Effects of Ferret Control on Cattle Reactor Incidence, Ferret Tb Prevalence, and Rabbit Numbers — The North Canterbury Ferret Control Trials

Final Report

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1. Summary

1.1 Project and Client

With the help of the Canterbury Regional Council, MAF Quality Management (now AgriQuality New Zealand), researchers from Lincoln and Canterbury Universities, and local farmers, Landcare Research evaluated the effects of controlling feral ferrets (*Mustela furo*) on levels of bovine tuberculosis (*Mycobacterium bovis,* Tb) in cattle and ferrets and on the rate of increase of rabbits in North Canterbury for the Animal Health Board (Project R10407). This report presents the final results from the study, which started in December 1994 and finished in May 1998. Previous progress reports are listed in Appendix 12.1.

1.2 Objectives

- To assess annual changes in ferret abundance resulting from ferret control.
- To assess annual changes in Tb prevalence in ferrets resulting from ferret control.
- To assess annual changes in the incidence of Tb in cattle resulting from ferret control.
- To measure the effect of controlling predators on the rate of increase of the local rabbit populations.

1.3 Results

- There has been a significant 40–50% mean decrease in the incidence of Tb in cattle as a result of ferret control, supporting the hypothesis that ferrets transmit Tb to cattle.
- Leg-hold trapping at the Scargill Valley and Tiromoana/Mt Cass sites in North Canterbury during 1994–1998 removed 779 and 757 ferrets, respectively. Additional direct and indirect control of ferrets was undertaken each year at both sites by farmers using leg-hold traps and poisoning rabbits.
- Trapping reduced the abundance of ferrets by an average of 60% at the Scargill Valley. However, no reduction in ferret abundance was achieved at the Tiromoana/Mt Cass site.
- Tuberculous ferrets were caught at both sites in each year from 1994–1998. The age-specific prevalence of macroscopic lesions attributed to *M. bovis* infection in ferrets did not change as a result of ferret control. However, the absolute prevalence of gross macroscopic *M. bovis* infection in ferrets decreased as a result of trapping reducing the age-structure of the population. This result, combined with the reduction in ferret abundance, produced a significant reduction in the abundance of tuberculous ferrets. Ferrets from the Scargill Valley site had a higher mean prevalence of tuberculous lesions (11.5% during May trapping sessions) than those from the Tiromoana/Mt Cass site (2.9% during May trapping sessions).

- Possums were present in significant numbers in the Scargill Valley site, though numbers decreased after the study began, probably because of broadscale rabbit control using aerially-sown and/or furrow-sown 1080 carrot bait. Within suitable habitat in the Scargill Valley site, the possum Residual Trap Catch (RTC) averaged 13.1% at the end of the study. Possums were much less abundant at the Tiromoana/Mt Cass site, because most of this site was subjected to annual possum maintenance control. Within suitable possum habitat in the Tiromoana/Mt Cass site, the RTC averaged 3.6%.
- Conditions during 1995/96 and 1996/97 were ideal for rabbit reproduction and survival. Uncontrolled rabbit populations along Reeces Road increased significantly by 30-fold from October 1995 to April 1997. This increase occurred on two farms, one subject to predator control, and the other not. There was no difference in the rate of increase of rabbit numbers with and without predator control.
- Rabbit haemorrhagic disease virus infection spread into the rabbit populations at Tiromoana/Mt Cass, Scargill Valley and Reeces Road during August/September 1997, causing moderate (35–58%) reductions in rabbit abundance at all sites.

1.4 Conclusions

- The results support the hypothesis that tuberculous ferrets are transmitting Tb to cattle.
- Leg-hold trapping at the intensity used in this study is not an effective method to achieve lasting control of ferret populations, and even in the short-term provides only moderate (0–30%) levels of control.
- Moderate control of ferret populations reduces the absolute prevalence of grossly tuberculous ferrets by lowering the age structure of the population, and in so doing lowers the abundance of grossly tuberculous ferrets. It does not, however, reduce the age-specific prevalence of *M. bovis* infection in ferret populations, suggesting that continued transmission of *M. bovis* infection to ferrets is independent of ferret density for the range of densities studied.
- Upsurges in rabbit numbers appear independent of whether predator populations are controlled under the conditions encountered in this study. Conditions during 1995/96 and 1996/97 were ideal for rabbit reproduction and survival, resulting in orders of magnitude increases in rabbit abundance even in the absence of predator control. Predators were unable to prevent this upsurge in rabbit abundance.

1.5 Recommendations

- Alternative methods should be developed for controlling feral ferrets.
- Inference from surveys of ferret populations for *M. bovis* infection should account for the age structure of the sample.
- Control of ferret populations should be regarded as a short term tactic for reducing the incidence of *M. bovis* infection in cattle.
- Research should be undertaken to determine the underlying source of *M. bovis* infection in ferret populations.

2. Introduction

The effects of controlling feral ferrets (*Mustela furo*) on levels of bovine tuberculosis (*Mycobacterium bovis,* Tb) in cattle and ferrets and on the rate of increase of rabbits in North Canterbury were evaluated by Landcare Research for the Animal Health Board (Project R10407), with the help of the Canterbury Regional Council, MAF Quality Management (now AgriQuality New Zealand), researchers from Lincoln and Canterbury Universities, and local farmers. This report presents the final results from the study, which started in December 1994 and finished in May 1998. Previous progress reports are listed in Appendix 12.1.

3. Background

Wildlife other than possums may transmit Tb to domestic livestock (cattle and deer) in New Zealand. Feral ferrets (*Mustela furo*) infected with Tb have been found in many parts of New Zealand, often in conjunction with Tb infection in livestock (de Lisle *et al.* 1993; Walker *et al.* 1993; Cowan 1994; Ragg *et al.* 1995a; Caley 1998). In semiarid areas, where possum abundance is thought to be low and ferret abundance high, many farmers, livestock officers, and veterinarians consider it likely that ferrets are acting as a wildlife reservoir of the disease and transmitting Tb to cattle. A plausible mechanism for transmission of Tb from ferrets to domestic livestock has been described, whereby inquisitive cattle closely investigate moribund tuberculous ferrets (Sauter & Morris 1995). However, tuberculous possums have usually been found at the same sites as tuberculous ferrets (de Lisle *et al.* 1993). In order that sound management decisions can be made, there is a need to clarify whether ferrets are (i) maintenance hosts of *M. bovis*, and (ii) transmitting *M. bovis* to domestic livestock. There is also a need to determine whether controlling ferrets affects the rate of increase of rabbit populations, to ensure that management of one problem does not exacerbate another.

This report presents the final results of a 4-year study of a Tb-endemic area. By manipulating and monitoring changes in ferret abundance, and assessing subsequent changes in the prevalence of tuberculosis in ferrets, the yearly incidence of Tb in cattle, and rate of increase of rabbit populations, the study aimed to determine whether ferrets are transmitting Tb to cattle and/or limiting rabbit numbers.

4. Objectives

- To assess annual changes in ferret abundance resulting from ferret control.
- To assess annual changes in Tb prevalence in ferrets resulting from ferret control.
- To assess annual changes in the incidence of Tb in cattle resulting from ferret control.
- To measure the effect of controlling predators on the rate of increase of local rabbit populations.

5. Methods

5.1 Study areas

The study was carried out at three sites in North Canterbury: Scargill Valley (172°57'E, 42°56'S), Tiromoana/Mt Cass (172°53'E, 43°05'S), and Reeces Road (172°55'E, 43°03'S)(Figure 1). At Scargill Valley and Tiromoana/Mt Cass, ferret populations were subject to control, starting in Nov/Dec 1994. The Scargill Valley site (3672 ha) was selected because five contiguous cattle herds — 'core properties' — had become infected with Tb originating from a wildlife source in 1992/93 or 1993/94. Possum densities were considered to be low and possums therefore not to be the cause of the herd breakdowns. Tuberculous ferrets were detected at the site following the herd breakdowns. The Tiromoana/Mt Cass site (2596 ha), with two 'core properties', was chosen because a cattle herd at that site had an ongoing Tb problem which had not improved despite limited possum control. Before 1994, a tuberculous feral cat (*Felis catus*) was the only wildlife host from which *M. bovis* had been isolated at this site. Intensive possum control was begun by the Canterbury Regional Council at the Tiromoana/Mt Cass site during the winter of 1993, using a combination of aerially-sown 1080 carrot bait and 1080 jam in bait stations. Possum maintenance control using poison-bait stations has continued since, except on an area (Wash Creek) of one of the properties. This area was subject to initial possum control during 1993, but maintenance control was last carried out in December 1994.

