Animal Health Board Project No. R-50634

Identifying the Causes of, and Solutions to, Vector-related Tb Persistence near Featherston

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Summary

Project and Client

The causes of the failure to reduce bovine tuberculosis (Tb) from livestock about Featherston (in comparison with rates achieved in most other areas with infected livestock in New Zealand) and ways in which the likelihood of eradication of Tb there may be enhanced, were investigated for the Animal Health Board (AHB; Project R- 50634). *The work was undertaken in a collaborative study by Landcare Research and Epicentre, Massey University*, between February 2004 and August 2005, with input from the Greater Wellington Regional Council (GWRC) and AgriQuality.

Objectives (Landcare Research)

To identify practical and cost-effective solutions to the elimination of bovine Tb from wildlife vectors and livestock near Featherston, by:

- Reviewing the history of local Tb vector control, and using this to help explain outcomes of recent and current control
- Determining, by mapping of possum density, whether Tb persistence reflects patchy control of resident possums in forest and scrub within 1 km of farmland
- Determining the scale and location of immigration by possums from 'deep' forest to farmland
- Determining (a) the prevalence of Tb in feral pigs, (b) an indication of the number of pigs killed annually by local hunters, and (c) the likelihood that pig carcass remnants are disposed of in places accessible to ferrets
- Determining the density of ferrets, likely scale of their movements, and the likelihood of intraspecific transmission of Tb within ferrets
- Assessing all potential wildlife sources of infection, and providing the AHB with recommendations that, if implemented, are likely to eradicate Tb from the vector populations and livestock in the Featherston Vector Control Area (VCA).

Findings

Official possum and ferret control and monitoring

- Possums in the predominantly gorse-covered hills west of Featherston were controlled by aerial 1080 poisoning in 1996 and 2001. Both operations appeared to follow standard operating protocols and achieved the operational targets in place at that time.
- Ground control of possums and ferrets in the VCA has progressively intensified over the last 5 years, with the division of the area into high, medium and low Tb-risk strata (resulting in better targeting of control), the progressive control of all areas in the VCA, and the instigation of formal monitoring of many operations to encourage contractors to achieve targeted levels of operational success.
- Ground control of possums over the scrub/forest-covered hillsides has, until 2003/04, omitted some areas close to Featherston, and in other areas been confined to forested gullies. Overall coverage has therefore been incomplete.
- Operational monitoring of ground control has sometimes differed from the national monitoring protocol, and formal audits of monitoring in some high-risk strata have not always been undertaken.

- Ferret control has not been applied consistently, and there has been no downward trend in annual ferret catch over the period monitored. The survival of tagged ferrets during control operations indicated suboptimal management of this species.

Research trials and Tb necropsy

- Mapping of possum locations in the forest/scrub-covered hillsides immediately west of Featherston did not indicate any consistent increase in possum density with increasing distance from the pasture margin. Highest densities were recorded in the poorly controlled or uncontrolled areas of gorse and native scrub north of Abbots Creek, and highest numbers of juveniles were found within 200 m of the pasture margin.
- Young possums were dominant on the forest/scrub-covered hillsides in three out of four of our seasonal samples in our immigrant flow study. Such animals were taken most frequently at the rear of the control block, in forested gullies and stream catchments, and only rarely on gorse-covered ridges and faces. Approximately 4.5 young possums were captured per kilometre per year of bush margin.
- Four feral pigs out of a sample of 29 were confirmed as infected (a point prevalence of 13.8%). They were widely distributed across the scrub and forest in the VCA.
- Pig heads staked out on the VCA scrub–pasture margin (mimicking heads of pigs discarded by hunters) were rarely scavenged by local wildlife. Interactions by possums and ferrets were limited to ‘sniffing’ only, while scavenging was confined to several rats, one cat, and one or more Australasian harriers. In contrast, scavenging on possum carcasses was recorded by pigs only, and demonstrated a likely route of infection in the local pig population.
- Necropsy of 139 possums from the scrub and forest-covered hillsides in the VCA did not identify any animals infected with Tb.
- Necropsy of 54 ferrets taken from farmland in the VCA did not identify any animals infected with Tb.
- Juvenile radio-collared ferrets confined their activities largely to gorse/scrub–pasture margins and appeared to avoid either large areas of gorse or farmland devoid of scrubby gullies or hedgerows. Dispersal from original capture sites ranged from 0.2 to 4.0 km with a median value of 0.6 km. Only one animal dispersed a significant distance from its natal area. Based on trapping data only, the population density of ferrets on farmland within the VCA was c. 2 ferrets/km^2.

Conclusions

Official possum and ferret control and monitoring

- Unless aerial baiting strategies are improved from those used in 1996 and 2001, the new and more stringent control targets for heavy scrub habitats may not be achieved reliably.
- Strategies used for the ground control of possums in scrub habitats and on farmland require improvement. The non-random placement of widely spaced poison lines along streams and the deliberate avoidance of many patches of gorse and blackberry are likely to result in patchy, uneven control. Of lesser importance, the continued use of Timms kill-traps for possum control on farmland away from houses is likely to be less cost-effective than the use of more traditional leg-hold traps.
- Possum population monitors must follow the intent of the national monitoring protocol if they are to provide useful strata-related Residual Trap Catch Index (RTCI) data for pest managers. As some recent monitors have failed to do this, and as no operational audits have been undertaken, the achievement of disease control targets in past years is uncertain.
- The nature of the input monitoring (catch per unit effort) used to assess the effectiveness of ferret control provides data of limited value for audits of operational success.

- The survival of juvenile ferrets after control operations appears to be a consequence of both timing and intensity of the control undertaken.
- Effective possum and ferret control in the VCA is heavily constrained by the attitudes of local landowners and the general public, and greater effort is needed to ensure free and unencumbered access for control teams to all pest habitats and for ongoing use of the most cost-effective control tools.

Research trials and Tb necropsy

- Mapping of possum populations confirmed recent historical control has been patchy, predictably being least effective in the most difficult and inaccessible habitats.
- Despite this patchy control, overall levels of Tb in possums resident within the VCA appear to be close to or at zero. There appears to be a modest flow of immigrants (almost exclusively juveniles) from the 'deep' forest to the west, which could potentially reintroduce Tb. However, the numbers of such immigrants likely to reach farmland is modest, so that likelihood is very low.
- Tb was observed in aged pigs only, suggesting that the source of the infection in all wildlife may be declining. Such infection presumably reflects the scavenging behaviour of this species on other wildlife, particularly possums, although no other wildlife species were confirmed as infected. The transmission of Tb from discarded pig heads to other wildlife appeared unlikely, as filmed interactions about pig heads by other key wildlife Tb hosts were few. Such a low level of interaction is likely to reflect past control of possums and ferrets in the VCA.
- The absence of Tb in any of the ferrets necropsied should be treated cautiously as the size of the combined sample necropsied and its geographically restricted collection meant the likelihood of us missing infected animals was relatively high.
- Young radio-collared ferrets showed no dispersal patterns likely to export Tb out of the VCA.

Recommendations

- Because ground control is difficult, we recommend greater use of aerial poisoning in the VCA wherever possible. Future aerial control should be upgraded by increasing the sowing rate to 3 kg/ha and sowing a pre-feed to encourage all possums in the dense scrub find baits and eat them. Based on outcomes from other studies cinnamon essence should be applied to bait at standard operational rates as a mask to 1080, to ensure possums encountering baits find them palatable.
- Strategies for ground control of possums should be revised to ensure complete coverage of all possum habitat.
- Monitoring of possum abundance should conform to the national protocol and, at least in high-risk strata (e.g. HR1), be followed by independent audits of compliance. An increase in the number of monitor lines in high-risk strata is warranted to increase the precision of the density indices generated and to meet the requirements of the latest Monitoring Protocol for 50% more monitor lines in high-risk strata (based on both the need for better line coverage and on increases in monitor costs deemed acceptable to Vector Managers).
- Where contract agreements permit it, post-control monitors should be delayed for at least 1 month and preferably 3 months, to help overcome some of the bias inherent in population monitoring undertaken immediately after control.
- Senior managers involved in local pest control should continue to work to improve the acceptance of this programme by the key Featherston landowners and residents opposed to its implementation, through programmes of increased public information, liaison, and buy-in via the development of local 'working' groups.

- The annual 'control' of ferrets should be formally structured as disease surveillance, and focus primarily on the forest–pasture margin where the risk of Tb reintroduction appears greatest.
- The economics of controlling possums dispersing from uncontrolled deep forest, using lines of long-life toxic baits across hillsides, compared with such control along the pasture margin, needs further study as our research failed to properly evaluate this strategy.
- As long as the pig population remains infected, pig hunters and the local pig- hunting club should be encouraged to participate in a surveillance programme of age-specific prevalence and distribution of Tb in pigs. This programme should be structured so as to ensure the collection of pig heads either in freezer chests held by collecting agents or in scavenger-proof collection boxes for pig offal at key offal discard points and cleared following weekend hunting. Incentives to ensure hunter participation should include a modest bounty for each head recovered, and a clear understanding that while no formal pig control is currently planned, pig samples are required and will be collected with or without hunter involvement.
- If pig hunters are not prepared to become involved in a pig surveillance programme, the case for an immediate one-off pig control operation across the VCA to rapidly reduce the number of infected pigs present should be investigated further.
- Non-musterable cattle living in Lake Domain should be shot as their disease status is unknown and they may pose a threat to nearby cattle herds.

1. Introduction

The causes of the failure to reduce bovine tuberculosis (Tb) from livestock about Featherston (in comparison with rates achieved in most other areas with infected livestock in New Zealand) and ways in which the likelihood of eradication of Tb there might be enhanced, were investigated for the Animal Health Board (AHB; Project R- 50634). *The work was undertaken in a collaborative study by Landcare Research and Epicentre, Massey University*, between February 2004 and August 2005, with input from the Greater Wellington Regional Council (GWRC) and AgriQuality.

2. Background

In April 2003, the AHB requested research proposals aimed at identifying how Tb could be eradicated from livestock and wildlife populations near Featherston, Wairarapa, within 2 years. At that time, five of the 63 herds within the 5700-ha Vector Control Area (VCA) (Fig. 1) were infected, despite intensive vector control since 1992 both within the improved and largely ‘clean’ farmland and in the adjacent unfarmed forest, thick gorse, and native scrub on the foothills of the Rimutaka and Tararua ranges. Twelve different farms in the area have been infected at some time over 2001–2003. A local feral-animal survey in 2002 identified three infected ferrets; and infected possums, ferrets, and one cat have been identified in the same area in the past decade.

This study aimed to identify the most likely explanations for the greater than expected persistence of Tb in the area given the apparent adequacy and duration of the vector control. We therefore monitored the outcomes of specific vector control treatments applied in the VCA by the GWRC and its contractors and tested a comprehensive set of hypotheses that might explain the observed persistence of the disease. This approach was ambitious but, we believed, would provide results that can be applied both within and outside the Featherston VCA.

We identified four hypotheses that addressed all plausible explanations for the observed persistence of Tb in livestock at Featherston. These were:

1. Direct transmission from possums to livestock. For this hypothesis to be true, either Tb has persisted undetected in possums resident in or near farmland, or Tb is being continually imported to farm margins by infected immigrant possums from the adjacent ‘Featherston Crown’ VCA or from uncontrolled possum populations beyond it. The former would require either detection of Tb in adult, resident possums, or at least strong evidence of uneven control with large untreated patches containing possums at densities capable of sustaining Tb. The latter would require an annual flow of infected immigrant possums capable of producing new infection observed in livestock.
2. Direct transmission from ferrets to livestock. For this hypothesis to be true either ferret densities must be high enough for them to be a maintenance host of Tb (>2.9/km^2 year round; Caley & Hone 2005), or ferrets must function as link hosts (as proposed by Nugent et al. (2005) and Byrom et al. (2005)) and become infected by scavenging

possum carcasses or pig and deer offal left by hunters or the carcasses of pigs and deer dying of natural causes.

3. Direct transmission from live pigs and deer to livestock. For this hypothesis to be true, Tb must have persisted in local pigs and deer and infected individuals must have grazed alongside livestock.
4. Within- and between-herd Tb transmission. As new breakdowns occurred on farms with no apparent interactions with infected herds, and, crucially, because Tb has recently been confirmed in ferrets, this explanation was rejected.

Fig. 1 Featherston Vector Control Area, showing approximate boundaries of current control blocks (e.g. HR1, designated in 2002/03), location of cattle herds and wildlife infected with Tb from 2000/01 to 2003/04, and place names mentioned in the text.

Because (1) the area involved in the VCA (i.e. the farmland and adjacent Crown and New Zealand Forest Trust (NZFT) land) is not large, especially in relation to the dispersal distances of wildlife Tb hosts; (2) the number of infected wild animals is apparently small; and (3) there was a need to maintain or intensify eradication efforts, it was not possible to design and implement rigorous experiments with proper non-treatment sites to test all these hypotheses simultaneously. Instead we gathered data to 'confront' the hypotheses and predictions above, and used a combination of logic and evidence from other published and current studies to identify the most probable causes for the persistence of Tb at Featherston.

This project was, at AHB's request, combined with a related proposal from EpiCentre, Massey University. The aims and outcome of the EpiCentre research have yet to be documented and will be reported separately.

3. Objectives

To identify practical and cost-effective solutions to the elimination of bovine Tb from wildlife vectors and livestock near Featherston, by:

- Reviewing the history of local Tb vector control, and using this to help explain outcomes of recent and current control
- Determining, by mapping of possum density, whether Tb persistence reflects patchy control of resident possums in forest and scrub within 1 km of farmland
- Determining the scale and location of immigration by possums from 'deep' forest to farmland
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- Determining the density of ferrets, likely scale of their movements, and the likelihood of intraspecific transmission of Tb within ferrets
- Assessing all potential wildlife sources of infection, and providing the AHB with recommendations that, if implemented, are likely to eradicate Tb from the vector populations and livestock in the Featherston Vector Control Area (VCA).

