground-shot animals were hung in the field for up to four days, but otherwise the deer and pigs were transported to the Animal Health Laboratory at Ruakura, Hamilton, on the day they were shot, for necropsy and subsequent incineration. All suspect lesions, and the pooled material from the tonsils and retropharyngeal lymph nodes of each deer and pig were cultured separately to test for Tb. Lower jawbones were taken to assess age (Fraser & Sweetapple 1993).

6. Results

6.1 Recovery of animal populations

Possums

Although the mean number of possum pellets found per line increased by 14% in the 3-km buffer and by 21% in the 7-km buffer between 1995 and 1996 (Fig. 2), these changes were not significant (paired t-tests, $p>0.05$). In the 1-km buffer the mean number of possum pellets per transect increased by c. 120% (Fig. 2), but again the change was not statistically significant ($t_{1\text{-tailed}}=1.44$, $p=0.19$) The lack of significance for the 1-km buffer reflects the low number of transects (two) and the marked difference in recovery between them. In 1995 the number of faecal pellets on these two 4-km long transects was similar, but by 1996 the number of pellets on the transect furthest from the forest-pasture margin had increased threefold ($t_{1\text{-tailed}}=1.95$, $p<0.05$).

By 1996 there appeared to be some spatial variation in the rate of recovery of possum populations within each of the buffers, but the pattern is not consistent (Fig. 3). In the 1-km and 7-km buffers, the possum population appears to be recovering quicker farthest from the forest-pasture margin (i.e., in deep forest where the buffer is adjacent to areas that were not subject to control). However, in the 3-km buffer the possum population appears to be recovering most rapidly closest to the forest-pasture margin.

A total of 134 possums were trapped in 1996 (Table 1, Appendix 11.1). Of the 22 possums killed at the edge of the 7-km buffer, seven were taken from the twice-annually controlled forest edge south of the Waihaha River and 15 were taken from the once-annually controlled area north of the River. However, when 1995 and 1996 data are combined there is no difference in the numbers of possums taken from these two areas. The trap-catch rate was low (3.6%) and still only c. 20% of pre-control levels. The trap-catch rates at the edge of the 7-km buffer (3.6%) and in the Lakeside Reserves (2.2%)were low, and still <20% of pre-control levels. In contrast, trap-catch rates in the 3-km buffer were moderately high (16.4%) or about 50% of pre-control levels.

Table 1 The number of possums trapped on the Hauhungaroa study lines 1994 - 1996.

	1994		1995	1996
	Pre-control	Post-control		
7-km (twice annual)	47	5	18	7
7-km (once annual)	68	4	4	15
Lakeside Reserves	27	2	2	7
3-km	172	8	not trapped	89

Seventy-one rats, 7 hedgehogs, 9 ferrets, 2 stoats, 1 cat, 1 rabbit, and 1 hare were also trapped. The number of rats trapped was substantially higher than in 1995.