The Reeces Road site consists of two separate farms, one chosen as a non-treatment site to monitor natural fluctuations in ferret and rabbit abundance, and the second chosen for a detailed investigation of the effect of experimentally removing predators on the rate of increase of rabbits.

Ideally, sites where tuberculous ferrets were present, but left uncontrolled, would have been used as an experimental non-treatment area. However, during the projects development, members of the North Canterbury Regional Animal Health Committee were adamant that leaving any Tb-infected ferret population uncontrolled was unacceptable, so this avenue was not pursued.

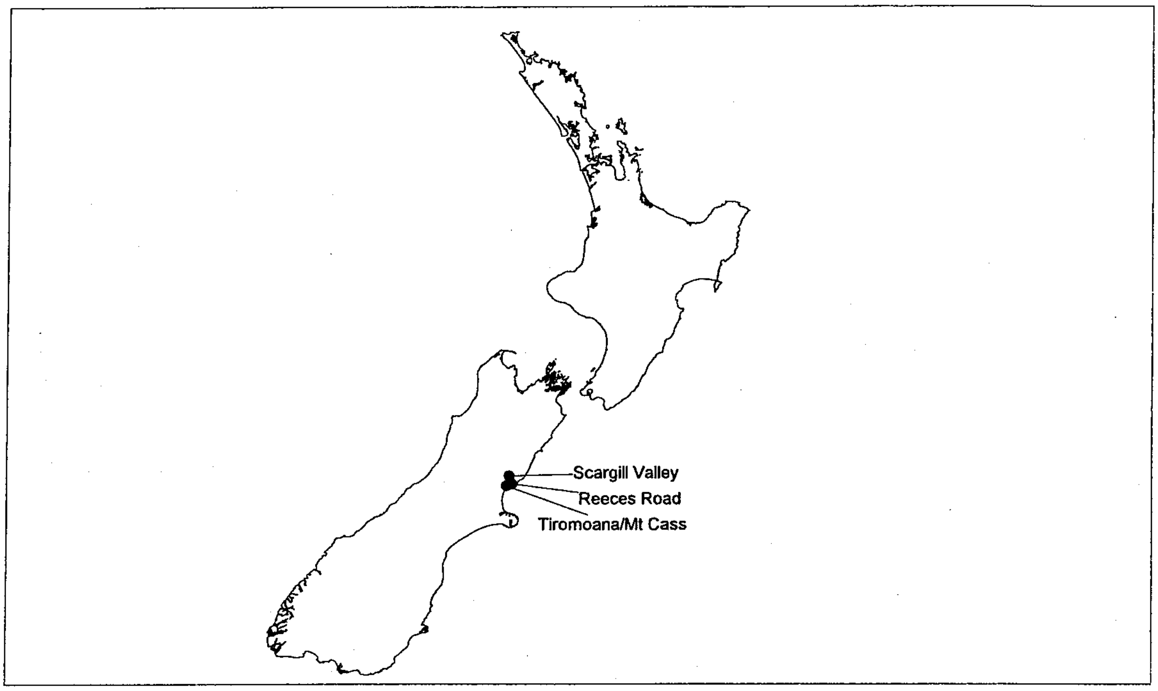

Figure 1. Location of study sites.

5.2 Population monitoring

Ferrets and cats

Standard predator trapping techniques were used to catch ferrets and feral cats. At the Scargill Valley and Tiromoana/Mt Cass sites, Victor Soft-Catch® leg-hold traps (size 1½) baited with fresh rabbit meat were set at 100–200 m intervals usually over 5–10 nights and checked daily. Animals were humanely killed at the trap site where they were captured. Bait was replaced as needed. Traps were set in all suitable habitats likely to be frequented by ferrets, such as gullies and areas with sign of high rabbit numbers. Additional traps were set on farms adjoining the core properties, to create a buffer area that would reduce immigration of ferrets. Traps were also made available to farmers to undertake their own ferret control. Some ferrets and cats were presumably killed through secondary poisoning by farmers undertaking rabbit poisoning at both sites.

Trapping was carried out on 11 occasions (November/December 1994, May 1995, August 1995, December 1995, February–May 1996, July 1996, November/December 1996, February 1997, May 1997, February 1998 and May 1998). Access to the study sites was restricted during the spring lambing period (late August to October), so trapping was not undertaken then. At the Reeces Road sites before predator control, wire cage traps were used and all animals captured were ear-tagged and released. Control of ferrets and cats on one of the two Reeces Road properties was started in April 1996 using both cage traps and leg-hold traps.

For each trapping session the abundance of ferrets and cats was estimated from the trapping success. The number of available trap nights was adjusted for the number of sprung traps and non-target species caught as recommended by Nelson & Clark (1973). Trap success was expressed as the number of animals caught per one hundred available trap-nights. As trap-lines were set for variable lengths of time, only the first 5 nights' data were used to provide standardised trap-catch indices for analysis. For comparison of ferret abundance between years, the trap-catch index from the trapping during May in each year was used. This enabled year-to-year variation in ferret abundance to be separated from the large seasonal fluctuations in ferret abundance.

Ferrets were initially classified as adult or juvenile by the size and the presence or absence of a sagittal crest on the cranium. Adult females were identified either from signs of current or previous lactation, and/or uterine signs of previous or current pregnancy. Using these criteria, adult and juvenile males could readily be discriminated during November to February, but not during March to October. Most adult and juvenile females could readily be discriminated during November to May, but not during June to October. Consequently, adult females that failed to breed will have been mistakenly classified as juveniles. A random sample of ferrets from each year was more accurately aged to the nearest year by sectioning and staining canine teeth and counting the number of cementum layers (Grue & Jensen 1979). The age of each animal was then calculated to the nearest month, from the date of capture and seasonality of breeding, with all ferrets assumed to have been born on 30 October. This date was set by estimating the median birth date of juveniles caught during February trapping sessions, using the growth curve for captive European ferrets (*Mustela putorius*) presented by Shump & Shump (1978).

The frequency of females breeding twice in the one year (double breeding) was calculated by examination for signs of pregnancy at necropsy of female ferrets captured outside the September–November period.

Complete details of all trapping sessions are presented in Appendix 12.1

Possums

Numbers of possums incidentally caught in traps set for ferrets provided an index of their abundance. As for ferrets, the index was calculated as the number of possums caught per 100 available trap-nights, based on the first 5 nights' trapping data. Possums caught at the Scargill Valley site were released in all trapping sessions, to avoid confounding the effects of ferret control on the incidence of Tb in cattle with possum control. Most possums caught at the Tiromoana/Mt Cass site after 1995 were killed and subjected to a standard necropsy looking for macroscopic lesions resembling Tb. The effect of rabbit control with aerially-sown carrot poisoned with 1080 (wt/wt concentration 0.018) on possum numbers was assessed during the winter of 1995 at the Scargill Valley site (see Section 5.5). Possums were also incidentally sighted during spotlight counts of rabbits (see below), providing a second index of abundance (possums sighted per kilometre of transect).

Standard residual trap-catch surveys of possum abundance following the guidelines of Warburton (1996) were undertaken at the Tiromoana/Mt Cass site during July 1996 (5 lines) and December 1997 (14 lines), and at Scargill Valley (12 lines) during February 1998 using leg-hold traps. Surveys followed the standard format of 20 m spacing between traps, lured with flour and icing sugar, over 3 fine nights. Trap lines were randomly placed within possum habitat (stratified random sampling). This was achieved by drawing all potential trap-lines of 20 traps on a 1:50 000 topographic map, numbering them, and randomly selecting a sub-sample for survey.

Rabbits

Rabbit abundance at each site was measured at 6-monthly intervals using spotlight counts on permanently marked transects by experienced staff of the Canterbury Regional Council. Observers riding motorcyles/quadbikes counted all rabbits seen in a strip transect illuminated using a 55–100w spotlight. The speed of travel was varied to enable all rabbits to be counted, and typically averaged about 6 kmph over the length of a transect. Rabbit counts were carried out on three properties at the Scargill Valley site (transect lengths 22, 12, and 13 km), two at Tiromoana/Mt Cass (transect lengths 20 and 12 km), and two at Reeces Road (transect lengths 12 and 20 km). As the properties at Scargill Valley and Tiromoana/Mt Cass are regularly subject to rabbit control, it was impossible to identify the effect of predator control on rabbit populations. At the Reeces Road site, rabbit populations were not subject to control, and therefore the two farms provided an opportunity to measure the effect of removing predators on rabbit populations (see Section 5.4).