4. Methods

4.1 Habitat description

The Featherston VCA includes the eastern flanks of the Rimutaka and Tararua ranges from the crest of the ranges to farmland between Owhanga Stream and the Tauherenikau River, as well as all farmland between the margin with forest/scrub and the Tauherenikau River, south to Lake Wairarapa (Fig. 1; c. 10 100 ha). The hill lands (control blocks HR1 and MR1 in Fig. 1) are divided by Abbots Creek, and comprise a variable mix of gorse (*Ulex europaeus*), native regenerating scrub dominated by *Pseudopanax* spp., mānuka (*Leptospermum scoparium*), and occasional stands of beech (*Nothofagus* spp.). North of Abbots Creek, gorse nearly impenetrable to humans dominates most faces and gullies, with limited native scrub overtopping it in south-facing wetter areas. South of Abbots Creek, gorse is dominant on most ridges and faces. Elsewhere, native scrub is interspersed with some mature beech and māhoe (*Melicytus ramiflorus*) forest and further scattered gorse. The adjacent farmland (control blocks HR2, HR3, HR4 and HR5) is mostly high-quality improved pasture, bordered in the east and south by willow (*Salix* spp.) and rough grasses in riparian vegetation alongside the Tauherenikau River and in the Lake Domain (in HR4).

4.2 Historical vector control

All documented aerial baiting for possum control in the last 10 years and all ground-based vector control undertaken by the GWRC and their contractors within the VCA on farmland and in the adjacent forest and scrub over the last 6 years (1998/99 to 2003/04), was reviewed in collaboration with GWRC staff. We followed the approach used to determine the effectiveness of aerial baiting and ground control undertaken for the management of possums in the Hokonui Hills (Coleman et al. 2003), and examined the nature (i.e. bait type, sowing rates, and sowing patterns) and location of aerial baiting, and the nature (bait and trap type), location, and intensity of all documented ground control for both possums and ferrets. We also reviewed the achievement of formal operational control targets (where these existed) and how operational monitoring was conducted for possums (RTCI) and ferrets (catch rates recorded during control), in relation to practice specified in the National RTCI protocol (NPCA 2002). These included the location and direction of trap lines, and the omission of areas of possum habitat controlled but not subjected to follow-up control monitoring. RTCI lines that failed to meet operational targets set by GWRC were considered in relation to the control strategies and tools chosen, and to the temporal and spatial features (geographical/topographical/cover) that may have led to individual line or operational failures. These data were also used to more precisely define the areas where possum control was likely to have been least efficient, as well as providing information that guided the focusing of our possum mapping effort (see below).

4.3 Mapping of pre-control possum density

To determine whether Tb in livestock was related to persistent patches of high densities of potentially infected possums resident near farmland (our hypothesis 1), we mapped possum occurrence across exotic and native scrub and forest in the Crown and NZFT area (HR1) adjacent to farmland immediately before maintenance control in January 2004. The area surveyed covered two blocks, a northern block of 90 ha between Boar Creek and Abbots Creek and a southern block of 230 ha south of Abbots Creek (see Fig. 1), and included areas where local possum control has been patchy and difficult to implement (G. Butcher, GWRC, pers. comm.). Sampling sites were located at 30-m intervals on parallel lines run on compass bearings directly back from the pasture margin. At every site, we placed at ground level a Feratox® bait and a Wax Tag® and at every third site also set a Victor No. 1 leg-hold trap lured with flour and icing sugar, and equipped with a single adhesive-coated jaw to collect fur from animals that touched it. Feratox bait was omitted from the first 200 m of two lines beginning on the Featherston town boundary, however, because of the risk it posed to local children. Lines were approximately 1.5 km long and 200 m apart and were checked on three successive days following establishment. The clusters of the different devices provided both an indication of the relative abundance of possums along each line, and of whether or not possums present were shy of Feratox baits, Wax Tags, and leg-hold traps, and/or the 'conventional' lure used for monitoring.

Indices of possum abundance obtained in such mapping were used mainly to compare possum densities in relation to habitat type, farmland, and past control, but also to provide an indication of absolute densities of possums from calibrations with indices of possum abundance developed in recently published spatial simulation trapping studies (Ramsey et al. 2005).

The age class and sex of each possum found at the poison stations were recorded, and all carcasses were tagged and removed to a central site where they were fully examined for lesions indicative of Tb (i.e. caseous or discharging lymph nodes or areas of consolidation in the lungs; see Coleman et al. (1994)) in all internal organs (lungs, liver, spleen and kidneys) and major lymph nodes (deep and superficial axillary, bronchial, mesenteric, and inguinal) identified as predilection sites for the infection (Coleman & Cooke 2001). Suspicious pathology was identified in only one possum during the study, and the suspect material was frozen and forwarded to the Infectious Disease Laboratory, AgResearch, Wallaceville, Upper Hutt, for culture and determination of its Tb status.

Similar smaller-scale mapping of possum distribution and abundance in the Lake Domain at the northern end of Lake Wairarapa was not completed as planned, primarily because the area was flooded on each occasion we attempted to undertake the survey. This work was originally planned because of continued persistence of Tb in nearby herds up until 2002. In addition, operational monitoring by the GWRC had already identified and rectified a previous failure to implement control and monitoring within the domain (G. Butcher, pers. comm.). These two developments, together with the presence of two non-musterable and apparently dangerous bulls, jointly rendered the proposed work redundant.

The data we recorded on possum distribution and abundance in January 2004 was made available to the contractor undertaking maintenance control of possums in mid-2004. In return, he provided records of his trapping effort, possum locations, and possum kill rates; information we used to help interpret the patterns observed in our data.

4.4 Flow of immigrant possums as a potential source of Tb

To determine whether there was sufficient immigration of possums from deep forest to farm margins to account for the observed number of herd breakdowns (hypothesis 1), we sampled possums on four transects between 2 and 3 km long spaced 200–300 m apart. Each line ran parallel to the scrub/pasture margin in the scrub/forest control buffer (HR1), beginning close to the main highway between Featherston and Wellington immediately south of Abbots Creek, and was first sampled in June 2004 immediately after maintenance control and population monitoring for that year. Line 1 was located alongside the pasture edge, while line 4 was located along the skyline ridge at the rear of the area under annual ground control. Beginning at the northern end of each line, sodium cyanide paste baits were alternated with 40 leg-hold traps at 20-m intervals for 1.6 km. The traps and baits were checked daily for 3 days before the entire line was cleared of cyanide paste and traps. The sampling process was repeated at 3-monthly intervals for 1 year, with the lines extended in the second (September) and subsequent samplings by cyanide paste baits alone located at 20-m intervals for a further 0.5 to 1.0 km. In addition, long-life Feratox baits were put out at each trap or cyanide paste site at the end of our first seasonal sampling and trialled as an ongoing sampling procedure between successive samples. However, such baits provided few extra data (one possum only) and were therefore not used thereafter. Finally, our forest-edge line was shifted laterally about 1 km from sample 2 onwards, to overcome landowner concerns (our presence on his property) and to ensure ongoing land access.

We trapped our lower two lines to near extinction in our final sample by setting traps and cyanide baits for a minimum of 7 nights, so that our total sample across all four transects and all four seasons provided a reasonable index of the maximum number of possums that could potentially have moved through this 1-km-wide strip of forest to farmland.

Any possums killed were necropsied as described in Section 4.2, aged from cementum annuli in its third molar (Pekelharing 1970), and its maturity determined (females judged as adult from the presence of a fully developed pouch and males from a combination of testes > c. 13 mm, a well-developed prostate (> c. 20 mm in diameter). We compared possum measurements and numbers of kills between transect four (c. 1 km from the forest–pasture margin and the other three transects, to assess whether there was a predominance of juveniles on all lines once most residents had been killed in the initial survey, and to determine where most juveniles were taken. We recorded possum kill location via GPS and related each animal to streams, main ridges, and the distance to the uncontrolled possum populations behind the buffer, to assess whether these were the main routes used by, and sources of, dispersing possums. The trial was also used to indicate the number of long-life baiting transects required to reduce the flow of dispersing young possums through controlled forest and scrub adjacent to farmland. Finally, we also scored the vegetation present at each trap/poison site and compared indices of possum abundance determined from our trapping and toxic baiting with that determined by RTCI monitoring following control over the same area immediately before our monitoring began, to assess the coverage achieved by the control (and reasons for the presence of any patches of surviving possums) and the rigour of the formal monitor.

4.5 Pigs, deer, and possum carrion as sources of Tb

To determine whether infected pig and deer carcasses left by hunters or from natural deaths were common enough to be a likely source of continuing infection in ferrets (hypothesis 2), we attempted to informally survey local hunters (as in project R10577; Nugent et al. 2003) to determine, in very broad terms, the approximate numbers of pigs or deer killed locally each year, where the carcass remnants (heads and paunches) were left, and whether any signs of Tb were observed in any carcasses.

We also collected a sample of pig heads and attempted to collect a sample of deer heads from hunters using the VCA. All the pig heads were inspected for the presence of Tb by excising the parotid, submaxillary, cervical, and retropharyngeal lymph nodes and the palatine tonsils. All suspect tissues and the pooled submaxillary lymph nodes from each pig were cultured and Tb strain typed if infected. A jaw was removed from each head for subsequent aging from tooth eruption patterns (Clarke et al. 1992).

To determine the likelihood with which post-mortem transmission of Tb occurred from pig carrion to scavengers such as ferrets, cats, or possums, 14 non-lesioned pig heads with all lymph nodes and tonsils removed were obtained from a pig farm free of Tb. During autumn 2004, single pig heads were located under an intact mānuka-dominated canopy 3–5 m high at six sites near the 'twin bridges' across Abbots Creek (where the numerous dumps of pig remains confirmed the area as a hunters' offal dump site). Five pig heads were placed in low (1–2 m) windswept regenerating native scrub and gorse above the Town Reserve, and three heads placed under an intact canopy of mānuka/beech 3–5 m high near the Tauherenikau River car park. Once there, their fate was monitored with Trailmaster™ 24-hour motion-activated video camera systems set up for a total of approximately 11 weeks to determine which wildlife species visited them, and the frequency and nature of any wild-animal – pig-head interactions. Such an approach followed that used in earlier AHB-funded studies for pigs (Yockney & Nugent 2003) and ferrets (Byrom 2004). Each head was wired down to prevent scavengers removing it from camera view. Camera units were located at sites where they were unlikely to be found and stolen.

Two camera systems were used: an 8-mm and a Digital 8 video system, and both were activated by an infrared sensor that detected the body heat and movement of visiting animals. Each offal site was lit during night events by a 30W red-filtered spotlight, under the control of the Trailmaster™ software. The 2-hour videotapes were changed at least once each fortnight, but sometimes all the available tape was used well before the replacement date as a result of frequent activation by flies or during scavenging by Australasian harriers (*Circus approximans*). In addition, most systems malfunctioned occasionally, so the record of events at each site was seldom complete. Although each camera system was in place for at least 2 weeks or until all of the pig head had decayed, operational times were thus often substantially shorter than this.

Each tape was reviewed on a large-screen TV, and the time, duration, and nature (species and behaviour) of each visit to each head by wildlife was recorded. The time until the first recorded visit to each site by each species was calculated and recorded as average time to discovery, while the duration of each event was recorded as tape-elapsed time and as such was considered to be the minimum time each species was involved in the interaction.

The fate of possum carcasses was similarly evaluated (hypothesis 1). Two or three ‘opened up’ possum carcasses taken in the NZFT area and free of any gross lesions were placed in front of each of four video-monitoring systems located separately along the scrub–pasture margins on the north-facing slopes above Abbots Creek in summer 2004. Carcasses were monitored for 1 week then replaced by a second set of carcasses that was monitored for a second week.

4.6 Ferrets as a source of Tb

To determine whether the density of ferrets along the bush–pasture margin of the VCA was above the Tb-maintenance threshold postulated for this species, the ferret population between Owhanga Stream and the Tauherenikau River (see Fig. 1) was surveyed in February–March 2004, by intensive live trapping with Holden cantilever traps over about 10 days. All ferrets trapped were lightly anaesthetised with Ketamine (following approval from Landcare Research’s Animal Ethics Committee) and assessed for their maturity from the presence of an obvious sagittal crest and large testes (males), from the condition and size of their teats (freely visible in females), and from the coarse nature of their tail fur (A. Byrom, pers comm.). All adults were killed and necropsied. A canine tooth was taken for subsequent aging following the technique described by Ragg (1997), and key lymph nodes including retropharyngeal, prescapular, deep and superficial auxiliary, inguinal, and popliteal, were taken for culture (following Ragg et al. 1995). All juvenile ferrets were palpated for gross superficial lesions indicative of Tb. Juvenile ferrets free of lesions were fitted with mortality-sensing radio-collars and released as disease sentinels, while any with suspect lesions were euthanased.

Annual trapping (control) of ferrets across all Featherston farmland by the GWRC in May–June 2004 and April 2005 provided further samples of ferrets (and of cats and stoats) for necropsy. All ferrets captured in these surveys were necropsied as above by Landcare Research and AgResearch staff. The ferrets taken in autumn 2004 were also aged, with their ages used to help explain the movement patterns and risks posed to livestock of any culture-positive animals.

Radio-collared ferrets were tracked to their den sites each day for 2–3 successive days in three successive months from their initial trapping until May 2004, and in July and September 2004 as opportunity permitted, with their locations and distances between recaptures providing limited data on their broad-scale movement patterns and habitat use. In particular, radio fixes of their location provided some indication of the extent to which they ranged into the gorse-covered hillsides. We also planned to generate estimates of ferret population density from the capture data of marked ferrets by control staff during official ferret control. As none of our marked ferrets were captured in the initial control following marking, we were unable to generate this statistic. Finally, we attempted to recover all radio-collared ferrets to determine how many of them had become infected.