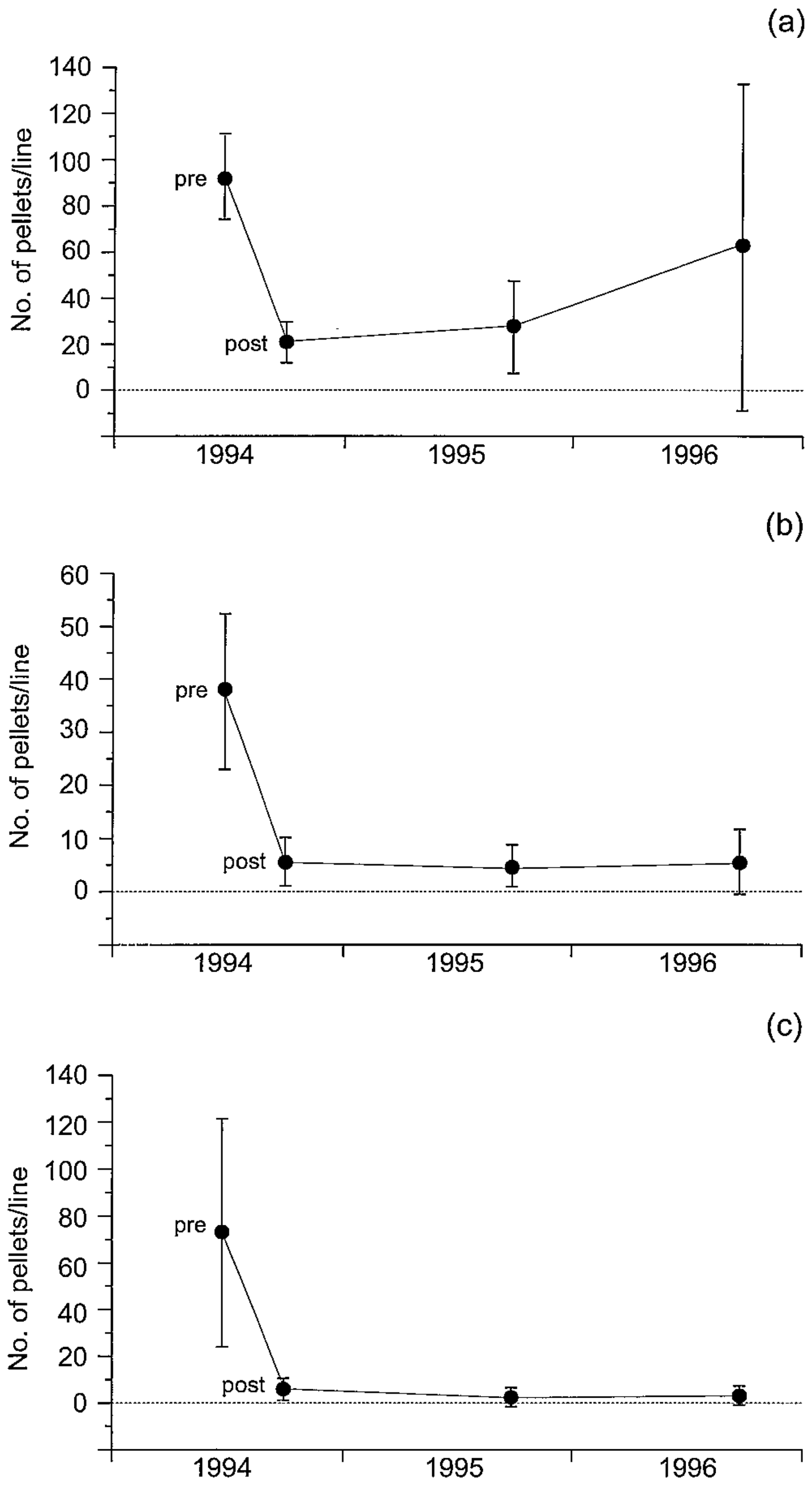

Fig. 2 Mean number of possum faecal pellets per line (±95% confidence limits) for 1994 - 1996 for the (a) 1-km, (b) 3-km, and (c) 7-km buffers.