5.3 Prevalence and incidence of tuberculosis

Ferrets

A standard necropsy was undertaken examining all major superficial and internal lymph nodes and body organs for macroscopic lesions resembling tuberculosis. Samples of any lesions found were submitted for mycobacterial culture and/or histopathology for disease diagnosis. Pooled material from the retropharyngeal, jejunal, and respiratory lymph nodes was collected from a random sample of ferrets from each session during 1994 and 1995, regardless of visible disease status, and cultured for the presence of *M. bovis* at the Central Animal Health Laboratory, Wallaceville. Liver samples were collected from all ferrets caught in 1996 and 1997, and a random sub-sample of these from each year was submitted for histopathological examination. Animals were classified as tuberculous if microscopic hepatic granulomas were present (Lugton *et al.* 1997a). Pooled material from the retropharyngeal, jejunal and prescapular lymph nodes was collected from all ferrets caught during May 1998, and a random sub-sample of these submitted for mycobacterial culture.

Logistic regression (Ahlbom 1993) was used to test for an effect of ferret control or site on the prevalence of macroscopic *M. bovis* infection, after accounting for the effects of age and sex. Ferret control started in December 1994. However, it was not until May 1995 that significant numbers of animals were removed. Hence for the purposes of testing the effect of ferret control on the prevalence of macroscopic *M. bovis* infection, the treatment 'ferret control' was deemed to start after May 1995. To test differences in prevalence before and after ferret control, animals born before, but captured after, May 1995 were excluded from the analysis (as their lifetimes spanned the different treatments). The test thus compared the prevalence of macroscopic *M. bovis* infection between animals born and captured before May 1995, with those born and captured after May 1995. The natural logarithm of age (in months), rather than age was fitted as a covariate to the model, as this provided a much better fit to the data. Ferret control, site and sex were all specified as factors when fitted to the model.

Cats and stoats

All cats and stoats captured during the November/December 1994 trapping session at the Scargill Valley and Tiromoana/Mt Cass sites were submitted for a standard necropsy as for ferrets. Further necropsies were conducted on cats caught from these two sites during 1995 and 1996 but not thereafter. Pooled lymph nodes from a sub-sample of stoats captured during 1994/95 were collected and cultured as for ferrets.

Cattle

Throughout the study, all cattle herds at Scargill Valley (5), Tiromoana/Mt Cass (2), and Reeces Road (2) were subject to annual or part-yearly tests for Tb using an intradermal tuberculin test. Logistic regression was used to test for the effects of ferret control and possum control on the incidence of Tb in herds at Scargill Valley and Tiromoana/Mt Cass. The yearly incidence of Tb was calculated as the number of reactors plus any grossly lesioned animals detected during routine abattoir monitoring of culls, divided by the effective herd size for the year. As nonspecific reactivity to the tuberculin test had not been a problem for herds at either site, the specificity of the tuberculin testing data was considered very high. The explanatory variables 'ferret control' and 'possum control' were specified as factors, and fitted in a forward stepwise manner. The order in which variables were entered into the model was varied, to identify possible problems of collinearity between variables. The final significance of each variable was determined using the deletion test.

There are obvious problems in the interpretation of the herd testing data for the Tiromoana/Mt Cass herd, which had been grazing land at Wash Creek not subject to annual possum maintenance control since 1994, particularly as there are no possum trap-catch data from 1993 or 1994 (since Regional Council monitoring was done by spotlighting). We therefore restricted inference on the effect of possum control on the incidence of Tb in cattle to the period for which possum control was deemed to have been effective. During July 1996, the mean Residual Trap Catch (RTC) for lines within the area subjected to yearly maintenance control was 2.5% (95% C.I. 0.7 – 4.3%) compared with 11.8% for lines outside this area. This latter figure was too high to be considered 'effective' possum control for experimental purposes. Therefore, the 1995/96 herd testing year was the last year that the Tiromoana herd was considered to be subject to the treatment 'possum control'. Data for analysis included the Tiromoana herd up to and including 1995/96, then only the Mt Cass herd thereafter. This was less than ideal, as it reduced the number of animals in the experiment at the Tiromoana/Mt Cass site to about 300 from 1996/97 onwards, but is more experimentally sound.

The design and analysis were also weakened by the absence of an experimental control site (i.e. no control of tuberculous ferret populations). Retrospective efforts to locate areas where *M. bovis* infection occurred in ferrets, though ferret populations had been subjected to little or no control, proved fruitless.

5.4 Effect of predator control on rabbit populations

Two farms at the Reeces Road site were chosen for a detailed investigation of the effect of removing predators on rabbit numbers. From October 1995 to July 1997, predator (ferret and cat) numbers were monitored bimonthly in winter and monthly in summer by setting about 60 cage traps on two permanent trapping grids for a 6-night session. At the same time, rabbit numbers were monitored monthly on fixed 10 km spotlight transects. Predator removal began at the 'treatment' farm during April 1996 and finished in July 1997; all predators captured during this and subsequent sessions were removed. Conversely, at the 'non-treatment' farm, predator numbers were monitored, but no predators were removed. To provide more extensive monitoring of changes in rabbit abundance on both these farms, an additional spotlight transect was established on both farms and monitored monthly starting in October 1995 and finishing in July 1997. The method used was the same as that used on the Canterbury Regional Council transects, only a more powerful spotlight was used (150 W). The effect of predator control on the rate of increase of rabbits was examined using analysis of covariance. For analysis, monthly counts were transformed using natural logarithms. Explanatory variables fitted were treatment, time and the interaction between time and treatment. The interaction term in the analysis tested whether the slope of the relationship between the natural logarithm of rabbit abundance and time (the exponential rate of population increase) differed between property (= treatment).

5.5 Effect of rabbit control on possum numbers

Study area: The Top Block (approx. 365 ha) of Foxdown within the Scargill Valley site was selected for measurement of the effect of rabbit control on possum numbers during the 1996 winter. The land is hilly and presents a mixture of scrubby gullies (*Coprosma* spp., *Cytisus scoparius*), open tussock faces (*Chionochloa* spp.), rocky outcrops, streams, and banks of bracken fern (*Pteridium esculentum*). Cabbage trees (*Cordyline australis*), matagouri (*Discaria toumatou*), mānuka/kānuka scrub (*Leptospermum scoparium*, *Kunzea ericoides*), and bush lawyer (*Rubus* spp.) are the other dominant plants. The southern slopes of Mount Benger on the neighbouring property immediately to the north of the Scargill Valley site were selected as a non-treatment area because they were also south-facing, of similar terrain and habitat, and had not been poisoned for rabbits in recent years.

Rabbit poisoning: The Canterbury Regional Council began the 1080 rabbit poison drop on 17 June 1996, after two earlier nontoxic pre-feed drops. The bait consisted of non-lured carrot chunks coated with 1080 at an intended concentration of 0.02% wt:wt and dyed green (Bayer V200 dye) as a deterrent to birds. Pre-feed carrot used in the first two drops (late May and early June) was not dyed, and was therefore distinguishable from the toxic carrot. A standard analysis of the toxic bait was carried out by the Landcare Research toxicology laboratory.

Monitoring possum abundance: The impact of the rabbit control operation on possum numbers was assessed from changes in trap-catch indices and from the survival of radio-collared possums, before and after the poison drop.

Standard trapping techniques (but with larger than normal spacing between traps) were used to catch possums at the two study sites. Before the poison drop, eight 'treatment' trap-lines and five 'non-treatment' lines were established, each with 15 traps at spacings of 35–45 m. Trap lines in each area covered a variety of habitats suitable for possums. Victor Soft-Catch® leg-hold traps (size 1½), lured with flour containing aniseed oil, were set for three fine nights. Traps were checked daily. Non-target species caught were recorded and then released if unharmed, apart from rabbits and mustelids, which were killed. All sprung traps that had evidence of possum occupation (i.e., possum fur in the jaws) were counted as possum captures. Captured possums were weighed, ear-tagged, and then released. Possums were sexed and classified as adult or juvenile from testis size or pouch development.

After the poison drop and once bait toxicity became negligible, all original survey lines were re-trapped for 3–4 days, along with an additional eight trap lines in the treatment area and five in the non-treatment area.