4.7 Analysis of data

The number of possums within the dense forest and scrub adjacent to farmland was analysed using GLMM (GenStat 2002, release 6.1), with the fixed effects being the monitoring device, distance from pasture, and their interaction, while the lines were used as random effects. Non-significant fixed effects were dropped sequentially from the model until only significant terms remained (Crawley 1993). The significance of the remaining terms was tested using a WALD test. The variation in the age of possums with distance from the pasture margin was analysed using the GLM procedure in the statistical package S-Plus (Version 6.2, Insightful Corp., Seattle, WA) (Venables & Ripley 2002).

Possum numbers and locations in relation to the pasture edge in our immigrant-flow study were analysed using the GLMM PQL routine in S-Plus based on a mixed model of poisson (count) and binomial (proportion) data, with the trap lines treated as random effects.

Dispersal distances for live-captured ferrets were calculated as the straight-line distance between the first and final locations for each animal (after Caley & Morriss 2001; Byrom 2002). For every possible pair of locations recorded for each ferret, the first recorded location was treated as the site at which the ferret nominally acquired Tb and the later location as the place where it was nominally killed and necropsied for Tb. The distance between each location and every subsequent location was calculated for each animal. The cumulative frequency distributions of these distances were then standardised by expressing the cumulative frequencies as a percentages of the total number of nominal 'infected-to-necropsied' distances calculated for each ferret.

5. Results

5.1 Historical vector control

Aerial baiting for possum control

Baiting patterns: Possum populations on approximately 3700 ha of Crown and NZFT lands between Owhanga Stream and the Tauherenikau River and between farmland and the crest of the Rimutuka and Tararua ranges were controlled with aerially sown 1080 bait in April 1996 and again in June 2001. The areas poisoned in these two operations were similar (Fig. 2), differing only in greater coverage at the rear of the block and on the southern hillside above Boar Creek in 2001.

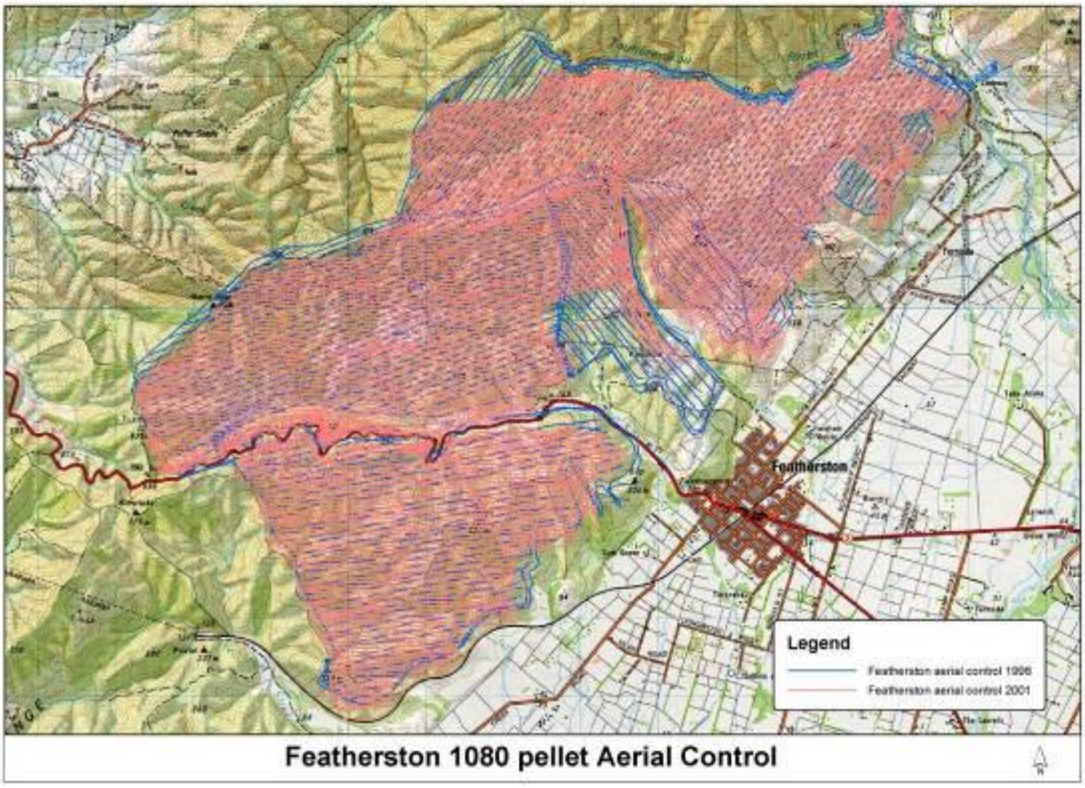


Fig. 2 Featherston Crown and NZFT areas aerially sown with 1080 bait in April 1996 and June 2001, and the flight paths taken by the aircraft involved.

In 1996, the area controlled was sown with 6-g Wanganui No. 7 cereal bait at 4.46 kg/ha (c. 1 bait/13.5 m^2). Baits were loaded with 1080 at 0.15% and lured with 'all spice'. No pre-feed was applied. GPS flight data indicated good bait coverage, with one small in-forest gap near Nicholl Peak south of Abbots Creek (Fig. 2). In addition, some small areas near the pasture edge were deliberately left untreated, but were covered by ground-based control the following year. The within-forest gap near Nicholl Peak was not. The operation followed standard practice for that time, and there are no reports of any field practices that might have adversely affected the outcome.

By comparison, more complete details of the bait and baiting strategy in 2001 were available for analysis. In that year, the area controlled was pre-fed with non-toxic 11-g Wanganui No. 7 bait masked with cinnamon essence at 0.4%. Thirteen days later, the same area was sown with the same bait type loaded with 1080 at 0.15%, 6 weeks after manufacture, and at a rate of 2 kg/ha (c. 1 bait/55 m^2). Coverage appeared to be complete. The flying was done under anticipated patterns of at least two nights of fine weather. While 4 mm of rain fell over the first 4 days after poisoning, no rain occurred over the following 12 days. Finally, heavy and continuous rain fell 16 days after baiting, leading presumably to substantial bait and toxin loss. Thus, this operation was followed by patterns of weather initially underpinning good possum kills, and later by the desired rapid detoxification of the bait. Independent analyses of bait quality provided no evidence of substandard bait (G. Wright, Landcare Research, report to GWRC).

Operational success: Monitoring of operational success in 1996 and 2001 followed somewhat different procedures from the monitoring protocol developed later (NPCA 2002).

Before control in 1996, pre-control trap-catch monitoring of eight randomly located lines of 20 traps set for three fine nights in the poisoned area indicated a high catch rate (26.8 ± 4.0%; 95% CI). Post-control monitoring along similar trap lines paired with seven of these lines revealed a trap catch of 4.2% (with no CI available), a reduction (‘kill’) of 84%, which was normal for operations at that time (Morgan & Hickling 2000). The post-control trap catch was below the 5% then set as the target for control operations (Coleman et al. 2002), and although the data indicated patchy survival with high residual numbers of possums in areas that caught high numbers prior to control, the operation was deemed a success.

Further monitoring of this area in 1999, based on 12 randomly located lines of 20 traps set for two nights, gave a population index of 13.2 ± 3.3%. This is three times higher than that immediately following control in 1996, and indicated a rate of increase far exceeding that possible for possums across medium to large control areas (i.e. intrinsic rates of increase of 0.22–0.59; Hickling & Pekelharing 1989). This increase likely reflects a bias in post-control trap catch estimates that has now been observed in a large number of operations and studies (e.g. Coleman et al. 2002; Forysth et al. 2003). Catches on these lines were variable. One of five lines catching large numbers of possums was located on the extreme rear margin of the baited block while two lines with similar high catches were located near the front margin. Catches on all three were probably influenced by local immigration: the rear line from possums immigrating from adjacent uncontrolled deep-forest populations, and the front lines because they were located in areas readily accessible to control staff and favoured as settling sites for dispersing possums (Green & Coleman 1984). The remaining two lines with high catches in 1999 were located in heavy gorse or native scrub, and appeared to reflect inadequate control.

Finally, in July 2001, following the second aerial baiting, a monitor based on 10 lines of 20 traps provided a trap-catch population index of 0.83 ± 0.44% and indicated a population reduction (‘kill’) of approximately 94%. This was in keeping with the higher kills that normally followed the introduction of GPS technology to bait sowing protocols in the early to mid-1990s (Morgan & Hickling 2000).

Ground control of possums

Official ground control of possums across the farmland began in 1991/92 and, because of ongoing disputes with several local landowners over vertebrate pest control on their land, has been undertaken in recent years only by GWRC staff well known to landowners. This strategy was strengthened in 2003/04, when all ground control of possums carried out was undertaken by a single 'preferred contractor' previously employed by GWRC.

Beginning in 1998/99 (the start of the period chosen for this study), ground control of possums was undertaken typically each autumn along the scrub–farm margins along the foothills of the Rimutuka and Tararua ranges (later called HR1 and Crown HR1; 1584 ha) but excluding the Town Reserve immediately behind Featherston. Control involved the use of brodifacoum in bait stations spaced at up to 100-m intervals on scrub margins baited for about 4 weeks, and Timms kill traps set over 680 ha about homesteads and the township. Trapping produced 84 possums at a catch rate of 1.4/trapper-hour or only 0.12 possums per hectare-trapped. However, the total number of nights the traps were set was not recorded, so this information is of little value in indicating local possum abundance. Possums were also controlled using brodifacoum bait in bait stations on six farms and the adjoining Lake Domain (c. 520 ha), a long-standing focus of infected livestock. Thirty-eight dead possums were seen following the control, but records of the effort expended were unavailable and operational success was not formally evaluated.

Ground control of possums in 1999/2000 was undertaken across approximately 6400 ha of farmland and adjacent scrub margins. The techniques included kill trapping over most farmland, baiting with brodifacoum about the Lake Domain and in gorse scrub, and baiting with hand-laid 1080 carrot across Pigeon Bush (the largest farm present) and in riparian vegetation along the Tauherenikau River. Trapping data indicated a kill of 3.7 possums/trapper-hour or one possum per 23 ha trapped. A post-control monitor across the farmland in July 2000 was based on nine lines of 20 traps set over three nights and provided a population index of 6.1 ± 5.4% (data for this and subsequent monitors shown in Table 1). The catch on eight lines on farmland and along gorse margins was less than 2%, but on one line in Lake Domain was 53.2%, with the latter reflecting problems of access into the frequently flooded swamp.

No possum control was undertaken in the VCA in 2000/2001, although a pre-control (trend) monitor was undertaken in May 2001 in the Lake Domain for a control of the area planned for May/June. However, control was held over till July 2001 because of an anticipated conflict between control staff and duck shooters at the earlier time (G. Lewis, ex-GWRC, pers. comm.). In that monitor of Lake Domain, six lines of 20 traps monitored for two nights provided a population index of 7.7 ± 3.1%, with individual line catches varying from 0 to 23% and lines with high catches both in the centre of the domain and on adjacent farmland. The combined results of the post-control monitor in July 2000 and pre-control monitor in May 2001 indicated the possum control undertaken in Lake Domain 18 months earlier was patchy and largely ineffective.

Table 1 Operational success in Featherstone VCA, indicated by RTCI monitoring following ground control of possums in 2000/01–2003/04. The operational target for each stratum from 2001/02 onwards was 2%. Failed monitors are bolded.

Year	Strata					
	Scrub/forest HR1 (%)	Scrub/farm HR2 (%)	Farm HR3 (%)	Farm HR4 (%)	Farm HR5 (%)	Farm MR1(%)
2000/01			6.1±5.4			
2001/02				7.7±3.1		
				7.0		
2001/02	4.0±2.8	9.5±12.7				1.0±1.0
	10.8±9.7	1.0±1.0				
2002/03	1.13±1.0 a					
	1.8±1.6 b					
	25.3±? c	0.9±1.0	0.2±0.4	0.0		0.0
	1.1±1.4c					
2003/04	2.5±1.2 d		0.0	0.2±0.5	0.0	0.0
	1.7±1.2		0.2±0.4			
	0.7±1.9 e					
	0.3±0.6 f					

Note: Letters indicate control areas; a = Boar Creek to Tauherenikau River; b = Abbots Creek to Tauherenikau River; c = Abbots Creek to Boar Creek; d = north face of Abbots Creek and scrub hillsides further north; e = Boar Creek; f = Abbots Creek to Owhanga Stream.

Possum control in the VCA in 2001/02 involved brodifacoum baiting in late winter in and about the Lake Domain (the same area controlled 2 years previously). A monitor of this operation 6 months later using three lines of 20 traps gave an index of 7.0% (no CI available), with one line of 23% indicating another poor kill in part of the area. Possums were also controlled using kill traps and brodifacoum bait in late winter along the north side of Abbots Creek and on Crown land (largely HR1; Fig. 1) to complement the adjacent aerial control completed 1 month earlier, and 450 possums were taken from an unknown number of trap nights. Subsequent monitoring (following the then newly drafted national monitoring protocol; NPCA 2002) indicated successful control in MR1 (i.e. the operational target of 2% achieved; area subsequently called HR5), but unsuccessful control in HR1 and HR2. Further ground control in March 2002 led to the achievement of operational targets in HR2 but a further operational failure in HR1. A satisfactory result for this stratum (HR1) was achieved only after a second ‘reworking’ (additional control) and remonitoring 12 months later. Two lines in two of these monitors failed to comply with the national monitoring protocol, being redirected away from ‘impenetrable’ patches of gorse, which is likely to have reduced the accuracy of the RTCIs.