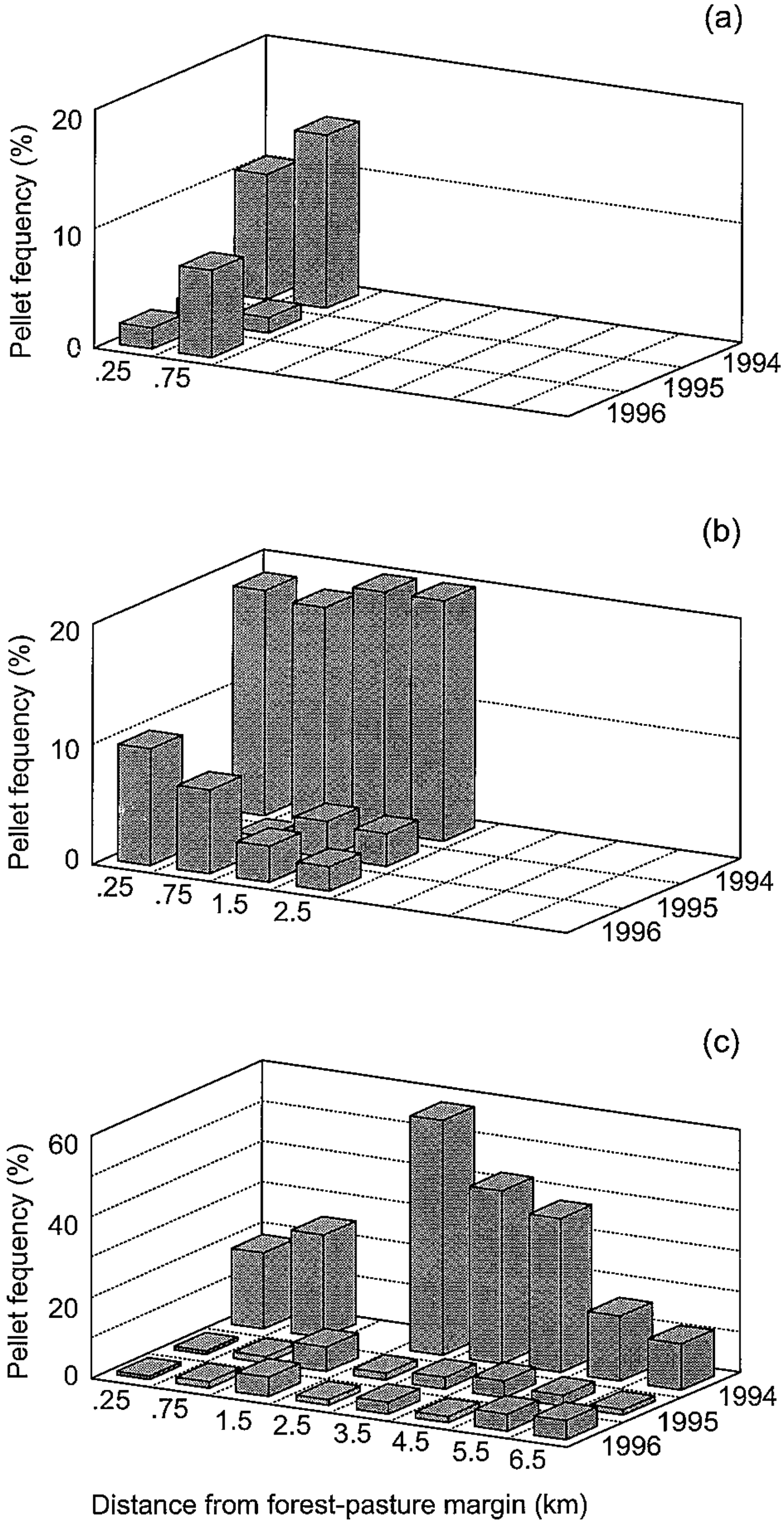

Fig. 3 Faecal-pellet frequency for possums in the (a) 1-km, (b) 3-km, and (c) 7-km buffers with increasing distance from the forest-pasture margin over the period 1994–1996.

We cannot easily explain the disparity between the moderately high trap-catch recorded on the three DoC lines (which are more than 1 km from the forest-pasture margin) and the low faecal-pellet counts recorded within the 3-km buffer (including low indices for each of the transects nearest the individual trap lines). The three DoC trap lines cover an area of only about 600 ha whereas the pellet counts represent the 8000-ha 3-km buffer as a whole. The high trap-catch on these three trap lines may therefore simply represent a small patch missed by the pellet counts where either initial control was not as effective as the overall average or where possums have for some reason reinvaded quickly. One of the trap lines is immediately adjacent to the unpoisoned area (Fig. 1), and all three are close to a patch of well-roaded exotic forest within the native forest.

Deer

Between 1995 and 1996 the index of deer abundance (pellet-group density) increased by 77% in the 1-km buffer and by 55% in the 7-km buffer, but only the latter result was significant ($t_{1\text{-tailed}}$=1.88, $p<0.05$; Fig. 4). Despite the greater change in the index for the 1-km buffer, high between-transect variance in deer density contributed to a non-significant result ($t_{1\text{-tailed}}$=1.32, $p=0.21$). There was no change in the index of deer abundance in the 3-km buffer (Fig. 4), which may be because recreational hunting pressure there has not declined as markedly as in the 7-km buffer. As with the 1994 post-control and 1995 estimates, 95% confidence limits around our 1996 deer density indices were wide, reflecting the lower densities of deer relative to possums and their greater degree of aggregation.

Indices of recreational hunting success (deer seen/day, deer killed/day) for the three hunting blocks that were poisoned (either partially or completely) in winter 1994 remained lower than pre-control levels. However, in two of the blocks (Ongarue and Waihaha) the sighting rate for the 1995/96 year was higher than in the 1994/95 year immediately after the control operation.

The reported number of hours hunted in Pureora Conservation Park has declined by >50% since the 1994 control operation because fewer permits are being issued and fewer hunters are returning their hunter diaries. Rather than examining in detail the trends in individual hunting blocks, we compared all the sighting and kill rate information for those parts of the Park where there was no poisoning with the data for blocks that were poisoned (Table 2). Elsewhere in Pureora Conservation Park (i.e., outside the control operation area), sighting rates and kill rates were similar before and after the control operation. However, for the three blocks that were either partially or completely poisoned the sighting rate has declined by c. 45% and the kill rate by c. 40% compared with pre-control levels. This result further supports the conclusion that the poisoning operation substantially reduced deer densities in the 3-km and 7-km buffers.