For each trapping session before and after rabbit control, the abundance of possums was estimated from trapping success. The number of available trap nights was adjusted to account for the number of sprung traps and non-target captures. Trap success was expressed as the average number of possums caught per one hundred available trap-nights averaged over 3 nights of fine weather.

A mixture of old and young possums (n=26) were selected to be collared with radio-transmitters. Eighteen of these were located in the treatment area and eight were located in the non-treatment area. The greater number of radio-collars in the treatment area was necessary owing to the expected higher variation in survival in this area. Just before the poison drop, the location of the radio-collared possums in the treatment area was recorded to confirm that they were in the Top Block poison area. After the poison drop, the fate of these eighteen possums was determined, along with the eight in the non-treatment area, by locating them with hand-held Yagi directional aerials. Surviving possums were re-trapped until all radio-collared possums had been released without their radio-collars. Dead possums found in the study area after the poison drop were checked for 1080 carrot in the digestive tract.

Analysis: The effect of rabbit poisoning on mean numbers of possums caught per trap line was assessed using a two-way repeated measures analysis of variance, testing for a significant 'area' by 'time' interaction (Sokal & Rohlf 1981). The effect of rabbit poisoning on the proportion of radio-collared possums surviving was assessed using Fisher's Exact Test, and the percent kill was compared with that derived from trap-catch data. The effects of body-weight on the survival of radio-collared possums were investigated using a Mann Whitney U-test (Zar 1984).

5.6 Animal ethics

All work undertaken in this study was approved by the Landcare Research Animal Ethics Committee (AEC Project No: 95/7/3)

6. Results

6.1 Population monitoring

Ferrets

Abundance: Leg-hold trapping at the Scargill Valley and Tiromoana/Mt Cass sites removed 779 and 757 ferrets in 20760 and 17951 trap-nights respectively, between December 1994 and May 1998. This equates to an annual removal rate of about 5.3 ferrets km^{-2} from the Scargill Valley site and 7.3 ferrets km^{-2} from the Tiromoana/Mt Cass site. While farmers undertook additional leg-hold trapping at both sites, quantifying this trapping effort and the number of ferrets removed proved difficult. At the completion of ferret control in May 1998, ferret abundance was 77% lower at Scargill Valley and 57.7% lower at Tiromoana/Mt Cass compared with May 1995 (the first summer of trapping) (Fig. 2). The average reduction in ferret abundance for the period 1996–1998 compared with 1995 was 60% at the Scargill Valley site, but only 1% at the Tiromoana/Mt Cass site due to ferret abundance increasing at this site in the two years following the start of control.

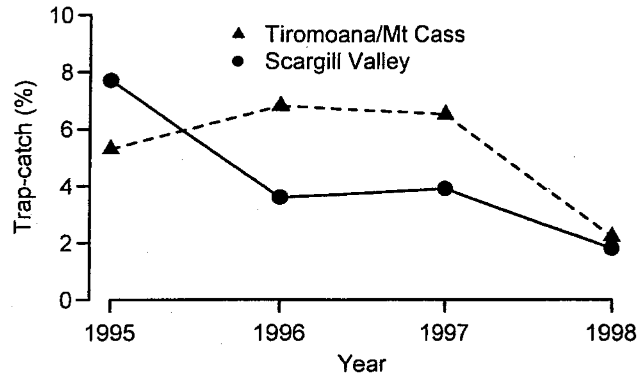

Figure 2. Trends in ferret abundance estimated by trap-catch indices calculated from the first 5 nights of trapping undertaken during May of each year. Estimates are corrected for non-target species captured and sprung traps.

Age structure: Aging using tooth cementum annuli was undertaken on 742 ferrets, which is 48% of the total number captured. The age structures of the ferrets (pooled across sites and years) captured in leg-hold traps during different seasons are shown in Table I. During December, the population contained roughly equal proportions of adults and the first juveniles born during the previous spring. By February the recruitment of juvenile animals was much more apparent, and they made up more than 90% of the sample (Table I). Juveniles clearly then undergo significant differential mortality (possibly because they are more trappable) compared with adults, as they make up progressively less of the sampled population as the year progresses (Table I). A proportion of juveniles undoubtedly die before reaching a trappable age, but as this proportion was not known, no attempt was made to use the standing age distribution to estimate life history parameters such as mortality rates.

Table I. The age structure of ferrets captured in leg-hold traps. Data presented are percentages; data in brackets are actual numbers. Data only includes animals randomly selected and aged by counting tooth cementum annuli.

	Age class (years)					
Season	0–1	1–2	2–3	3–4	4–5	Total
Late Spring (December)	51.2 (42)	41.4 (34)	7.3 (6)	0.0 (0)	0.0 (0)	100 (82)
Summer (Feb.)	93.0 (199)	4.7 (10)	2.3 (5)	0.0 (0)	0.0 (0)	100 (214)
Autumn (May)	88.9 (368)	7.7 (32)	2.7 (11)	0.5 (2)	0.2 (1)	100 (414)
Winter (July/Aug.)	46.9 (15)	46.9 (15)	3.1 (1)	3.1 (1)	0.0 (0)	100 (32)

Frequency of double breeding: Ferrets typically have a well-defined spring breeding season. However, of 796 females necropsied outside the period September-November, four were pregnant, all trapped in February. Three of the four cases occurred at the Tiromoana/Mt Cass site during February 1997 (3 of 80 females caught during this trapping session), a time when rabbit numbers were at unprecedented high levels. The mean litter size (in utero) was 6.25 (1, 4, 9, 11). The ferret with one foetus was a juvenile (as ascertained by cementum annuli), so represents precocious breeding. The remaining 3 ferrets have not yet been aged.

Possums

For ferret trapping undertaken during May, trap-catch indices of possums during the period 1996–1998 were 39% lower at Scargill Valley and 17% higher at Tiromoana/Mt Cass, when compared with 1995 (Fig. 3). The increase in mean catch rate at Tiromoana/Mt Cass was caused by a high catch rate during 1996 rather than a consistent increase in possum numbers. The reduction in the relative abundance of possums observed during 1996 and 1997 at the Scargill Valley site was most likely caused by mortality of possums arising from concerted efforts by farmers to control rabbits during the winters of 1995 and 1996 (see Section 6.5). Possum numbers at the Scargill Valley site appear to have recovered in 1998 following a reduction in the intensity of rabbit control in 1997. The mean Residual Trap Catch (RTC) of possums in the Scargill Valley site within possum habitat during February 1998 was 13.1%. Over the period 1995–1998, the mean number of possums counted during rabbit spotlight surveys was 0.05 per km at the Scargill Valley site, 0.07 per km at the Tiromoana/Mt Cass site, and 1.9 possums per km at the Reeces Road site.

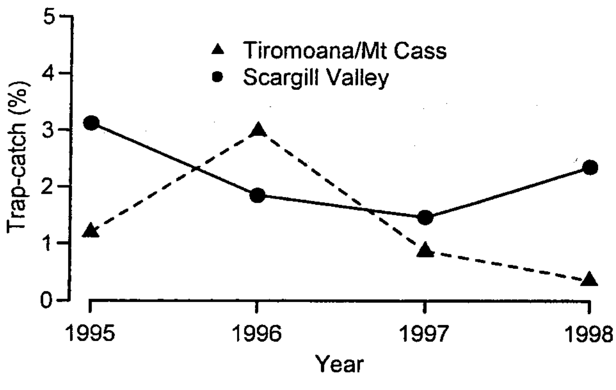

Figure 3. Trap-catch indices of possum abundance calculated from the first 5 nights of ferret trapping undertaken during May of each year. Estimates are corrected for non-target species captured and sprung traps. Note that these estimates are based on possums incidentally caught in traps targeted for ferrets, and are not comparable with standard trap-catch indices of possum abundance calculated using the protocol of Warburton (1996).

The mean RTC of possums within possum habitat at the Tiromoana/Mt Cass site during June 1996 was 4.3% (95% C.I. 0.4–8.2 %). Possums were patchily distributed, with the trap-catch per line ranging from 0 to 11.7%. During December 1997, the mean RTC for the 14 lines was 2.9% (95% C.I. 1.2%–4.6%). Again, possums were patchily distributed, with the trap-catch per line varying from 0 to 10.4%. Not all the Tiromoana/Mt Cass site was subject to maintenance control operations. The lines with the highest trap-catch of possums during 1996 (11.7%) and 1997 (10.4%) occurred in the Wash Creek area, outside the area covered by the Mt Cass possum maintenance control operation.