In 2002/03, the farmland in the VCA and the nearby scrub- and forest-covered hills (the Crown and NZFT areas) were split into five strata for possum control, and formal monitoring of each operation was undertaken in most strata (Table 1). Feratox bait at 3.5 bags/ha and Timms and Victor traps were used over c. 2200 ha of the Crown lands, and Timms traps used across c. 4300 ha of farmland. Lines of Feratox baits were laid along stream courses up into Crown blocks (as routes of easiest human access), but clearly left unbaited areas between bait lines 500–1000 m wide (see Fig. 3 for similar line locations used in 2003/04). Traps on the farmland captured 256 possums or one per 17 ha trapped. Monitoring, based on further stratification of HR1, indicated successful control in two of the three strata. However, in HR1c, an initial monitor result of 25.3% (no error statistics available) in July 2002 reflected the very limited earlier control immediately behind Featherston Township. Further control immediately thereafter in this area produced an acceptable RTCI of 1.1 ± 1.4%. Population monitoring later in 2002/03 in all other strata (Table 1) was uniformly low, and indicated the control target (2%) had been achieved, including in the troublesome Lake Domain (HR4). Two monitor lines did not comply with the monitoring protocol, being redirected away from patches of gorse.

Finally, in 2003/04, similar control was undertaken again in HR1, HR3, HR4, HR5 and MR1 (but with 1080 apple bait laid along the railway line and adjacent to Abbots Creek in HR1), and the subsequent population monitors including that of the Lake Domain generally indicated successful control (Table 1). Highest indices on lines were again confined to the area immediately north of Abbots Creek (HR1d, see Table1), where the scrub faces of the upper Boar Creek area and the Town Reserve within the town boundary were controlled for the first time. The number of small farm holdings in this area made pest management difficult, and the mean RTCI exceeded the target RTCI. Very low RTCI indices were recorded on farmland (HR3 monitored twice, HR4, HR5, and in the scrubland of MR1). However, in that year issues of non-compliance of trap line locations arose in three monitors, with six lines allocated in the Lake Domain (HR4) shifted because of ‘impenetrable swamp’, three lines in HR1 and two lines in HR6 altered to avoid impenetrable patches of gorse and blackberry, and one line abandoned because the traps used in the monitor were stolen. Control elsewhere in HR1 was also undertaken in April–May 2004 (HR1b & c, Table 1) using 1080 apple and Feratox for the second year in a row, but was largely confined to all minor stream beds (Fig. 3). A subsequent monitor indicated a very good kill (0.3 ± 0.6), with only one possum being taken in each monitor. In May–June 2004, further control using traps on One Tree Hill and its immediate environs resulted in a kill of 230 further possums, and reflected the very limited past control there.

Further possum control and associated operational monitoring was undertaken in the VCA in 2004/05. However, our efforts in that year were redirected to other aspects of this project, and we did not undertake any analyses of operational success.

Trapping of possums, while undertaken less widely in local ground-based control than toxic control, captured variable numbers of possums on farmland throughout the period monitored (Table 2). However, without access to better information on possum kill rates, we are unable to determine whether these catches reflected sustained high numbers of possums on farmland despite ongoing possum control, or increased effort in on-farm possum control of a declining possum population. Better kill data now being collected will help resolve this issue in the future.

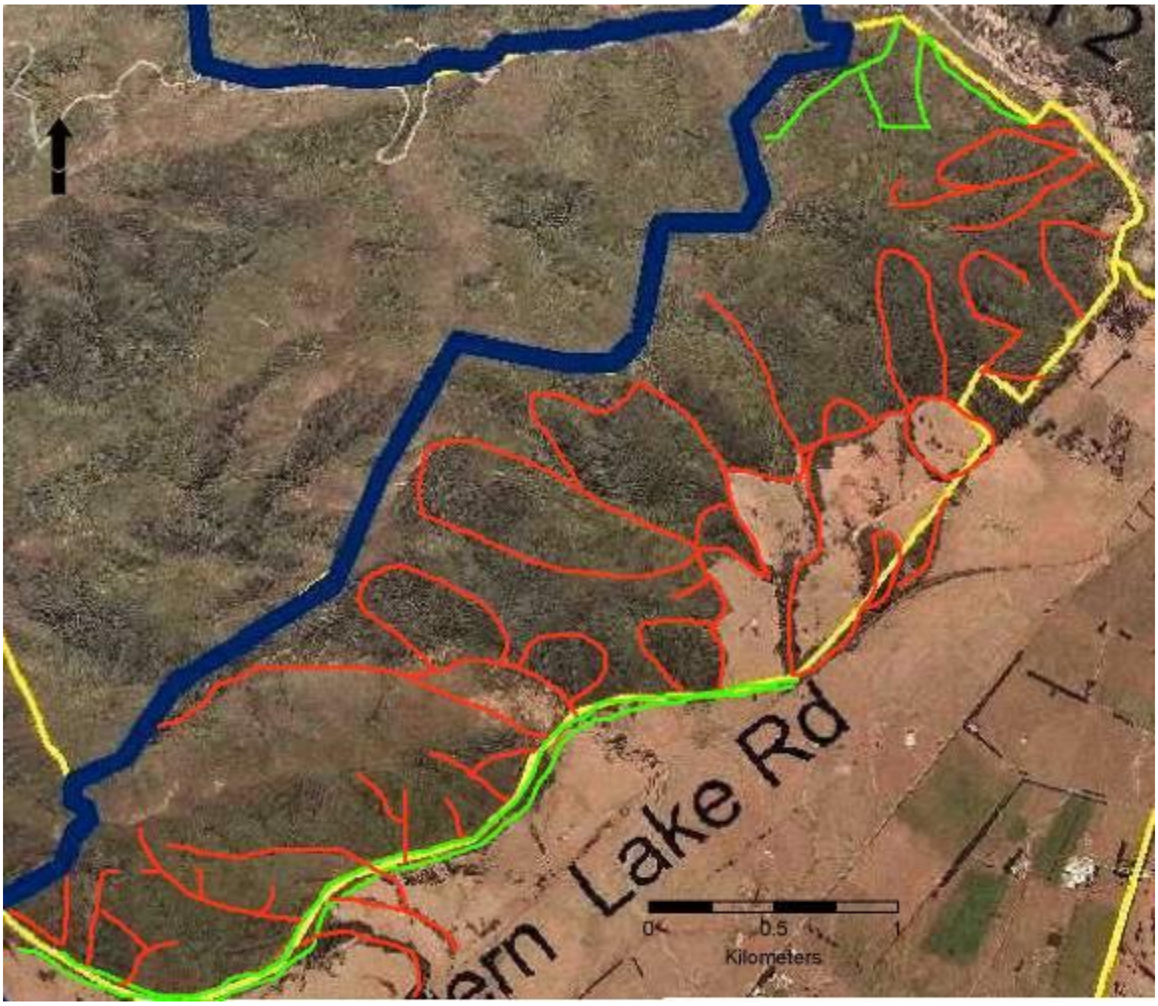


Fig. 3 Location of lines (Feratox® in red, 1080 apple bait in green) of toxic bait used to control possums in April–May 2004 in HR1 south of Abbots Creek. Note the substantial unbaited areas.

Table 2 Available information on number of possums taken in traps and catch rates from the Featherston VCA from 1998/99 onwards.

Year	Area	No. of possums	Catch/hr	Catch/ha
1998/99	Lake Domain	38+		
	Farmland	84	1.4	1/8
1999/2000	Farmland	Unknown	3.7	1/22
2000/01	Farmland	Nil		
2001/02	Scrub land	450		
2002/03	Farmland	256		1/17
2003/04	Town Reserve/Abbots Creek	297		

Ferret control

Ferret control in its present form began in April–June 2000, when all habitat thought to be optimal for ferrets (i.e. scrub–pasture margins with abundant rabbits) across the farmland in the VCA and along the west side of Lake Wairarapa was trapped by GWRC staff. For this work, Fenn and Timms kill-traps were set in tunnels at selected 'best' sites approximately 100 m apart and baited with rabbit meat for 5–15 nights. Results of this control and of control in subsequent years were determined by a simplified form of 'input monitoring' (approved by the AHB), i.e. from the catch achieved and hunter effort expended, rather than from the trap-catch index used for possums. No record was obtained of the number of trap sites used in 1999/00, but 59 ferrets (including one animal infected with Tb) and four weasels were trapped at a cost of one mustelid per 1.8 trapper-days, or per 1/95 ha. This data cannot be used to assess the effect of the control on ferret density, but while there appeared to be good coverage of the farmland, the scrub–pasture margin, and along riparian vegetation in the VCA, the lack of any formal audit of the control operation limited any serious analysis of its success.

No ferret control was undertaken in 2000/01. However, in 2001/02, ferret control was undertaken in March–June over all habitat thought to be favoured by ferrets, and 40 ferrets (20 males, 20 female), 3 stoats and 7 cats were captured. Three ferrets taken close to or on scrub–farm margins on the foothills of the Rimutaka and Tararua ranges were infected with Tb (see Fig. 1). However, no catch-per-unit-effort data were available for comparison with 1999/00.

Ferret control in 2002/03 was undertaken in autumn, mainly in Abbots Creek south of Featherston Township and in riparian vegetation along the Tauherenikau River. Sixty-four traps were set for approximately 2 weeks and no ferrets (but four cats) captured.

Ferret control in late May–June 2004 was restricted to trapping about Owhanga Stream, to all valleys from Abbots Creek to the Tauherenikau River, on farmland immediately west of Featherston Township, and throughout Lake Domain. Traps were set at 192 sites, and eight ferrets (1/32 traps set; 3%), 18 cats, and one stoat were captured. Four ferrets (and one stoat) were taken in Lake Domain, two near Owhanga Stream, and one each in Abbots Creek and north of Boar Creek (Fig. 4). Cats were taken across the entire area trapped. The ferret catch rate may have been affected by the killing of 10 adults and one juvenile ferret during the initial phase of our ferret dispersal study undertaken along the scrub–farmland margin of the Rimutuka and Tararua ranges in February–March 2004 (see Section 5.6). At least six radio-collared ferrets were known to be alive and within the area trapped for ferrets by GWRC in winter 2004 (see Section 5.6), but none of these were trapped, indicating a low kill rate.

Ferret control in April 2005 was undertaken over approximately 50% of the VCA farmland (blocks HR2–5, Fig. 1; 4984 ha), and appeared to target all areas likely to favour ferrets except the Pigeon Bush block south of Abbots Creek (where access was limited) and open farmland in the core of the block (Fig. 4). The programme captured 52 ferrets (c. 2/km^2), 11 cats and one stoat. Two captured ferrets had radio collars fitted 14 months previously. No more than six (and probably far fewer) radio-collared ferrets could have been present at that time, indicating at least moderately successful ferret control.

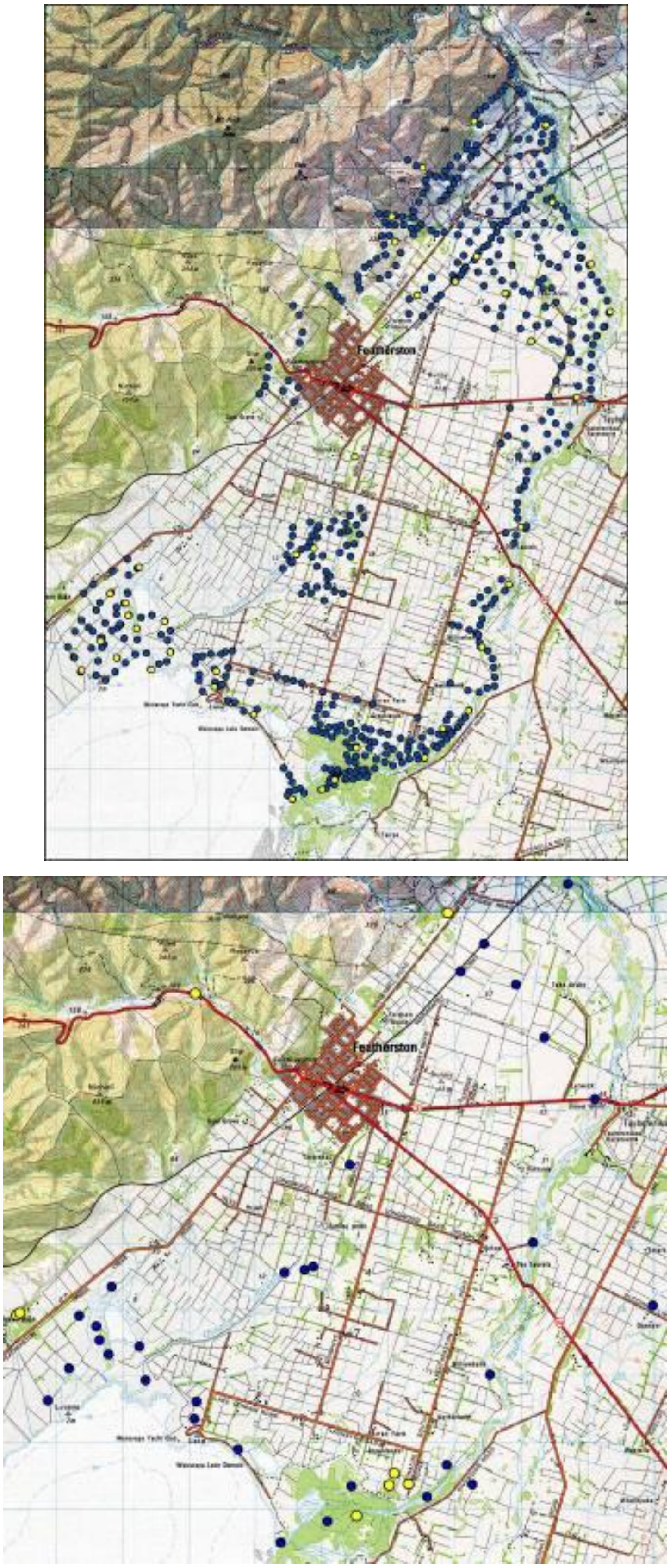


Fig. 4 Trap sets (blue circles) and capture sites (yellow circles) for ferrets during official control in the Featherston VCA in May–June 2004 (lower figure) and April 2005 (upper figure).