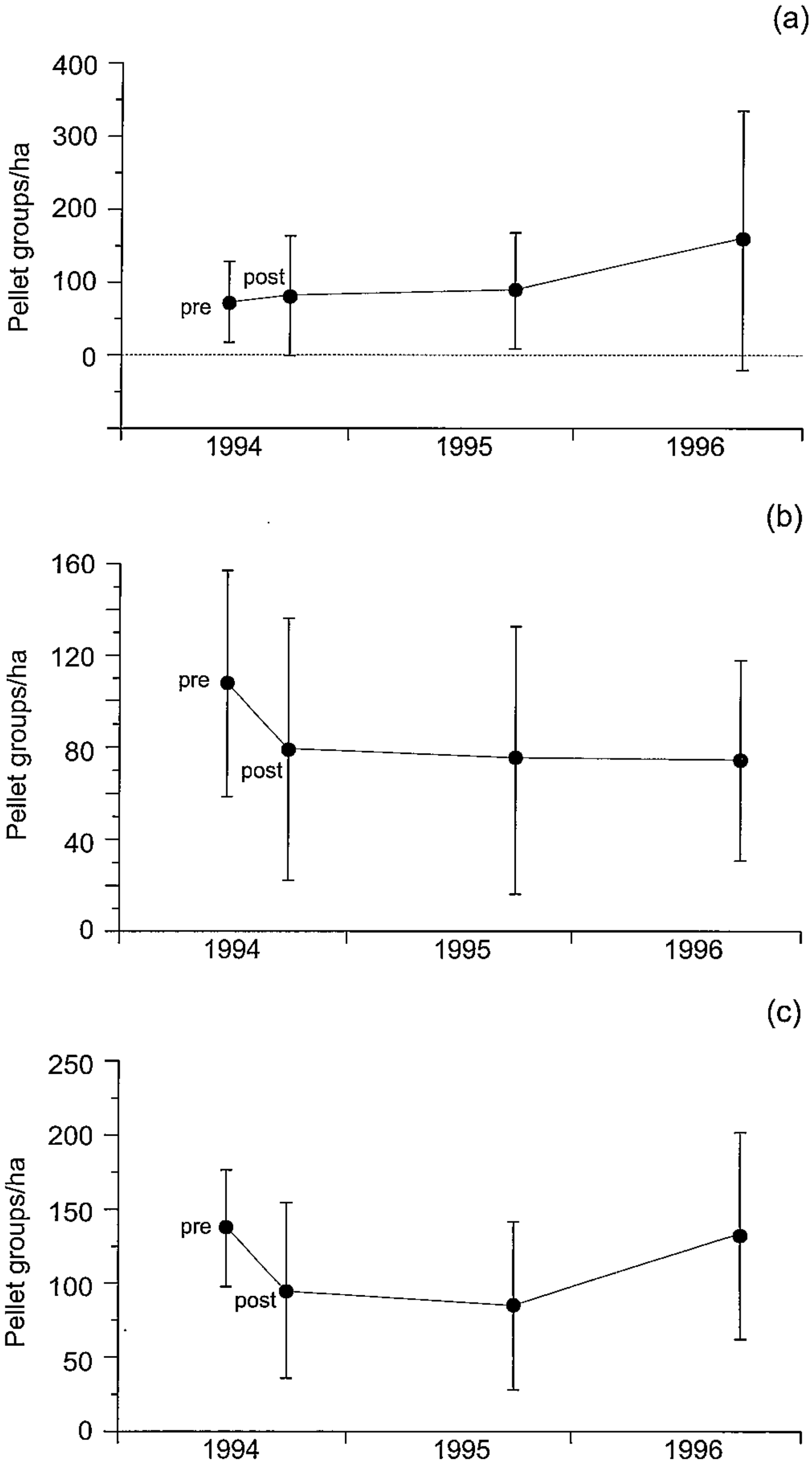

Fig. 4 Deer faecal-pellet group density (±95% confidence limits) for 1994 - 1996 for the (a) 1-km, (b) 3-km, and (c) 7-km buffers.

Table 2. Comparison of deer sighting and kill rates in Pureora Conservation Park before and after the 1994 control operation for poisoned and unpoisoned hunting blocks.

	Deer seen/day		Deer killed/day	
	1992-94	1994-96	1992-94	1994-96
Not poisoned	0.42	0.35	0.13	0.13
Poisoned	0.59	0.33	0.17	0.10

6.2 Tb prevalence

Cattle

Between c. 15 700 and 24 700 cattle on farms immediately adjacent to the 1-, 3-, and 7-km buffers were tested each year for Tb. The number of lesioned cattle (reactors and culls) varied between areas, with the lowest Tb incidences for 1996/97 being on farms adjacent to the 7-km buffer and the highest from farms near the 3-km buffer (Table 3).

Table 3. The percentage of Tb cattle (lesioned reactors plus culls) in herds immediately adjacent to the buffers (data from J. Adams, MAF, pers. comm.). Results for herds adjacent to the 7-km buffer are split into those in the areas subjected to once- and twice-annual maintenance control of possums.

Year	Cattle tested	1-km buffer	3-km buffer	7-km buffer Once annual	7-km buffer Twice annual	Total all areas
90/91	15706	0.60	2.25	0.48	1.30	1.65
91/92	18922	0.26	3.62	0.77	0.71	2.06
92/93	23276	0.93	2.43	0.73	0.96	1.72
93/94	19665	0.94	1.64	0.45	0.52	1.22
94/95	24727	0.67	0.97	0.78	0.27	0.77
95/96	20948	0.23	0.60	0.06	0.15	0.35

For all areas combined, Tb incidence rates decreased from 1.22% - 2.06% in the 4 years before the 1994 poison operation to just 0.35% in 1995/96. However, the temporal patterns in the incidence of lesioned cattle within each area differed markedly. In that part of the 7-km buffer with once-annual maintenance control, uniformly high annual incidences before 1995 are followed by a very low value in 1995/96 (Fig. 5a), providing convincing evidence that the 1994 poison operation has affected the incidence of Tb in cattle. In contrast, the results from the 3-km buffer (Fig. 5b) and that part of the 7-km buffer subjected to twice annual control (Fig. 5c) suggest that Tb incidence rates may already have been declining prior to the 1994 poison operation. For the 1-km buffer, the results are ambiguous (Fig. 5d).