Rabbits

Spotlight counts undertaken by the Canterbury Regional Council showed that rabbit abundance decreased significantly at the Scargill Valley site as a result of ongoing farmer control, but increased significantly at the Tiromoana/Mt Cass site (Fig. 4). Rabbit haemorrhagic disease virus (RHDV) was released at all sites during the spring of 1997, first at the Scargill Valley site (August/September) and later at the Tiromoana/Mt Cass and Reeces Road sites. From January 1997 to January 1998, rabbit numbers decreased by 58% at Scargill Valley, 35% at Tiromoana/Mt Cass, and 54% at Reeces Road (49% mean reduction over all sites). Presumably these decreases in rabbit abundance were a direct result of mortality arising from the RHDV epidemic.

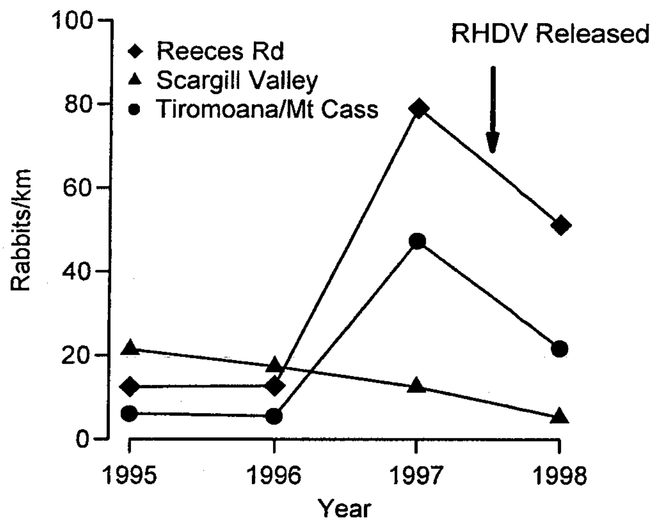

Figure 4. Mean numbers of rabbits seen per kilometre of spotlight transect surveyed by the Canterbury Regional Council during January of each year.

6.2 Prevalence and incidence of tuberculosis in wildlife

Ferrets

Macroscopic M. bovis prevalence: Tuberculous ferrets were caught at both sites during each year from 1994–1998. In total, 696 ferrets from the Scargill Valley site were necropsied, of which 64 showed gross lesions caused by *M. bovis* (Table II). In contrast, 23 of 741 ferrets caught and necropsied from the Tiromoana/Mt Cass site showed gross lesions caused by *M. bovis* (Table II).

Logistic regression modelling showed that the prevalence of macroscopic *M.bovis* infection was significantly lower in ferrets captured after ferret control began than beforehand ($\chi^2 = 9.6$, d.f. =1, $p < 0.001$), and significantly lower at the Tiromoana/Mt Cass site than at Scargill Valley. However, the effect of ferret control on disease prevalence vanished after the effect of ferret age (the natural logarithm of age fitted as a covariate) was included in the model ($\chi^2 = 0.5$, d.f. =1, p =0.48). Clearly, ferret control had no effect on the age-specific prevalence of macroscopic *M. bovis* infection, and the significant reduction in the unadjusted prevalence post-control must have been caused by difference in the age structure of the samples before and after the start of yearly trapping. Therefore, data from ferrets born before but captured after the start of ferret control were included for further analysis. After accounting for the effect of ferret age, the site effect remained highly significant ($\chi^2 = 20.0$, d.f. =1, $p < 0.001$). The odds of a ferret being infected were 78% lower at the Tiromoana/Mt Cass site compared with the Scargill Valley site. This was evident when examining the mean prevalence of macroscopic *M. bovis* infection of ferrets captured during May. At the Scargill Valley site this has averaged 11.5% compared to 2.9% at the Tiromoana/Mt Cass site (Fig. 5).

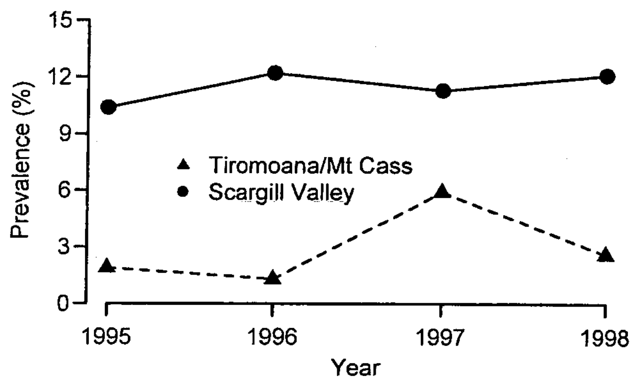

Figure 5. Prevalence of ferrets with macroscopic *M. bovis* infection captured during trapping in May of each year. Infection was confirmed in all cases by either isolation of *M. bovis* organisms, or the presence of acid-fast organisms seen during histopathological examination.

Table II. Prevalence of ferrets with macroscopic lesions resembling *M. bovis* infection, from which infection was confirmed by either isolation of *M. bovis* organisms or the presence of acid-fast organisms (AFOs) seen during histopathological examination.

		Scargill Valley			Tiromoana/Mt Cass		
Year	Month	Lesioned Tb +ve	Number necropsied	Prevalence (%)	Lesioned Tb +ve	Number necropsied	Prevalence (%)
1994	Dec.	9	65	13.9	2	12	16.7
1995	May	10	96	10.4	1	52	1.9
1995	Aug.	4	13	30.8	1	9	11.1
1995	Dec.	3	12	25.0	2	8	25.0
1996	Feb.	12	140	8.6	1	28	3.6
1996	May	5	41	12.2	1	78	1.3
1996	July	2	7	28.6	0	4	0.0
1996	Dec.	1	3	33.3	1	3	33.3
1997	Feb.	5	104	4.8	2	166	1.2
1997	May	7	62	11.3	6	101	5.9
1997	Dec.	0	1	0.0	1	5	20.0
1998	Feb.	2	119	1.7	4	236	1.7
1998	May	4	33	12.1	1	39	2.6
Total		64	696	9.2	23	741	3.1

Microscopic M. bovis prevalence: Samples from 178 ferrets from the Scargill Valley site and 131 ferrets from the Tiromoana/Mt Cass site were selected randomly (i.e. without regard for visible disease status) and submitted for either mycobacterial culture of pooled lymph nodes (including lesions if present) or histopathology of liver samples. All these ferrets had been subject to a standard necropsy with results presented in Table II. 39 from the Scargill Valley site and 20 from Tiromoana/Mt Cass site were confirmed to be infected with *M. bovis* (Table III), a significantly greater figure than those that exhibited macroscopic *M. bovis* infection. The proportion of tuberculous ferrets that did not show characteristic lesions at necropsy was estimated to be 33.9%, and thus the actual prevalence was shown to be about 50% greater than that determined macroscopically. This assumes that the sensitivity and specificity of liver histology is similar to that of mycobacterial culture (Lugton *et al.* 1997a).

Table III. Frequency of microscopic and gross *M. bovis* infection in ferrets randomly sampled from the Scargill Valley and Tiromoana/Mt Cass sites. Prevalence estimates are given in brackets.

Site	Sex	No. Examined	No. infected[a]	No with gross lesions[b]
Scargill Valley	Male	74	17 (23.0)	9 (12.2)
	Female	104	22 (21.2)	18 (17.3)
	Combined	178	39 (21.9)	27 (15.2)
Tiromoana/Mt Cass	Male	62	14 (22.6)	9 (14.5)
	Female	69	6 (8.7)	3 (4.3)
	Combined	131	20 (15.3)	12 (9.2)

[a]Diagnosis based on the isolation of *M. bovis* from pooled lymph nodes or lesions or the observation in liver samples of acid-fast organisms and/or microscopic hepatic granulomas characteristic of *M.bovis* infection.
[b]Includes gross lesions considered to have been caused possibly by *M. bovis* infection as well as gross lesions typical of *M. bovis* infection. However, final diagnosis of infection was always based on the isolation of *M. bovis* from lesioned material or sighting of acid-fast organisms in lesions during histopathology.

The prevalence of *M. bovis* infection in ferrets was highly age-specific. Differences between the age-specific prevalence of gross *M. bovis* infection and those with any evidence of infection are shown in Figure 6. No differences in prevalence were detected between the sexes ($\chi^2 = 1.2$, d.f. =1, P = 0.27). The youngest ferret with macroscopic *M. bovis* infection was 3 months old. One ferret (1.3% of grossly infected ferrets) had a draining sinus originating from a lesion in the inguinal lymph node.