Official control killed similar numbers of ferrets in 1999/2000, 2001/02, and 2004/05, but fewer animals in 2003/04 (Table 3). The low catch in 2003/04 is likely to reflect the smaller area trapped that year, the earlier removal of 11 ferrets by us, the more geographically limited trapping undertaken compared with that in other years, and perhaps partly because trapping was undertaken later in the year when ferrets are harder to catch (Anon. 1996). The data collected from ‘input monitoring’ does not permit any estimate of percent kill nor of population trend. The lack of an effect on our radio-collared ferrets in 2003/04 suggests percent kill was low, at least in that year, whereas the very limited data (two kills) in 2004/05 suggests at least a third of adults may have been killed that year.

The number of cats caught in traps set for ferrets was generally less than 20% of the number of ferrets, except in 2003/04 when the ferret catch was far lower and cat catch far higher than usual. The reason for this is unknown.

Table 3 Ferrets captured each year in the Featherston VCA control programmes.

Year	Area trapped	No. ferrets	Other mustelids	Cats
1999/00	All farmland	59	4	
2000/01	Nil			
2001/02	All farmland	40	3	7
2002/03	Abbots Ck/Tauherenikau R.	0	0	4
2003/04	Scrub margins/ Lake Domain	8	1	18
2004/05	All farmland	52	1	11

5.2 Mapping of pre-control possum density

Location and distribution of possums

Mapping of possums undertaken immediately before annual ground control on trap/poison lines located over c. 90 ha between Boar Creek and Abbots Creek (northern block) and over c. 230 ha south of Abbots Creek (southern block), indicated possums occurred throughout most of the forest and scrub surveyed (Fig. 5). Bite marks on the Wax Tags provided the clearest picture of possum distribution. We recorded ‘unknown’ interferences on most Feratox baits (apparently involving both possums and rats attracted to the paste lure and tearing bags apart in a manner often indistinguishable from one another), making the true level of interference by possums on Feratox baits unknown. Only baits interfered with and accompanied by a possum carcass were therefore scored as a possum interference, but the dense gorse scrub and/or steep slopes present must have resulted in a substantial number of unrecovered carcasses. In far easier terrain and more open habitat in Hochstetter Forest, Westland, about 50% of radio-collared possums killed by Feratox were not found on the bait line (B. Warburton, pers. comm.). Similarly, the sticky-trap option at Featherston provided many ‘unknown’ strikes, largely because traps rapidly lost their stickiness after rain (a problem primarily in the southern block where most rain was encountered) and, though sprung, provided few recognisable possum ‘strikes’.

All three indices of possum abundance produced different estimates of possum interference, although all indicated higher possum numbers in the northern block, in line with past patterns of control. Thus while possum interference on Feratox baits was scored at 15.7% and 3.1% on the northern and southern blocks respectively and led to the recovery of 0.44 and 0.08

possums per hectare, interference on Wax Tags occurred at rates of 18.7% and 14.3% and on sticky traps at rates of 12.8% and 2.5% in the same blocks.

A comparison of possum interference rates with sticky traps with estimates of animal abundance from simulated trapping (Ramsey et al. 2005) indicated population densities of about 2–3 and 1 possum/ha for the northern and southern blocks, respectively, and thus close to or under the operational targets sought by GWRC for the scrub blocks within the VCA. Such a comparison should, however, be treated cautiously, as trap interference may not necessarily equate with trap control.

Fig. 5 Location of lines used in mapping of possum presence in Featherston Crown Area (HR1), and location of possums (green circles) taken on Feratox® baits on the lines. Note, the cluster of possums taken at the rear of the northern block are scattered across c. 1 km of trap line from the nearby pasture shown at the origins of lines 1–3.

Bearing the restrictions of all three techniques in mind, the proportion of possum strikes on our interference indicators was less than 0.20 on most devices in successive 200-m strata in both blocks (Figs 6 and 7). Interferences by all possums in the northern block on all three indicators did not differ significantly with the technologies used ($\chi^2_2 = 3.23$, $P = 0.198$), with distance up to 1000 m from the pasture edge ($\chi^2_1 = 3.45$, $P = 0.063$), or with any interaction between detection devices and distance from pasture ($\chi^2_2 = 1.65$, $P = 0.438$), although beyond 1000 m the few devices present indicated possum interference (and hence possum numbers) increased on all interference indicators (Fig. 6). In contrast, in the southern block, neither the interaction between detection devices ($\chi^2_2 = 0.82$, $P = 0.66$) nor distance from the pasture edge ($\chi^2_1 = 2.72$, $P = 0.10$) was significant, but the main effect of the detection device was highly significant ($\chi^2_2 = 41.72$, $P < 0.0001$), with interference on Wax Tags greater than that on Feratox baits or traps (Fig. 7).

Analysis of carcass distribution (arising from Feratox baits) also indicated no significant effect of distance from pasture edge in both the northern ($T_{40} = 1.46$, $P = 0.15$) and southern blocks ($T_{41} = 1.02$, $P = 0.31$).

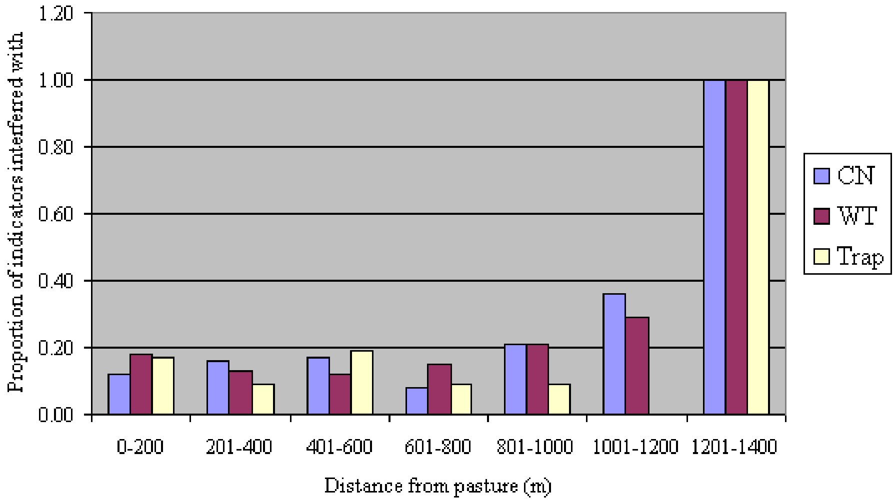


Fig. 6 Proportion of Feratox® baits (CN), Wax Tags® (WT), and sticky traps (Trap) interfered with by possums with distance from the pasture margin in the northern block, Featherston VCA.

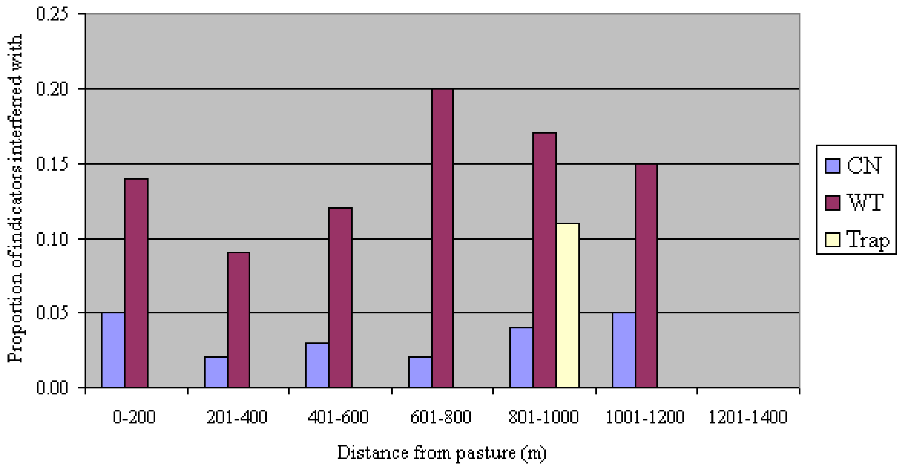


Fig. 7 Proportion of Feratox® baits (CN), Wax Tags® (WT), and sticky traps (Trap) interfered with by possums with distance from the pasture margin in the southern block, Featherston VCA.

Sixty possums were taken on Feratox baits from both blocks combined (Fig. 5). Forty-one of these animals were recovered on lines dominated by heavy gorse on the hillside in the northern block, and only one of these animals was taken within 100 m of the pasture margin. It thus appears that possums surviving control in this block occurred very largely in the most remote scrub and in patches of dense gorse, and infrequently within 200–300 m of the scrub–pasture margin. The gorse-covered slopes above Boar Creek had been largely omitted from any ground control before our survey, apparently because much of the area was within the town supply water catchment (G. Lewis, ex-GWRC, pers. comm.). In contrast, only 19 possums were taken from lines on the hillside in the southern block, and 11 of these occurred in the mixed gorse and regenerating native scrub on the rear half of each line. Possums captured in this study block reflected a survivor population scattered thinly across the study site. While this block contained less gorse and more patches of native forest and scrub than in the northern block, possums tended once again to be captured in the least accessible habitat. The data are consistent with the history of possum control in the surveyed areas. Both blocks were aerially poisoned in 2001 (see above) but while ground control in 2001/02 and 2002/03 in the northern block has been largely confined to within c. 200 m of the scrub–pasture margin, that in the southern block has been undertaken annually throughout the area, although confined to the more accessible travel routes along watercourses.

The ratio of juveniles to adults (21:38, one unaged) taken across the full width of both blocks combined, did not vary with distance from the pasture margin ($\chi^2_6 = 6.53$, $P = 0.37$). While juveniles outnumbered adults by 4 to 2 in the 0–200-m strata, further back into the forest, juveniles typically made up a third of the catch and more closely represented that expected from a species that has a roughly equal sex ratio and normally produces one young per year (Fig. 8). Proportionately fewest (1 of 7) juvenile possums occurred in the deepest strata (1001–1200 m) closest to the possum population uncontrolled by ground baiting nearby. Thus, while such dispersion patterns were not significant, there appeared to be weak evidence that juvenile possums surviving control or in the adjacent uncontrolled population, had emigrated down towards the pasture edge following earlier control.

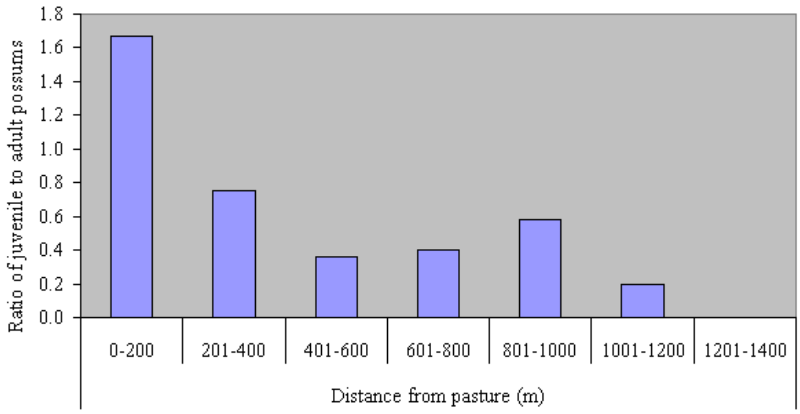


Fig. 8 Ratio of juvenile to adult possums with distance from the pasture margin into the scrub/forest in the Featherston VCA, of all possums taken on Feratox® baits during possum mapping.

5.3 Flow of immigrant possums as a source of Tb

Location and distribution of possums

The total number of possums sampled each season across all four trap and poison lines running parallel to the pasture margin in the Crown, private, and NZFT areas from Abbots Creek to immediately north of Prince Stream was similar ($F_{3,9}$ = 1.84, P = 0.21) (Fig. 9). Highest numbers of animals were taken from traps, fewer from cyanide paste baits, and fewest from the Feratox baits (see Appendix 1). As only one possum carcass was recovered from Feratox baits left out between our first and second seasonal samples, the technique was discontinued. Traps were clearly more effective than either cyanide paste or Feratox baits at capturing possums at this site, and anecdotal evidence from past research suggests that this is often so (Coleman unpubl. data).

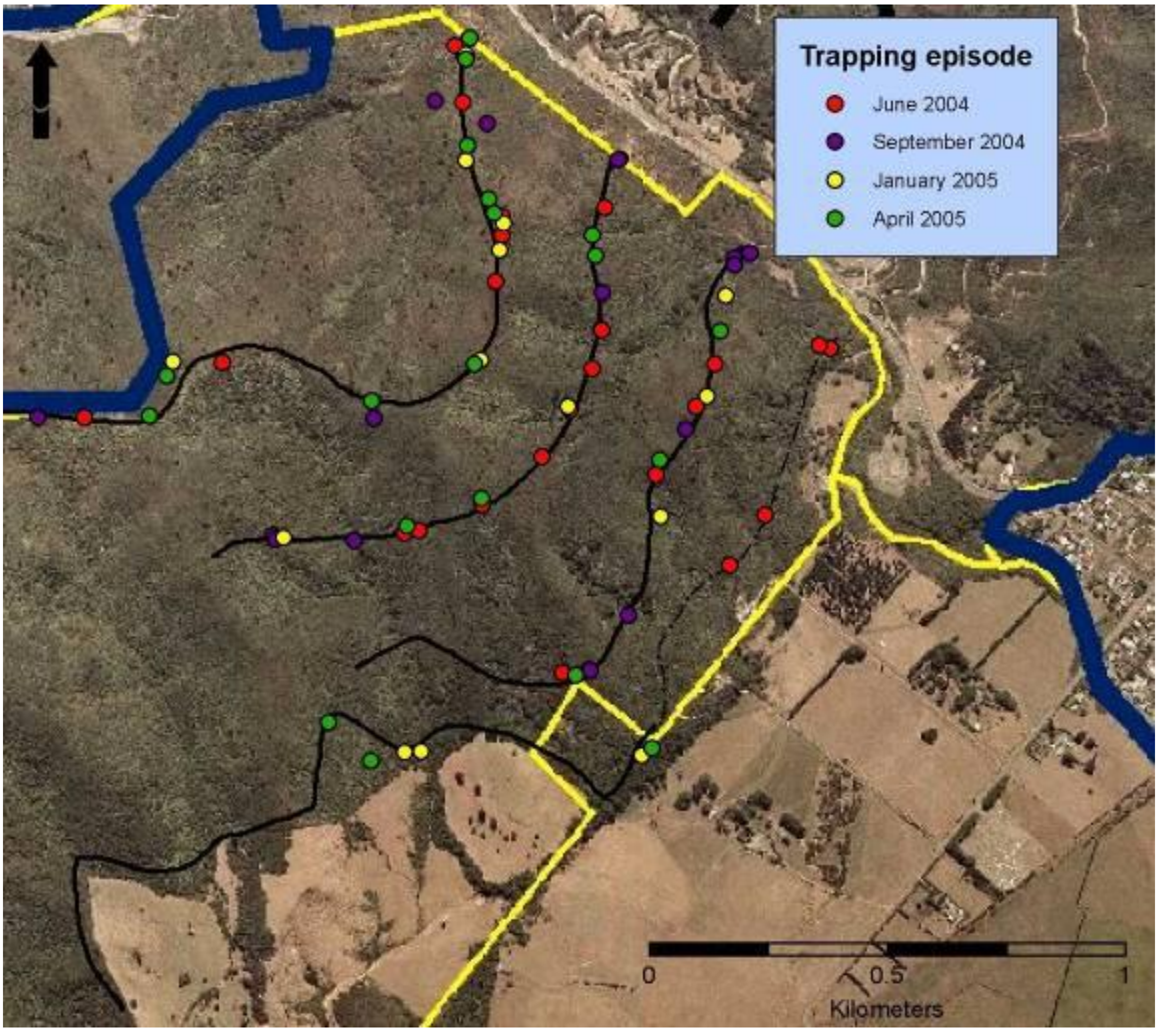


Fig. 9 Location of the lines surveyed and possums captured each season across the Featherston Crown and NZFT areas, from June 2004 to April 2004, in our Immigrant Flow study.