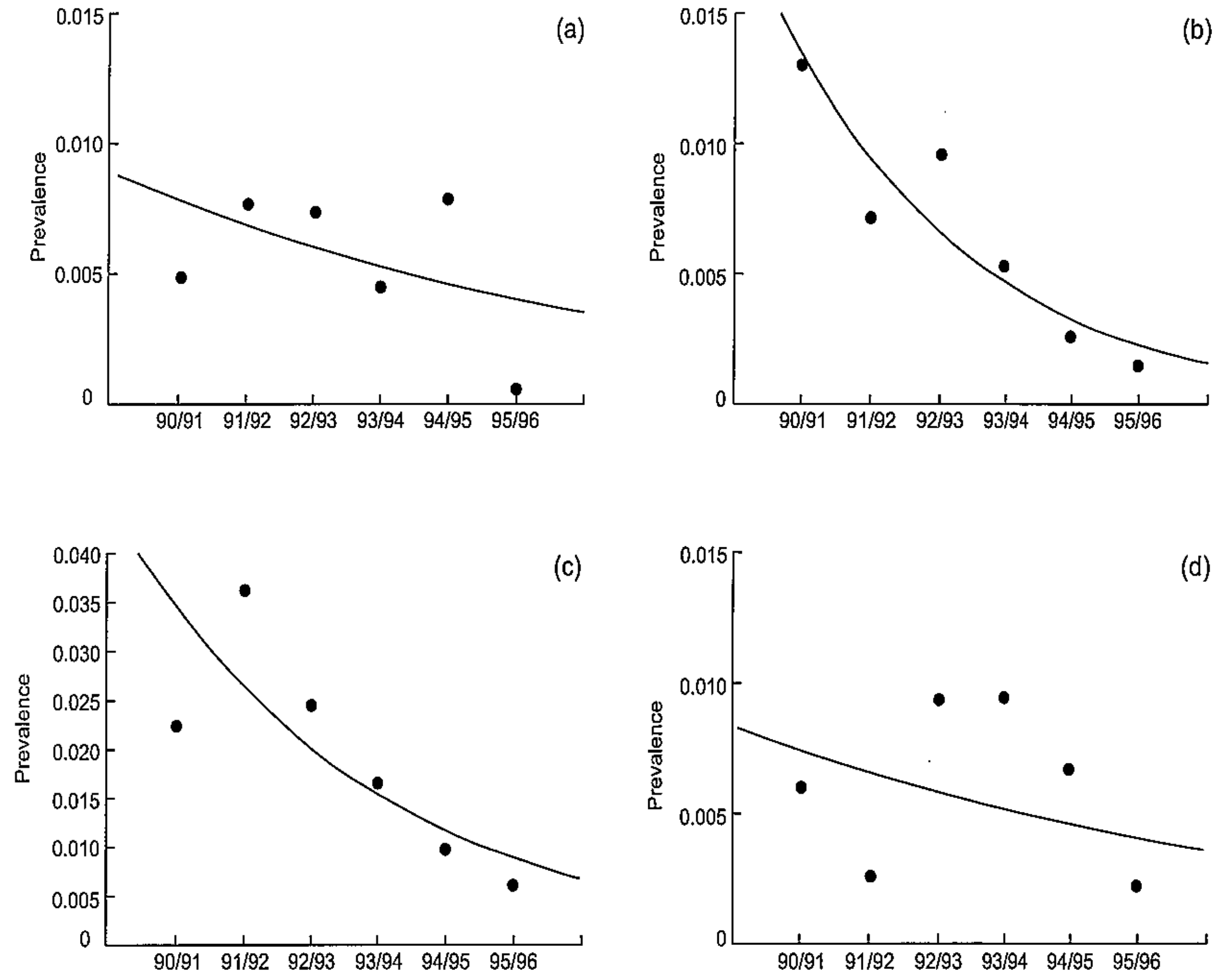

Fig. 5 The incidence of lesioned (reactor and cull) cattle from herds adjacent to (a) the part of the 7-km buffer subject to once-annual maintenance control of possums, (b) the part of the 7-km buffer subject to twice-annual maintenance control, (c) the 3-km buffer, and (d) the 1-km buffer. The fitted line is a regression based on a binomial sampling model.