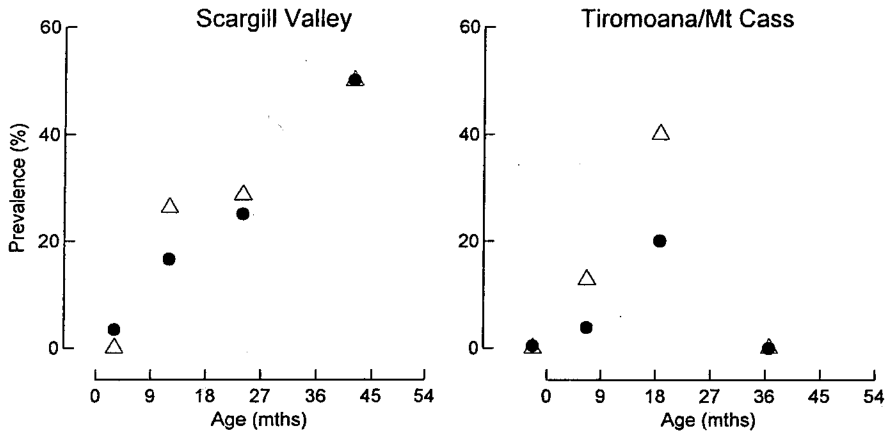

Figure 6. The age-specific point prevalence of *M. bovis* infection at the Scargill Valley and Tiromoana/Mt Cass sites. The solid circles represent the proportion of all necropsied ferrets that exhibited macroscopic *M. bovis* infection. The open triangles are the proportion of ferrets selected randomly from which *M. bovis* was isolated or characteristic microscopic hepatic granulomas observed (with or without AFOs).

The combined effects of changes in ferret abundance and the absolute prevalence of grossly *M. bovis* infection resulted in a lowered abundance of grossly infected ferrets in the Scargill Valley site, though no change in the abundance of grossly infected ferrets in the Tiromoana/Mt Cass site (Figure 7).

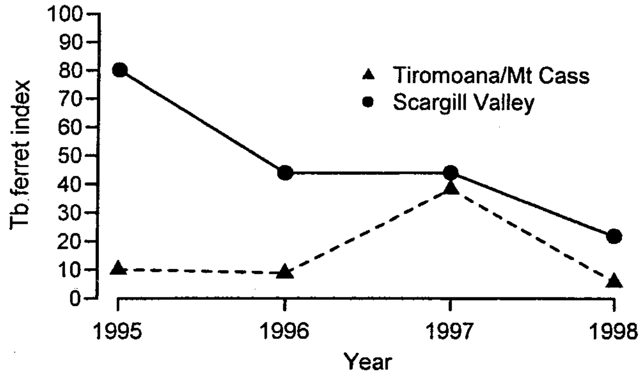

Figure 7. Changes in the abundance of grossly tuberculous ferrets as indexed by the product of the raw trap-catch by the prevalence of macroscopic infection in ferrets during the May trapping session of each year.

Cats and stoats

None of the 56 cats captured at the Scargill Valley and Tiromoana/Mt Cass sites during Nov/Dec 94 showed macroscopic lesions resembling tuberculosis at necropsy. None of the 167 cats necropsied during 1995 or the 16 cats necropsied during 1996 showed gross lesions resembling tuberculosis from which either *M. bovis* was isolated for AFOs seen. No further necropsies were undertaken on cats subsequently captured. Thirty-three out of 82 stoats captured at the Scargill Valley site, none of which showed gross lesions consistent with *M.bovis*, were randomly selected to have pooled lymph nodes (retropharyngeal, mesenteric, respiratory) submitted for mycobacterial culture. *M. bovis* was isolated from 3 of the 33 (9.1%). Only 3 of 17 stoats necropsied (none grossly lesioned) from the Tiromoana/Mt Cass site were subject to culture of pooled lymph nodes, with no isolation of *M. bovis.*

Possums

All possums trapped at the Scargill Valley site were released, hence their Tb status could not be adequately determined. A possum captured in March 1995 by a farmer on the lower slopes of Mt Alexander, several hundred metres from the boundary of the Scargill Valley site, was infected with *M. bovis* based on positive histology and culture, so it is highly likely that *M. bovis* infection is established in the local possum population. None of 128 possums necropsied from the Tiromoana/Mt Cass site had macroscopic *M. bovis* infection.

6.3 Incidence of tuberculosis in cattle

There were on average 817 and 654 head of cattle tested yearly from 1989/90 until 1997/98 from the Scargill Valley and Tiromoana/Mt Cass sites, respectively (excluding the Tiromoana/Mt Cass herd testing data after 1995/96). At the Scargill Valley site before the 1991/92 testing year, no tuberculous cattle were known for which wildlife were the source of infection. Two herds had positive reactors in 1992/93, and the remaining four either recorded reactor cattle or culls in 1993/94. The combined (reactors and culls) incidence of Tb peaked at 1.9% in 1993/94, shortly before ferret control started (Figure 8a). Two herds were classified as infected as of September 1993, all five herds as of September 1994 and September 1995, four herds as of September 1996 and one herd as of September 1998.

The history of *M. bovis* infection in cattle goes back further at the Tiromoana/Mt Cass site than at the Scargill Valley site, with a single reactor occurring on one property in 1989/90 and a reactor on the other property in 1990/91. Since then, the reactor incidence for both properties combined increased to a high in 1992/93 of 1.1%, after which it declined, with no reactors or culls recorded during the 1995/96 testing year. Two reactors (one lesioned) occurred on one farm during 1996/97, and a further three reactor and two culls during 1997/98 on the property not wholly covered by the Mt Cass possum maintenance control operation (Fig. 8b). One herd was classified as infected as of September 1998.

The incidence of Tb (reactors and culls combined) in cattle was significantly reduced by control of ferrets ($\chi^2 = 6.0$, d.f.=1, $p < 0.014$), after inclusion in the model for any treatment effect of possums, which in this case was not quite significant ($\chi^2 = 2.6$, d.f. =1, $p = 0.11$). Ferret control was estimated to reduce the average odds of a cow being a reactor or a cull by 40%, and possum control was estimated to reduce the mean odds of a cow being a reactor or a cull by 41%. Reanalysing the data to include only grossly lesioned reactors and culls produced qualitatively similar results (ferret control: $\chi^2 = 5.3$, d.f.=1, $p < 0.02$). Ferret control was estimated to reduce the mean odds of a cow being a lesioned-reactor or a cull by 49.4%.

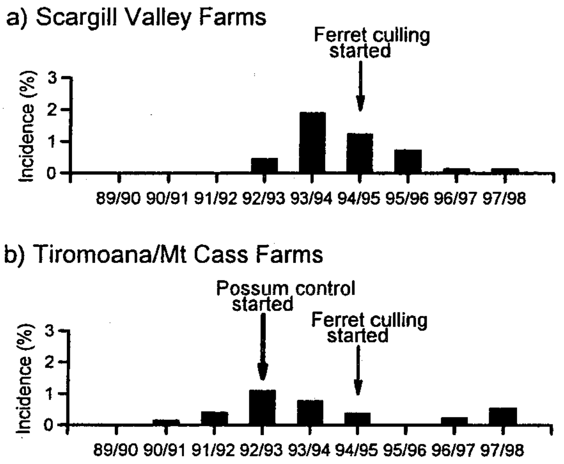

Figure 8. Percentage incidence of Tb in cattle (reactors and culls combined) from (a) the Scargill Valley site (817 cattle on 5 farms); and (b) the Tiromoana/Mt Cass site (770 cattle on 2 farms) on a testing year (1 Sept.–31 Aug.) basis. Note that the incidence at Tiromoana/Mt Cass during 1995/96 is zero. Ferret trapping started in November 1994. Possum control at the Tiromoana/Mt Cass site began during the winter of 1993 using a combination of aerially-sown 1080 carrot bait and ground-sown 1080 jam in bait stations.

6.4 Effect of ferret control on rabbit populations

After intensive monitoring of rabbit populations started during October 1995, and before predator removal began on the treatment farm, rabbit abundance steadily increased on both farms at the Reeces Road site (Fig. 9). In the pre-control period from October 1995 to April 1996, rabbit numbers increased by about 215% on the treatment farm and 245% on the non-treatment farm. From April 1996 until April 1997, rabbit abundance increased by 974% on the treatment farm and 731% on the non-treatment farm (Fig. 10). In total, rabbit abundance on both sites increased by about 30-fold between October 1995 and April 1997. The average exponential rate of increase (Caughley & Birch 1971) at the non-treatment farm was 0.20/mth (s.e. =0.01), and the treatment farm was 0.21/mth (s.e. =0.01). There was no significant difference between these rates of increase ($p = 0.50$).