Most possums in our winter sample were adults (>2 years old; 17 of 28, 61%), but young possums predominated increasingly in our spring, summer, and autumn samples (10 of 16, 12 of 15, and 18 of 20; Table 4; $F_{3,8}$ = 6.27, P = 0.02). When averaged over the year, young possums were least common on the line closest to pasture and most common (2.9 times greater) on the deepest forest line, indicating that most were probably dispersing into the control block from the uncontrolled adjacent forest. However, this difference was not significant for either absolute numbers ($F_{3,9}$ = 2.23, P = 0.15) or for the proportion of young possums sampled on different trap lines ($F_{3,8}$ = 0.09, P = 0.96), probably because of the small sample sizes.

Table 4 Catches of possums (Males/Females) on four lines set to monitor the seasonal flow of immigrant possums in HR1.

Sample	Line 1(bush edge)		Line 2		Line 3		Line 4 (ridge)	
	M	F	M	F	M	F	M	F
June 04 Adult	0	4	2	1	2	4	1	3
Imm.	1	0	1	2	2	1	2	2
Sept. 04 Adult	0	0	2	1	1	0	1	1
Imm.	0	0	1	2	4	1	1	1
Dec. 04 Adult	0	0	0	0	1	0	2	0
Imm.	3	0	1	2	1	0	4	1
Apr. 05 Adult	0	0	1	0	1	0	0	0
Imm.	2	1	2	1	2	1	5	4
TOTAL	6	5	10	9	14	7	16	12

This distribution indicated that few of the young possums captured were born in the controlled area to possums surviving recent control, as 37 juveniles were taken over the final three surveys and only two adults. It was very unlikely that young possums could have either dispersed into our survey area from nearby pasture, where possum control was most effective and possums were in extremely low numbers, or have travelled into the area laterally across the study site along heavily controlled scrub margins from uncontrolled populations.

Fifteen juvenile possums were captured on the two lines closest to the pasture margin between September 2004 and April 2005, a period which included the two main times of year when young possums disperse. If all these were dispersers, this represented an immigrant flow of 4.5 possum per kilometre of bush edge. If (as a worst-case scenario) all of the juveniles trapped during this period eventually reached farmland, the estimate would increase to 11.4 possum per kilometre of bush edge. Such possums, coming from a higher-density population last controlled in 2001 and at its closest point 1 km from pasture, appear to pose an additional threat of Tb infection to livestock over that of adult survivor possums living along the annually controlled bush edge.

Finally, the location of possums captured in our immigrant-flow study appeared to be strongly influenced by the physiography and vegetative cover of the hillside. Twenty-four of the 28 possums (86%) captured during the June 2004 survey, 2 months after official control, were trapped or poisoned within 100 m of streams (see Fig. 3 for control line locations), and only 7 (9%) taken more than 200 m from streams. Further analysis of the relationship between our possum catch and the location of official control lines was limited, as the poison lines laid by control staff were mapped using ‘best guess’ on aerial photographs. That said, the distribution of our catch appears to support the control strategy of ground baiting streams and gullies (see Section 5.1) but indicates inadequate control between stream catchments.

5.4 Pig and deer abundance and pig and possum carrion as sources of Tb

Pig hunter survey data

Office holders and club members of the Southern Wairarapa Pig Hunting Club refused all involvement in our study, arguing that the likely repercussions arising from such involvement would adversely affect their local sport. Some information on local pig-and-deer hunting practices were obtained from an ex-DOC hunter (R. Abbot) and from staff at the local DOC office (J. Hansen), but we were unable to assess the size of the local pig population or annual kill in any quantitative manner.

However, Mr Abbot provided us with site locations and heads of 29 pigs killed over a 15-month period from summer 2004 and had killed at least one other pig but only one deer during that time. Consistent with this, both he and J. Hansen (DOC) report that deer are uncommon in this area, apparently due to the dominance of gorse over deer-preferred native vegetation, and are generally only taken incidentally by pig hunters during pig hunting expeditions. As a consequence of their low numbers, we have no information on the disease status of any of the deer present in the VCA. Despite that, their presence affects possum control planning: in 2004/05 possum control planned for the HR1 forest block south of Abbots Creek was delayed until after the 'roar' in autumn 2005 to avoid any impact on deer hunting (G. Butcher, GWRC, pers. comm.). In contrast, the ability of a single hunter to obtain 30 pigs in 15 months, and the existence of an active pig-hunting club in Featherston, indicate the pig population is likely to number in the hundreds.

Tb infection in pigs

Of the 29 pigs obtained, 17 were killed in summer 2004, seven in winter/spring 2004, and five in autumn 2005. The sample comprised 15 males, 12 females, and two animals for which the sex was not recorded. The average age of the 23 pigs killed and aged in 2004 was 21.4 ± 11.93 (SD) months (range 6–42+ months). The pigs killed in 2004 were taken from across HR1 and MR1, between the Abbots Creek and Owhanga Stream catchments in the southern end of the study site (Fig. 10), as were four pigs killed in autumn 2005. The fifth pig from 2005 was killed near the Tauherenikau car park, approximately 6 km north of Featherston.

Of the 17 pigs killed in summer 2004, lesions confirmed as Tb by culture were found in the retropharyngeal and submaxillary lymph nodes of only one, a large 30-month-old boar taken mid-slope on the northern side of Abbots Creek, approximately 3 km upstream of Featherston (Fig. 10). In the same season, a further pig of unknown age and sex shot on the NZFT land was considered by Mr Abbot to be so grossly lesioned with Tb that it was too risky to recover for our study. His field diagnosis cannot be confirmed, but it appears that one and probably two of 18 pigs (6–11%) killed at that time were infected.

Of the seven pigs from winter and spring 2004, three (43%), all with lesions in the submaxillary and retropharyngeal lymph nodes were confirmed by culture as tuberculous. Two of these three infected pigs were large (>45 kg) aged boars (42+ months) and one was an aged (42+ months) sow, with the boars taken from the forest/scrub–pasture margin between Abbots Stream and Owhanga Stream, and the sow at least 3 km into the forest/scrub in the Owhanga catchment (Fig. 10).

None of the five pigs killed in autumn 2005 had gross lesions and all were negative from interim culture 6 weeks later.

Taken together, the four confirmed infected animals indicated an overall prevalence of 13.8%. None of the 23 pigs born in 2002, 2003, or 2004 were infected, compared with four (66%) of the six born before 2002. All four infected pigs appear to be distributed throughout our study area, with two of them likely to have recently foraged close to, if not on farmland.

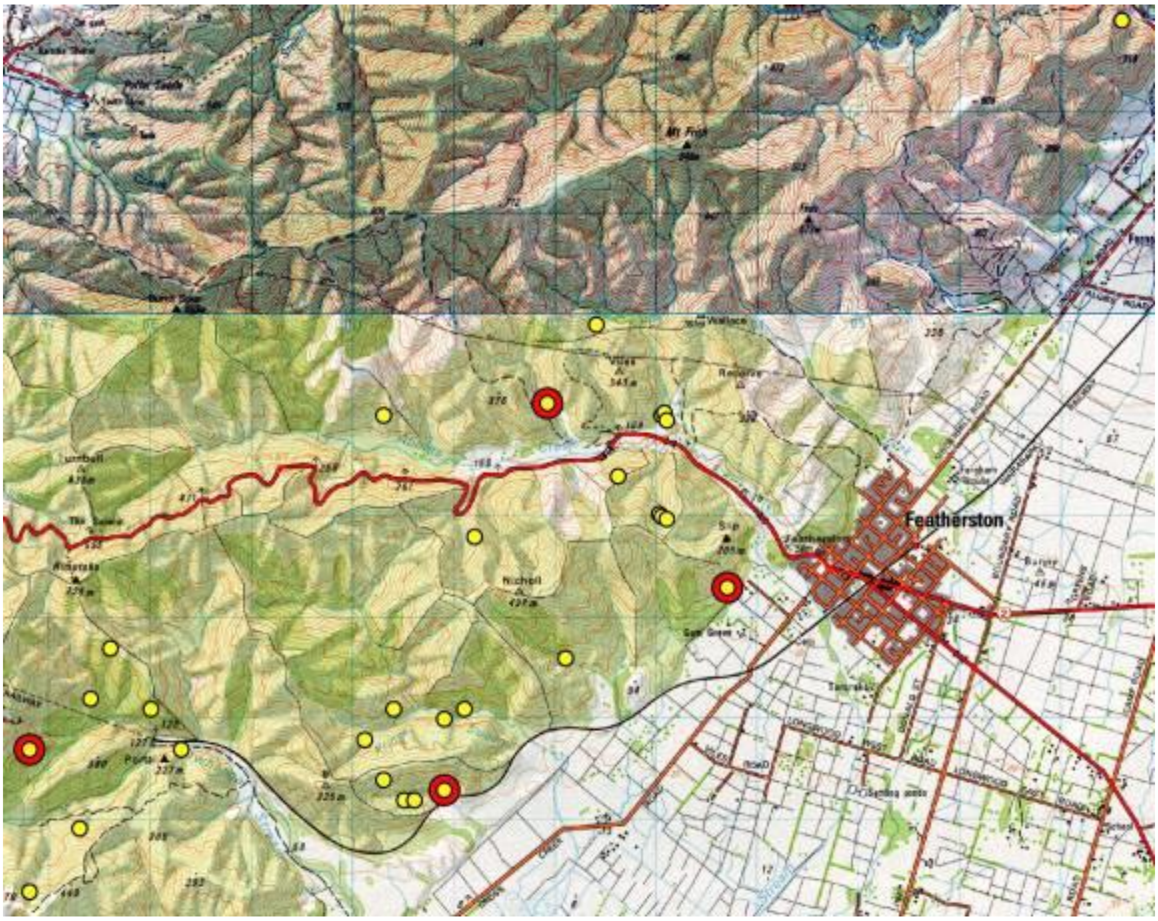


Fig. 10 Location of pigs captured and heads recovered for necropsy from the Crown and NZFT lands about Featherston in 2004 and 2005, together with the location of those confirmed as tuberculous (outlined in red).

Scavenging about staked-out pig heads and possum carcasses

In all, 116.5 days of functioning camera time in autumn 2004 and winter indicated that five heads were not visited or not found by vertebrates, seven heads were visited by only 1–2 vertebrate species, and only two heads were visited by more than two vertebrate species (Appendix 2). Most species recorded were present at most sites, although our data were insufficient to indicate any influence of habitat type on the number or species visiting each station.

Species that may play a role in the dissemination of Tb that visited the pig heads in order of most to least frequent were Australasian harriers, followed by rats and hedgehogs, with possums, cattle, and a single ferret, stoat, and cat each visiting one head only (Table 5). Most of these species took at least one day to discover the heads. Only Australasian harriers, rats, and the single cat scavenged the heads, with the activity of the remaining species confined to touching, sniffing or licking them.

Table 5 Percent of pig heads (n = 14) visited by wildlife species and cattle, with average time to discovery and the percent of heads touched or sniffed, licked, or scavenged.

Species	% heads visited	Average time to discovery (hours)	% heads touched or sniffed	% heads licked	% heads scavenged
Australasian harrier	36	25	7	0	36
Rat	36	10	36	0	14
Hedgehog	14	19	14	14	0
Possum	7	26	7	0	0
Cat	7	179	0	0	7
Cattle	7	106	7	7	0
Ferret	7	33	7	0	0
Stoat	7	23	7	0	0

Most visits to the pig heads by vertebrates were of short duration. Only visits by scavenging Australasian harriers and rats, sniffing and licking by cattle and rats, licking by cattle, and ‘passing’ (observing but not touching) by Australasian harriers and rats took 10 or more minutes (Table 6). All other visits were very brief and exploratory, and apparently not followed up by more comprehensive interactive visits. Given the existing discarded rubbish and scavenged carcass remains found at some of the camera sites selected, the number of scavengers visiting the sites was unexpectedly low.

Most interest and most scavenging was undertaken by Australasian harriers followed by rats, with both species recorded frequently at four heads (29% of sample) and scavenging for approximately 4 and 2 hours respectively. One cat spent 4.5 minutes scavenging on a pig head, while cattle sniffed and licked a head in short bouts on one occasion for approximately 84 minutes.