Possums

Two of 89 possums taken from trap lines in the 3-km buffer had very large "cheesy" lesions typical of Tb, and both cases were confirmed at culture. Both animals came from the same trap line and were trapped c. 150 m apart. One was a juvenile male with large (>1.0 cm) discharging lesions in both its deep and superficial left axillary lymph nodes, a large (>1.5 cm) lesion in its spleen, and numerous small (<0.5 cm) lesions in its lungs and liver. The other was an adult male with a very large (c. 6.0 cm) lesion in a mesenteric lymph node and a large (c. 2.0 cm) pus-filled lesion in the retropharyngeal/mandibular nodal complex. The possums trapped on these trap lines in 1994 were not necropsied, so there is no previous data on Tb prevalence to compare the 1996 data with.

None of the 29 possums trapped on the edge of the 7-km buffer or associated Lakeside Reserves, and none of the 16 possums taken on cyanide lines within the 7-km buffer had Tb lesions. This result is similar to that obtained in both of the earlier surveys (0/13 in 1994, 0/31 in 1995) conducted since the initial control. However an infected possum was found within the 7-km buffer in December 1996. It was one of 96 possums collected since winter 1995 from an 800 ha area in the upper reaches of the Waihaha catchment about 3 km west of the forest-pasture margin. They were collected as part of a concurrent but independent study of possum diet.

None of the non target species necropsied had Tb-like lesions.

Deer

Of the 31 deer shot (20 males and 11 females), lesions typical of Tb were identified in six, and one further deer had a lesion thought to be Tb. All seven of these lesioned deer proved to be culture positive, and culture of pooled tonsils and retropharyngeal lymph nodes revealed one other infected deer that had no visible lesions. Overall prevalence of Tb in the deer was therefore 26%, with a similar increase in prevalence with increasing age to that noted in both the 1993/94 and 1995 samples (Table 4).

Table 4 Tb prevalence in deer in the Hauhungaroa Range, by sex and age class for the 1993/94, 1995, and 1996/97 samples. The 1995 sample was split between those obtained from the 7-km buffer and those from the central unpoisoned area. The 1993/94 sample includes 13 deer necropsied by Environment Waikato in 1993 for which no culture was undertaken, so prevalences for that sample are likely to be conservative (Fraser *et al.* 1995).

	Percentage of deer infected (sample sizes in brackets)			
Age-sex class	1993/94 pre-control	1995 unpoisoned	1995 poisoned	1996/97 poisoned
Fawn (<1 year)				
Male	0 (6)	0 (1)	0 (3)	20 (5)
Female	0 (4)	(0)	0 (2)	0 (2)
Both sexes	0 (10)	0 (1)	0 (5)	14 (7)
Sub adult (1-2 years)				
Male	41 (17)	66 (3)	0 (4)	24 (12)
Female	33 (6)	0 (2)	(0)	0 (2)
Both sexes	39 (23)	40 (5)	0 (4)	21 (14)
Adult (>2 years)				
Male	46 (13)	(0)	60 (5)	66 (3)
Female	47 (19)	50 (2)	100 (2)	29 (7)
Both sexes	47 (32)	50 (2)	71 (7)	40 (10)
Totals for all age classes				
Male	36 (36)	50 (4)	25 (12)	30 (20)
Female	38 (29)	25 (4)	50 (4)	18 (11)
Both sexes	37 (65)	37 (8)	31 (16)	26 (31)

The infected deer were:

- A c. 1-year-old male fawn, shot c. 0.8 km east of the Hauhungaroa Range crest, with a 0.3-cm caseous lesion in an ileojejunal lymph node;
- A 2-year-old male, shot c. 0.1 km east of the Range crest, with a 3.0-cm caseous lesion in a bronchial lymph node and a 1.0-cm caseous lesion in the lungs;
- Two 2-year-old males, shot together c. 1.7 km east of the Range crest, one with a 0.3-cm caseous lesion in a retropharyngeal lymph node, and the other with a 0.1-cm caseous lesion in a retropharyngeal lymph node and a 0.3-cm caseous lesion on a tonsil;
- A 3-year-old female, shot c. 1.9 km east of the Range crest, with no visible lesions;
- A 5-year-old male, shot c. 5.9 km east of the Range crest, with an active 2.0-cm lesion in a retropharyngeal lymph node;
- A 7-year-old female, shot c. 2.0 km east of the Range crest, with an active 2.0-cm caseous lesion in an ileocaecal lymph node;
- A 9-year-old male, shot c. 0.5 km east of the Range crest, with multiple large lesions (up to 5.0-cm) in the ileocaecal, ileojejunal, hepatic, and popliteal lymph nodes, and on the liver.

All four infected deer born since the control operation (the first three bullet points above) were males. They were all shot within c. 1.7 km of the unpoisoned area, and three of them had only one or two very small lesions. In contrast, the four infected deer born before the poison operation included some females, were not clustered near the unpoisoned area, and had relatively large (>2.0 cm) lesions (except for the female with no visible lesions).

In 1996/97, just under half the deer were shot within 2 km of the Range crest (i.e., the area not poisoned in winter 1994), and the remainder further east. A greater percentage of those shot within 2 km of the unpoisoned area were infected (Table 5).