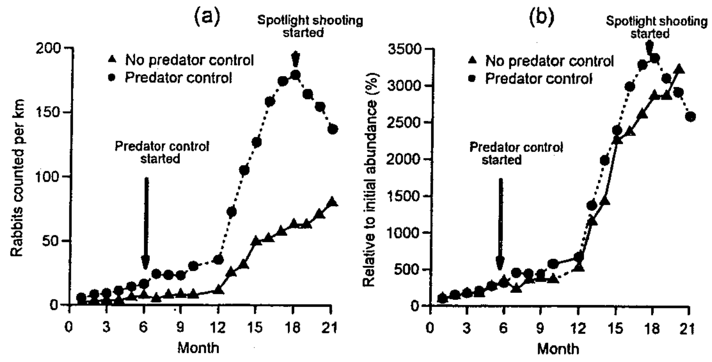

Figure 9. Changes in (a) spotlight count of rabbits and (b) percentage changes in rabbit abundance relative to initial abundance, on the treatment (●), and non-treatment (▲) farms, Reeces Road, in North Canterbury. The first month corresponds to October 1995 The arrow marks the start of predator control on the treatment farm during April 1996 (month 6). Spotlight shooting by the owner on the treatment farm began in April 1997 due to concerns at high and increasing rabbit numbers.

6.5 Effect of rabbit control on possum populations

Rabbit poisoning: The average concentration of 1080 in carrot baits was 0.018% (95% CI ±0.002), slightly less than the intended 0.02% dose for the poison operation. The average weight of carrot bait fragments was 3.4 g (95% CI ±0.7 g).

Trapping: During the 1994 survey, a catch rate of 15.7 possums per 100 trap nights was recorded. Before the poison operation, mean catch rates were 13.2 and 13.4 possums per 100 trap nights for the treatment and non-treatment areas, respectively. After the poison operation, mean catch rates were 9.8 and 11.3 possums per 100 trap nights for the treatment and non-treatment areas, respectively. This represents a 25.8% decrease in possum abundance in the treatment area and a 15.8% decrease in the non-treatment area. The percentage kill in the treatment area after adjusting for the decrease in trap-catch in the non-treatment area was estimated as 12.0% (95% CI ±1.7). However, trap-catch means did not differ between areas or with time, and there was no significant interaction between treatment (poison or no-poison) and time (pre-poison and post-poison) (two-way ANOVA; P=0.551), so the trap-catch monitoring detected no significant reduction in possum abundance due to rabbit poisoning.

Radio tracking: Ten of the 18 radio-collared possums (56%) released in the treatment area survived the rabbit poisoning operation. The eight that died all had undigested toxic carrot bait in their stomachs, indicated by the presence of green dye. In contrast, seven radio-collared possums in the non-treatment area (88%) survived and one died. There was no evidence of carrot bait in the stomach of this carcass, nor any other evident cause of death. The percentage kill caused by 1080 carrot baits was estimated by radio-tracking as 36.5% (95% CI ± 15.7). The proportion of possums that survived in the treatment area was very nearly significantly different from that in the non-treatment area (Fisher's exact test; P=0.063). The status (dead or alive) and initial capture weights of radio-collared possums in the treatment area were analysed for a weight-mortality relationship. Surviving possums (2.9 kg) were significantly heavier than those that died from ingesting toxic bait (2.3 kg; Mann Whitney U-test; $P < 0.025$).

7. Discussion

7.1 Ferret population reduction and demography

Trapping during 1995 to 1998 resulted in a moderate reduction in mean ferret abundance at the Scargill Valley site, but little or no reduction at the Tiromoana/Mt Cass site. The greater availability of suitable habitats for ferrets at the Tiromoana/Mt Cass site may have made targeted control more difficult in comparison with the Scargill Valley site. Another possible reason is that the numerical response of the ferret population at the Tiromoana/Mt Cass site to the massive increase in rabbit abundance was too great for removal trapping to have any effect. In contrast, rabbit populations at the Scargill Valley site have been kept under control since the study began, to the point that spotlight count data shows a steady decline in rabbit abundance. This difference in rabbit abundance appears to be a key reason as to why leg-hold trapping at the Scargill Valley site achieved a reduction in ferret abundance.

Achieving lasting reductions in ferret abundance is difficult. This is well illustrated by North Canterbury farmer Bob Hammond, who continued to trap many ferrets over several consecutive years (Hammond 1996). The current project aimed to reduce ferret population to less than an arbitrary 30% of pre-control levels. This was not achieved using leg-hold trapping at either site. Ferret populations recover after control through both *in situ* breeding and immigration. The relative contribution of each is not known, although rapid influx of new ferrets into an area after secondary poisoning of resident ferrets with brodifacoum has been observed (Alterio 1996). This study has shown that the frequency of ferrets breeding twice in the one year is too low to contribute significantly to the rate of population increase. It is likely that large potential litter sizes in combination with compensatory survival of juvenile ferrets are major reasons why ferret populations appear able to withstand substantial control efforts. Control efforts are also significantly hampered by the apparent reduced trappability of ferrets during the June–December period.

7.2 Ferret tuberculosis

M. bovis infection continued to be detected in ferret populations at both the Scargill Valley and Tiromoana/Mt Cass sites throughout the period of ferret control. Controlling ferrets reduces the overall prevalence of gross *M. bovis* infection, but does not reduce the age-specific prevalence of the disease, suggesting that ferrets continue to encounter *M.* bovis infection at a similar rate, regardless of whether the population is being controlled. This raises the obvious question of the source of *M. bovis* infection in ferrets. If cannibalism and availability of ferret carcasses are important sources of *M. bovis* infection in ferrets, why then did removing these carcasses by culling fail to produce a reduction in the rate at which ferrets acquired disease? While pseudo-vertical transmission would be relatively insensitive to population reduction, the general absence of infection in young offspring effectively rules this out as an important route of transmission (Lugton *et al.* 1997b). Intraspecific transmission via bite wounding is also thought to occur (Lugton *et al.* 1997b), though it is unclear whether control should reduce the per capita rate of transmission via wounding by reducing the frequency of fighting, etc. Finally, the lower prevalence of disease at the Tiromoana/Mt Cass site may be due to the possum control that occurs there. This fits with the broadscale correlation observed by Caley (1998) between the prevalence of macroscopic *M. bovis* infection and possum abundance. The simplest way to test this hypothesis would be to control the possum population at Scargill Valley, and also to assess its Tb status better. Both are currently underway.

7.3 Incidence of tuberculosis in cattle

Herds of cattle at the Scargill Valley and Tiromoana/Mt Cass sites were clearly contracting infection from a wildlife source. This research has provided considerable evidence that ferrets do in fact transmit *M. bovis* infection to cattle, supporting the observations of some farmers, veterinarians and livestock officers in the region. Because the robustness of the design was affected by management restrictions on leaving tuberculous wildlife populations uncontrolled, the possibility still remains that the experiment was partially confounded. The two most likely possibilities for this are: (1) a natural epidemic of Tb occurred in the possum population, starting at the beginning of the trial, and progressively died out as the trial continued; or (2) significant mortality of possums arising from rabbit poisoning operations removed a significant proportion of *M. bovis* infection from the possum population.

Under both options, it would be expected that the age-specific prevalence of the disease in ferrets would decrease as either the epidemic in possums waned, or tuberculous possums were killed (assuming tuberculous possums are the common source of infection for both ferrets and cattle). This did not occur. Although attempts were made to minimise the mortality of possums within the Scargill Valley site, it appears that some mortality occurred as a result of rabbit poisoning operations. However, the reduction in the incidence of Tb in cattle was of a far greater magnitude than the reduction in possum abundance. Ceasing ferret control, and starting intensive possum control, whilst monitoring the incidence of disease in both ferrets and cattle, provides an opportunity to check further whether the trial has been confounded. If, after significantly reducing possum abundance (after ceasing ferret control), the incidence of Tb declines in ferrets and remains low in cattle, this will fit with the model that tuberculous possums are the source of tuberculous ferrets, which then cause a significant amount of the observed incidence of Tb in cattle. If, however, after significantly reducing possum abundance (after ceasing ferret control), the incidence of Tb in cattle undergoes a resurgence and the high prevalence is maintained in ferret populations, this will fit with the model that Tb is cycling within ferret populations, and that ferrets readily transmit Tb to livestock. Analysing this type of data, where treatments are applied and withdrawn using appropriate randomisation tests, would provide a reasonably robust test of the various models of *M. bovis* infection among possums, ferrets and cattle. Increasing the level of inference is important, and is usually achieved via the execution of critical experiments, such as those proposed by Krebs *et al* (1998) for determining the role of badgers (*Meles meles*) in transmitting bovine Tb to cattle in Britain.