Few interspecific or intraspecific interactions between visitors were filmed, reflecting the overall limited number of animal visits recorded. One cat displaced an Australasian harrier scavenging on a head, while one possum displaced another possum during a sniffing visit.

Table 6 Number (*n*) and total duration of four behaviours observed during visits to all pig heads by wildlife and cattle. Behaviour classes are exclusive (e.g. an animal that sniffed or fed on a head is not included in the 'Passing' category, even though it would have had to pass in front to the camera).

Species	Scavenge		Sniff		Lick		Passing		Total	
	n	Time (min)	n	Time (min)	n	Time (min)	n	Time (min)	n	Time (min)
Possum	-	-	2	3	-	-	-	-	2	3
Cat	1	4.5	-	-	-	-	-	-	1	4.5
Cattle	-	-	2	66	1	10	1	7.5	4	83.5
Australasian harrier	41	241	1	1.5	-	-	12	18	54	260.5
Hedgehog	-	-	4	6	-	-	6	9	10	15
Ferret	-	-	1	1.5	-	-	-	-	1	1.5
Stoat	-	-	1	1.5	-	-	-	-	1	1.5
Rat	76	127.5	12	19.5	-	-	19	31.5	107	178.5

The fate of possum carcasses was also determined at three sites (one camera unit failed to function) under scrub canopies over 2 weeks per site in summer, early 2004, with 34.8 days of observational time achieved. The visitors included possums, hedgehogs, rats, pigs and passerine birds (Table 7) but not cats, stoats, ferrets, or Australasian harriers.

Table 7 Number *(n)* and duration of three behaviours observed during visits to possum carcasses by wildlife. Behavioural classes are exclusive (e.g. an animal that sniffed or fed on a carcass is not included in the 'Passing' category, even though it would have had to pass in front of the camera).

Species	Scavenge		Sniff		Passing		Total	
	n	Time (min:s)	n	Time (min:s)	n	Time (min:s)	*n*	Time (min:s)
Possum	-	-	2	1:15	1	0:30	3	1:45
H/hog	-	-	3	4:15	1	0:25	4	4:40
Rat	-	-	5	6:30	2	0:45	7	7:15
Pig	4	94:20	1	1:20	-	-	5	95:40
B/bird	4	9:35	-	-	-	-	4	9:35
Quail	1	1:03	-	-	-	-	1	1:03

Most visits to possum carcasses were of short duration, involving cursory sniffing for a few seconds by most species. One exception was hedgehogs which climbed onto the carcasses and either fed on them or on the maggots present. Only four visits by pigs and feeding by a blackbird (again probably on insects associated with a carcass) extended beyond 5 minutes.

All other visits were exploratory, and except for a quail that fed near one carcass (also probably on carrion-feeding invertebrates).

One lactating sow fed on possum carcasses at two of our sites about 300 m apart (see Appendix 3). This sow fed on the two carcasses in one site on January 15, and revisited the site briefly on both January 16 and 17 with her litter of eight piglets to fossick amongst the 'soiled' litter. She then fed on the carcasses at the nearby site later on January 17, and returned on January 18.

5.5 Possums and ferrets as sources of Tb

Infection in possums

Only one of the possums captured in our mapping (*n* = 60) and immigrant-flow *(n* = 80) studies had Tb-like lesions, and culture of this material excluded Tb. Both studies systematically covered the areas surveyed at possum-home-diameter scale or less, and the immigrant-flow study clearly removed most of the resident possums. As the probability of absence when Tb is not detected is the same as the proportion of the population sampled, we have a high degree of confidence that Tb was absent from resident possums in the survey areas north and south of Abbots Creek, but without estimates of absolute density or percent kill it is not possible to quantify that precisely.

The absence of infection in the 37 juveniles killed in the immigrant-flow study indicated an upper binomial 95CI of 9% about the estimate of zero prevalence in this group of possums.

Based on both these datasets, there appears to be very strong evidence that Tb in the possum population in the areas sampled is very low or zero. Assuming gross infection levels of 10% in pockets of infected possums (a figure at the low end of the infection spectrum; Hickling1995), a sample of 28 randomly caught possums in such pockets would be needed to be 95% confident of capturing an infected individual (G. Forester, pers. comm.). Our sample north of Abbots Creek (41), while not random, caught slightly more possums than this, but the likelihood of missing existing infection, though low, must be real, particularly as infected animals are unlikely to be randomly distributed. Conversely, our much larger sample (99) taken south of Abbots Creek gave us confidence in the outcome of our disease survey there.

Ferret Tb prevalence – results from live-trapping study

Twenty ferrets were trapped for radio-collaring on the scrub–pasture margin of the VCA in February–March 2004. Nine of these animals were judged to be adults, including five males and four females, and all were euthanased. Six of these animals were found to be between 12 and 24 months old, while three were approaching 12 months old and had just reached adulthood. Four of these adults came from a cluster of trappings in the lower Owhanga Stream and five from a similar cluster of trappings immediately north of Boar Creek (see Fig. 11), indicating a distinct patchiness of free-ranging ferrets at that time. All nine adults were free of macroscopic lesions indicative of Tb, and culture results were also negative. One juvenile ferret palpated positively and was also euthanased, but this animal also cultured negative for Tb. The remaining 10 animals were all juveniles and, showing no external signs of Tb, were radio collared and released.

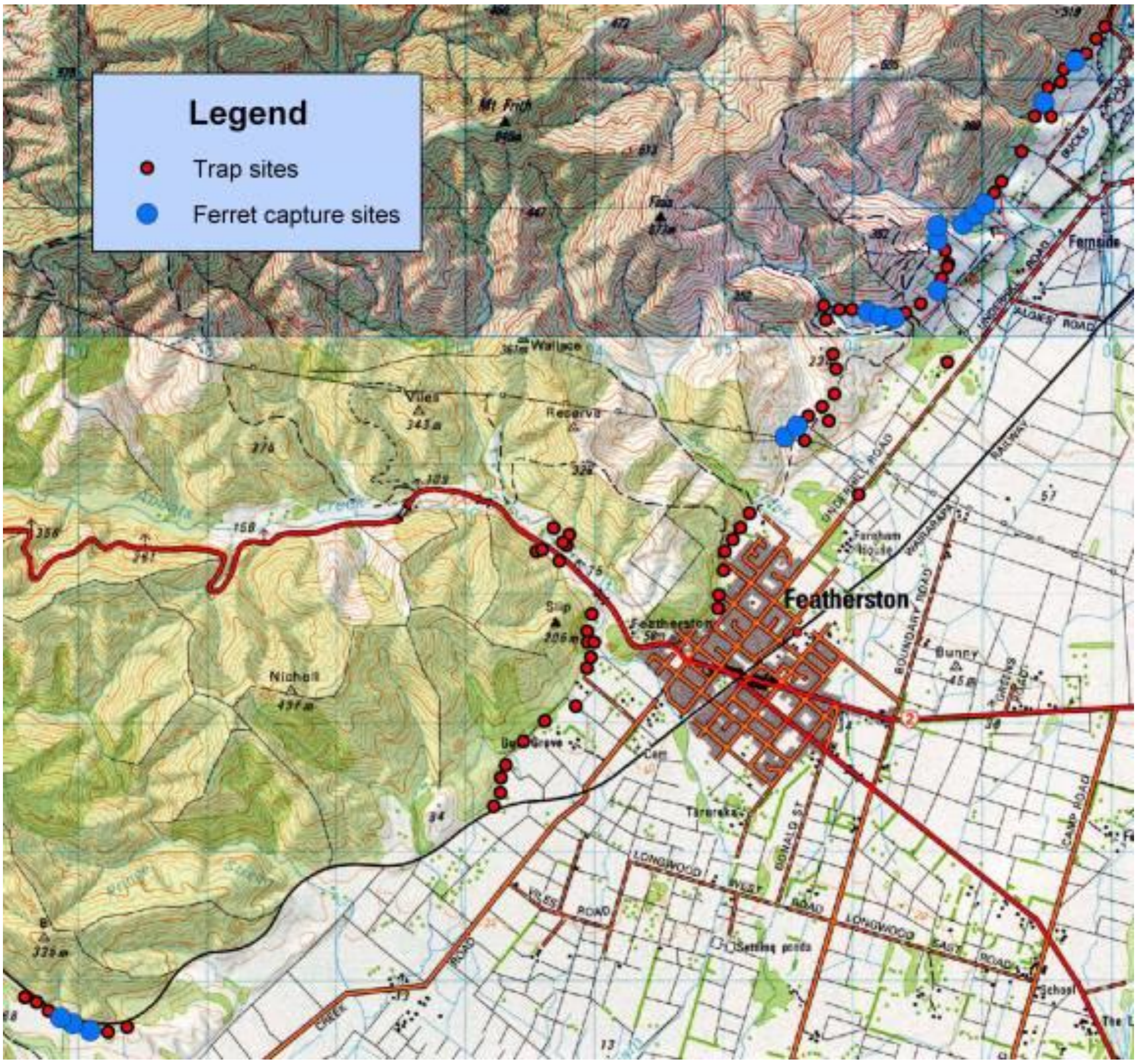


Fig 11 Location of traps set in February–March 2004 to capture ferrets for our movement study, and of the ferrets captured. Four sites captured two different animals, with each of these paired captures being an adult and a juvenile ferret.

No ferret trapping was conducted on the scrub–pasture margin along the rear boundary of Pigeon Bush farm, as we could not obtain permission. As Pigeon Bush comprised most of the farm margin in the VCA south of Abbots Creek, our understanding of ferret abundance and their Tb status south of Featherston is minimal.

Ferret Tb prevalence across the Featherston management are – from annual ferret control operations

All eight ferrets taken during ferret control in May–June 2004, including five adult males and three adult females and aged <12 months (5), 12–24 months (2), and 24–36 months (1), 18 cats, and the single stoat (see Section 5.1, Fig. 4) were free of gross lesions indicative of Tb. Subsequent culture of pooled lymph nodes of all the ferrets and the single stoat confirmed this field diagnosis. Lymph nodes from the cats were not submitted for culture as this had not been past practice for cats recovered from the VCA. Tb prevalence in cats is typically lower than that recorded in other predators in the same area, and cats are considered to be spillover or amplifier hosts only (Coleman & Cooke 2001).

Thirty-six of 52 ferrets taken in control operations in April 2005 were recovered and necropsied, and all of these animals were free of gross lesions indicative of Tb. Preliminary culture results 6 weeks after submission again proved negative.

Ferret movements on the scrub–farmland margin

Eleven juvenile ferrets (six males and five females including the individual euthanased) were taken from four adjacent properties immediately north of Boar Creek (Fig. 11). From the closeness of their initial trap location and their similar physical size, these animals appeared to be littermates from 2–3 litters. Ten of these ferrets were released after radio collaring. Only two were subsequently recaptured and their carcasses recovered, and thus the eventual disease status of the remaining eight animals is unknown.

Radio-fixes were obtained from the 10 radio-collared juvenile ferrets over varying intervals of time, with one animal (Collar 49) dying within 1 month of initial capture, and two being killed during official control operations 15 months after initial trapping (Collars 14 & 68; Table 8). Radio signals from on four juveniles (collars 6, 18, 27 and 39) ceased after 1–5 months, presumably either because their transmitters had failed or because they had moved too far away to be detected. However, as we had established several ‘listening points’ scattered widely about the adjacent countryside, this latter possibility seemed unlikely.

Of the four ferrets ‘known’ to have died during our monitoring, one was trapped and killed by a farmer, one drowned in a home swimming pool, and two were located in inaccessible field sites (down a deep hole and underneath a farm building), apparently dead of natural causes (although these animals conceivably could have slipped their collars). As the fate of 4 of 10 radio-collared animals was unknown, and three further animals died of unnatural causes (killed), no attempt was made to estimate a ‘natural’ mortality rate for this population.

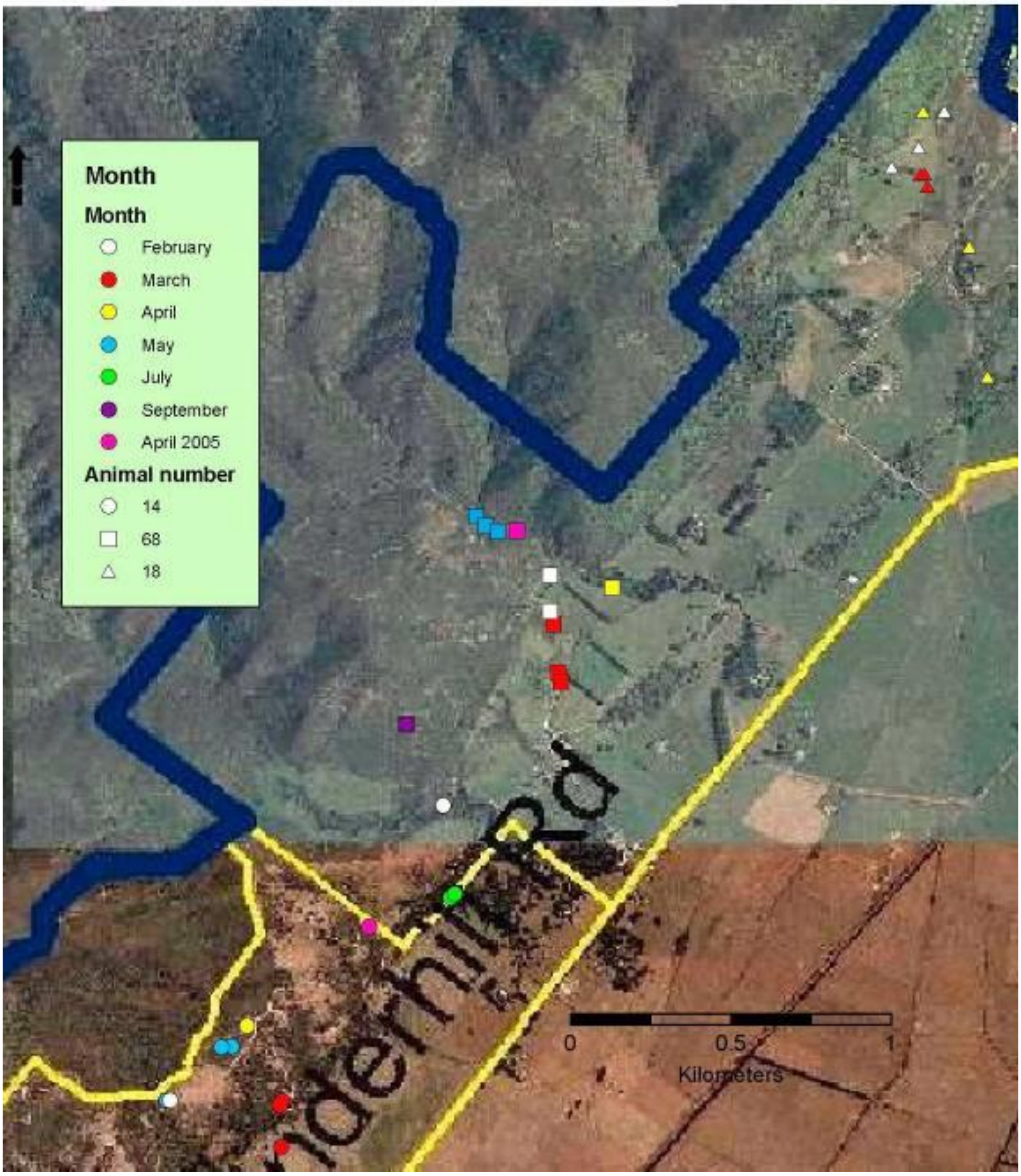
Table 8 History of radio-collared juvenile ferrets between initial capture and final radio-fix, including distance moved, and fate.