While prevalence appears to be declining, the overall difference between the three annual samples (Table 4) is not statistically significant. However, excluding any deer shot within 2 km of the unpoisoned area, the 13% (n = 23) prevalence in the combined 1995 and 1996/97 samples from the 7-km buffer is significantly lower than the 37% prevalence in the 73 deer shot in unpoisoned areas in 1993/94 or 1995 (Fisher's Exact test, p = 0.031).

Table 5. Sample sizes and percentages of Tb-infected deer shot in 1996/97 in two "distance-from-unpoisoned area" classes, split into deer born before and after the winter 1994 poisoning operation.

	Deer shot <2 km from the Range crest[1]		Deer shot >2 km from the Range crest[1]	
	No. of deer	% infected	No. of deer	% infected
Born before poisoning	3	100	6	17
Born after poisoning	12	33	10	0
Total	15	47	16	6

[1] i.e., the margin of the central area not poisoned in winter 1994.

Pigs

Although not specifically targeted, 20 pigs were encountered and shot in 1996/97, compared with none in 1995 and 5 (4 infected) shot in 1993/94. All of the pigs shot in 1996/97 were less than 2.2 years old and had therefore all been born after the poison operation. Thirteen pigs had lesions typical of Tb, all of which proved to be culture positive. Another pig with a prescapular lesion classed as equivocal proved to be culture negative. None of the pigs with no visible lesions were found to be infected. The overall prevalence of Tb in pigs was therefore 65%.

The submaxillary lymph nodes had been destroyed by a bullet in one of the infected pigs, but these nodes were infected in all 12 of the remainder, usually with multiple granulomas of 1.0-5.0 cm diameter. Other nodes or tissues were sometimes also lesioned. These included the prescapular nodes in one pig, the subiliac, ileojejunal, and ileocaecal nodes in a second, the parotid nodes and lungs in a third, the parotid node in a fourth, and the parotid and bronchial nodes, and lung and liver in a fifth.

All three of the 2-year-old pigs shot were infected, as were three (42%) of the seven 1-year-old pigs, and seven (70%) of the 10 pigs <1 year old. Three of four pigs <6 months old were infected. All but four of the pigs were shot >2 km east of the Range crest, mostly in the upper Waihaha catchment furthest from the unpoisoned central area of the Range.

The high prevalence of Tb in pigs, particularly in those born as recently as spring 1996, is puzzling. Transmission between live pigs is thought to be low because Tb declined naturally in an Australian pig population after sympatric infected cattle and buffalo were removed (Nugent *et al.* 1995), so the most plausible explanation is that high prevalence results from pigs scavenging from the carcasses of infected animals (possums and/or deer and/or pigs). We have only found one Tb-infected possum among 186 possums killed within or near the 7-km buffer since 1994 so it is unlikely that the young pigs shot would have eaten enough possums during their brief lives for most of them to have encountered one with Tb. In contrast, deer densities in the 7-km buffer are similar to pre-poison levels, and over a quarter of them are infected, so natural or Tb-induced mortality and hunter kills would still provide a supply of potentially infective whole or part carcasses that could account for the high prevalence observed, particularly if all or most of family groups of pigs can be simultaneously infected by feeding on the same grossly infected deer carcass. An alternative explanation is that pigs have large home ranges that include unpoisoned areas with infected possums. However, McIlroy (1989) reports home ranges of only a few hundred hectares for pigs in native forest and scrub near Murchison in the South Island.

7. Conclusions

Population recovery

Just over 2 years after poisoning, within-forest possum densities in the 3- and 7-km buffers remain low. In the 1-km buffer, however, the possum population is recovering rapidly and may already exceed 40% of its pre-control density. If the pre-control density is presumed to have been close to carrying capacity, the 1-km buffer is above the threshold identified by Barlow (1991) for elimination of Tb from possums.

For the 1-km and 7-km buffers, the apparently faster recovery of the possum populations at the back (deep forest) margin of the buffers suggests some immigration of possums from unpoisoned areas. For the 3-km buffer the recovery near the forest-pasture margin is faster than at the back margins. When combined with the higher 1995/96 incidence of Tb in cattle on farms adjacent to the 3-km buffer and the moderately high trap-catch rates recorded on the Regional Council trap lines close to that margin, this suggests less effective initial and/or maintenance control of the possum populations on the farms adjacent to it.

The low trap-catch rate of possums (3.6%) recorded along the eastern forest margins indicates that ongoing maintenance control there is keeping on-farm populations at low levels. There is, as yet, no evidence that bi-annual maintenance control produces lower possum densities or Tb incidences in cattle than does annual maintenance control.

Deer densities in the 7-km buffer have increased. However, the wide confidence limits around our pellet count indices means we cannot as yet infer much about the rate of increase or be certain that densities have already returned to pre-control levels as is indicated by our indices.