Although ferret control caused a minor to moderate reduction in ferret abundance, it induced a much greater reduction in the abundance of grossly tuberculous ferrets, as the prevalence in the smaller residual population was also reduced due to the lowering of the age structure. Continually removing tuberculous ferrets could also lessen the exposure of livestock to the disease by removing tuberculous ferrets before the disease becomes sufficiently advanced for significant external shedding of *M. bovis* bacilli. Externally draining lesions were rare in this study; and that of Ragg *et al.* (1995b). However Lugton *et al.* (1997b) demonstrated that infected ferrets shed *M. bovis* organisms in the faeces and urine, and that about one quarter of tuberculous ferrets had evidence of oral excretion of bacilli, apparently unrelated to the stage of disease. All moribund tuberculous ferrets probably excrete large numbers of bacilli capable of infecting cattle that contact these animals. The route of transmission of *M. bovis* infection from ferrets to cattle remains unconfirmed, although Sauter & Morris (1995) postulated that it could occur during close contact between inquisitive livestock and moribund, terminally-ill ferrets. If this is correct, continually removing tuberculous ferrets before the disease has a chance to produce morbidity could lessen the exposure of inquisitive cattle to *M. bovis* infection.

7.4. Possum abundance

This study has shown that, within favourable habitats, possums occur in moderate abundance in areas of North Canterbury. Possums should therefore not be ruled out as a significant source of *M.bovis* infection in these regions. Indeed, given that tuberculous possums have been found in a number of areas, it would be highly unusual if the disease were not endemic in possum populations here. During this study, farmers were invariably surprised at the number of possums on their properties, understandable because they rarely saw them when spotlighting for rabbits. If *M. bovis* is indeed cycling within possum populations in North Canterbury, and infection in these populations is not controlled, control of ferrets will prove fruitless for achieving lasting reductions in the incidence of Tb in livestock, as the ferrets will have reservoirs of *M. bovis* infection from which to be continually reinfected.

The pattern of infection at the Tiromoana/Mt Cass site looks disturbingly similar to the pattern of disease in cattle after initial control of possums is undertaken (see Barlow 1991), where a resurgence in the incidence of Tb in cattle starts 4–5 years following a one-off possum control operation. Indeed, four of five tuberculous ferrets caught at the Tiromoana/Mt Cass site during 1998 came from the Wash Creek area not subject to possum maintenance control, pointing to the possible role of possum populations from this area in infecting ferret populations.

7.5. Effect of ferret control on rabbit populations

Rabbits increased at similar rates regardless of whether predator control had been undertaken, suggesting that conditions during 1995/96 were very favourable to rabbit reproduction and survival. Removal of predators thus did not exacerbate increases in rabbit numbers under the prevailing conditions.

7.6. Effect of rabbit control on possum populations

Possum populations may suffer significant mortality because of poisoning operations using toxic 1080 carrot at a 0.02% wt/wt loading targeted at rabbits. The moderate disparity between mortality estimates from trapping and radio-tracking is difficult to explain. Of the two techniques, radio-tracking is considered the more accurate as it does not suffer from biases caused by edge effects, immigration, competition for traps, weather, modified trap behaviour, etc. However, it is probably not as precise owing to the smaller number of animals monitored. We therefore consider the true mortality to be closer to 36.5% (from radio-tracking) than 12% (from trapping). Almost the entire Scargill Valley site was subject to rabbit control either by aerial application or by furrow baiting during the first 2 years of this study (1995 and 1996). We believe that the consequences of this rabbit control may explain the 29% decline in the catch rate of possums caught in traps targeted for ferrets. The alternative explanation – that possums become wary of traps – does not fit with the fluctuating rate of possum capture observed at the Tiromoana/Mt Cass site. The extent of possum mortality caused by rabbit control was not sufficient serious to compromise the validity of the trial for measuring the effect of ferret control on the incidence of Tb-reactor cattle. Now that farmers increasingly use RHDV in preference to 1080 as a control method for rabbits, the level of control of possum populations inhabiting tussock habitats will be reduced. This will clearly have a negative effect on the management of *M. bovis* infection in possum populations on-farm.

8. Conclusions

- The results support the hypothesis that tuberculous ferrets are transmitting Tb to cattle.
- Leg-hold trapping at the intensity used in this study is not an effective method to achieve lasting control of ferret populations, and even in the short-term provides only moderate (0–30%) levels of control.
- Moderate control of ferret populations reduces the absolute prevalence of grossly tuberculous ferrets by lowering the age structure of the population, and in so doing lowers the abundance of grossly tuberculous ferrets. It does not, however, reduce the age-specific prevalence of *M. bovis* infection in ferret populations, suggesting that continued transmission of *M. bovis* infection to ferrets is independent of ferret density for the range of densities studied.
- Upsurges in rabbit numbers appear independent of whether predator populations are controlled under the conditions encountered in this study. Conditions during 1995/96 and 1996/97 were ideal for rabbit reproduction and survival, resulting in orders of magnitude increases in rabbit abundance even in the absence of predator control. Predators were unable to prevent this upsurge in rabbit abundance.

9. Recommendations

- Alternative methods of improved efficacy be developed for controlling feral ferrets.
- Inference from surveys of ferret populations for *M. bovis* infection should take into account the age structure of the sample.
- Control of ferret populations should be considered as a short term tactic for reducing the incidence of *M. bovis* infection in cattle.
- Research should be undertaken to determine the underlying source of *M. bovis* infection in ferret populations.

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12. Appendices

Appendix 12.1. Details of previous reports arising from the study.

Caley, P. 1995: Effects of possum maintenance control and ecological factors on levels of bovine tuberculosis in cattle and possums. Year one progress report. Landcare Research contract report no. LC9495/120 (unpubl.). 27 p.

Caley, P.; Thomas, M.; Morley, C. 1997: Effects of ferret control on cattle reactor incidence, ferret Tb prevalence, and rabbit numbers. Year two progress report. Landcare Research contract report no: LC9697/034 (unpubl.). 18 p.

Caley, P; Morley, C. 1998: Effects of ferret control on cattle reactor incidence, ferret Tb prevalence, and rabbit numbers. Year three progress report. Landcare Research contract report no: LC9798/106 (unpubl.). 19 p.

Appendix 12.2. Details of effort and results of leg-hold trapping targeting ferrets undertaken at the Scargill Valley and Tiromoana/Mt Cass sites.

Site	Year	Months	Trap nights	Ferrets	Stoats	Cats	Possums	Other
Scargill Valley	1994	Nov/Dec	2372	65	9	20	108	275
	1995	May	1577	96	6	68	42	108
	1995	August	959	13	14	7	12	12
	1995	December	1712	12	19	18	47	235
	1996	February	1655	182	32	20	14	138
	1996	May	1597	83	25	75	40	320
	1996	July	1519	7	8	7	15	60
	1996	Nov/Dec	799	3	17	7	9	82
	1997	February	2196	104	20	73	13	180
	1997	May	1821	62	21	35	19	69
	1998	February	2090	119	10	56	32	343
	1998	May	2463	33	16	67	42	191
	Total	All	20760	779	197	453	393	2013
Tiromoana /Mt Cass	1994	Nov/Dec	1826	12	3	37	41	143
	1995	May	1216	53	2	61	11	114
	1995	August	866	10	1	20	13	21
	1995	December	628	8	1	6	14	56
	1996	February	612	28	0	7	2	32
	1996	May	1400	79	4	48	31	138
	1996	July	495	17	3	22	24	27
	1996	Nov/Dec	814	3	2	2	8	91
	1997	February	3170	167	2	61	28	152
	1997	May	1805	101	19	111	9	53
	1998	February	2663	236	9	123	12	340
	1998	May	2456	39	14	95	12	235
	Total	All	17951	753	60	593	205	1402