Tb Prevalence

The 1994 poisoning operation appears to have helped reduce the incidence of Tb in cattle on the eastern side of the Range. Although it is possible that Tb incidence had already declined by 1994 in some of these eastern areas as a result of previous possum control efforts, the proportionately greater overall decline since 1994 suggests that the poison operation (and subsequent maintenance control) was a major factor in achieving the universally low incidence recorded on these farms in 1995/96.

The number of infected possums in the 1- and 7-km buffers is now very low. However, the single infected possum taken from the "middle" of the 7-km buffer in late 1996 proves that Tb can persist in a population for at least 2.5 years after a 92% reduction in overall density.

The weak evidence of a decline in the prevalence of Tb in deer in the Hauhungaroa Range matches the weak evidence of a similar decline in the prevalence of Tb in deer in the Umukarikari Range southeast of Turangi following aerial 1080 poisoning for possums and deer in winter 1994 (Nugent & Coleman 1997). The most likely explanation is that transmission from possums has declined since the poison operation.

The presence of Tb in four male deer shot within the western part of the 7-km buffer that had been born after possum numbers had been reduced is important because it appears to contradict our preceding conclusion that Tb is mainly transmitted to deer from possums. However, these deer may all have dispersed from the unpoisoned area after becoming infected, or, alternatively, come into contact with infected possums that had dispersed from the unpoisoned area. The east-west gradient in the prevalence of Tb in deer that appears to have been developing since 1994 (Tables 4, 5) provides evidence that deer do not move freely over the whole area, and suggests that most deer, and females in particular, have stable home ranges less than c. 3 km in diameter. This study may therefore be able to define the buffer widths needed to separate infected "deep forest" deer populations from farmland.

The high prevalence of Tb in pigs is likely to be mainly the result of scavenging infected deer carcasses. We predict the prevalence in pigs in the 7-km buffer will decline only if the prevalence in the deer there continues to decline.

8. Recommendations

- Because indices of possum densities in the 1-km buffer now exceed 40% of pre-control levels, particularly in the rear half of that buffer zone, further possum control should be undertaken there within 1-2 years.
- For the 3-km buffer, possum densities along the forest-pasture margin and on the adjacent farms should be assessed to determine whether the rapid recovery along that margin evident from our pellet counts reflects less effective possum control on those farms.
- Possum and deer population recovery should be monitored in all buffers in 1997, and in the 3- and 7-km buffers in 1998. The annual assessments of possum density and Tb prevalence along the eastern forest-pasture margin and the annual assessments of Tb prevalence in cattle, possums, deer and pigs should also be conducted as planned in both 1997 and 1998.
- The AHB should extend the survey of Tb prevalence in deer and pigs to include the central unpoisoned area, and, ideally, some other unpoisoned areas with deer, pigs, and Tb-infected possums present. When coupled with the related survey of Tb prevalence in deer in the Umukarikari Range, that would provide a rigorous experimental design for testing the various hypotheses outlined in section 7 about transmission between these species.

9. Acknowledgements

We thank the many people involved in the extensive faecal-pellet, trapping, and cyanide surveys, but particularly Hugh Fitzgerald and Phil Knightbridge for sharing much of the organisational workload. We thank Bill Curnow, Ben Dellow, Dion Patterson, Chris Cross, and Noel Hutchins for shooting and transporting deer and pigs, Adrian Julian and the other Animal Health Laboratory staff for performing the deer and pig necropsies, and John Adams for supplying the cattle-Tb data. We also thank Ian Coulter, Jack Kimberley, Doug Semmens, and Neville Sinton for providing accommodation and/or access through their properties. Richard Barker and Aaron McGlinchy provided statistical advice, Tom Pearson drafted the figures, Terry Fletcher and Megan Ogle-Mannering made constructive comments on the manuscript, and Wendy Weller completed the final word processing.

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11. Appendices

11.1 The number of possums and non-target animals trapped or poisoned in May 1996.

Line location	Line No.	No. of traps or cyanide baits	No. of trap or bait nights	No. of possum kills	No. of non-target kills
7-km cyanide	1	100	200	1	0
	2	100	200	1	0
	3	100	200	2	0
	4	100	200	2	0
	5	100	200	3	0
	6	100	200	1	0
	7	100	200	6	0
7-km margin	MO1.	65	195	2	10
	MO2	16	48	4	6
	MO3	19	57	1	1
	SI4	33	99	8	3
	CA5	44	132	2	12
	CA6	25	75	5	4
Lakeside	WA7	20	60	0	1
	MO8	24	72	4	6
	MO9	24	72	1	8
	S10	19	57	1	7
	S11	19	57	1	7
3-km buffer	RC1	50	150	23	6
	RC2	22	66	13	3
	RC3	24	72	15*	2
	DOC1	32	94	14	4
	DOC2	32	96	11	2
	DOC3	33	65	13	2
Totals				**134**	**92**

* includes two infected with Tb