Collar no.	Period monitored (months)	No. trap locations	No. fixes following trapping	Maximum distance between fixes (m)[1]	Fate of animal
6	5	1	9	890	Unknown
14	15	2	11	1260	Killed in control
18	3	4	7	1270	Unknown
27	1	2	1	260	Unknown
32	2	3	1*	4010	Killed by farmer
39	5	2	10	2250	Unknown
46	2	1	4*	300	Dead in burrow
49	1	2	1*	700	Drowned in pool
68	15	3	9	770	Killed in control
72	7	2	10*	1370	Dead under shed

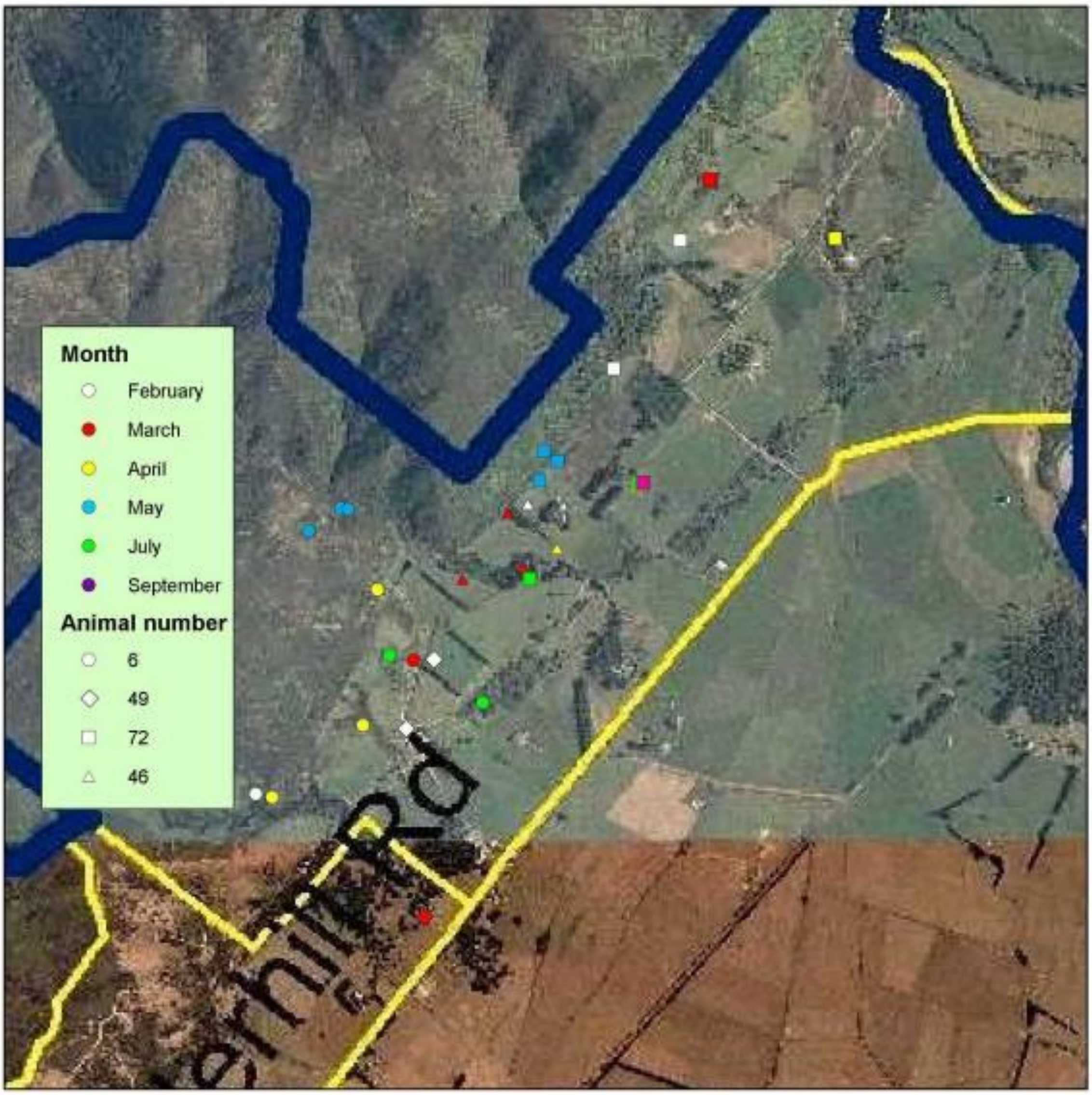
* Includes radio fix of dead ferret
[1] Includes trap sites

Daytime den locations of all radio-collared ferrets were in rabbit burrows either on scrub–pasture margins, or in scrubby gullies within improved pasture. No animal denned more than 100 m into the gorse-covered hinterland, confirming our belief this habitat was largely avoided. Range use of the six ferrets with 10 or more trap and radio-fixes combined (collars 6, 14, 18, 39, 68, and 72) indicated that these animals had home ranges centred on their February trap sites (Fig. 12).

(a)



(b)


Month
February
March
April
May
July
September
Animal number
6
49
72
46
Rd

(c)

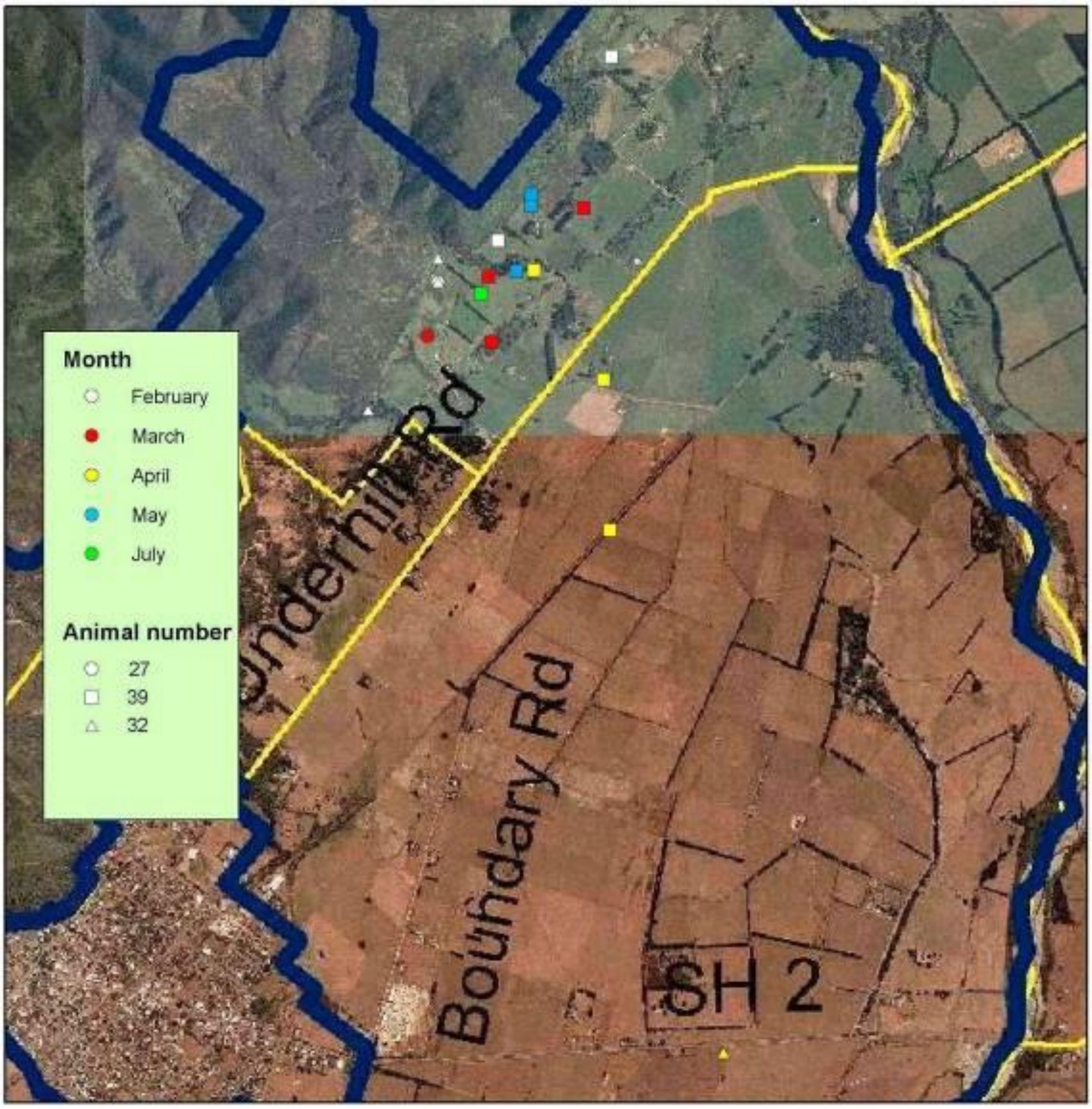


Fig. 12a, b and c Locations of radio-collared ferrets in the Featherston VCA, including initial trap sites and subsequent radio-fixes of live and dead animals. Note, the occurrence of radio-fixes on the same site has resulted in some animals having fewer graphically portrayed fixes than those recorded in Table 8.

The maximum distance between any two fixes varied between 0.77 and 2.25 km for the six ferrets with seven or more re-locations, (Table 8). However, ferret no. 32, which was re-located only once 2 months after release, moved 4 km out across farmland. By comparison, the straight-line distance between the first and final location ranged from 0.16 to 4.0 km (Fig. 13), with a median distance of 0.63 km.

The cumulative distribution of nominal 'infection-to-necropsy' distances (Fig. 13) indicates that 90% of infected juvenile ferrets captured during autumn control operations in the VCA (should any be captured in future) are likely to be killed within 1–2 km of where they acquired Tb. However, one ferret moved 4.0 km out into clear farmland, illustrating a mechanism by which Tb could occasionally be transferred from the western forest margins to the ‘clean’ centre of the VCA.

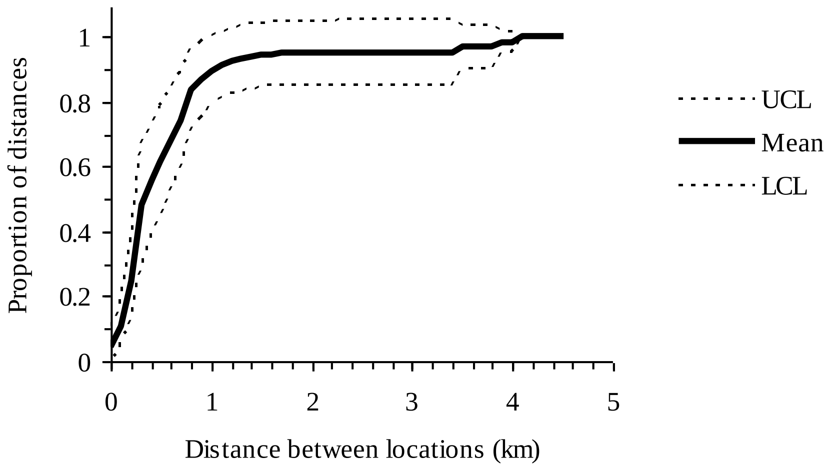


Fig. 13 Dispersal curve for young ferrets in the Featherston VCA, based on data from 10 animals.

6. Conclusions

6.1 Historical vector control

Aerial control in 1996 in the VCA appeared to be successful by the standards of the day, but insufficient documentation now exists to assess the strategies used or results achieved with any rigour. By contrast, the 2001 operation followed standard bait protocols (see Henderson & Frampton 1999), and used good-quality recently manufactured cereal bait, sown along predetermined monitored flight paths under ideal weather conditions. Several issues associated with this work are however of concern. Firstly, although tenders were called for the work, no external tenders were received and the work was therefore completed by GWRC. This was hardly surprising as few commercial operators had such capacity at that time. Nevertheless, having both control and its assessment (monitoring) undertaken by the same agency is clearly not ideal. Secondly, the sowing rate, based on the lowest rate normally used (from Morgan 1993), appears to have been too low for the Featherston Crown Area, despite the favourable post-control RTCI obtained (see immediately below). Morgan based his recommendations on a 6-g bait sown at 2 kg/ha (or c. 1 bait/30 m^2) over a normal high forest canopy. Operations at Featherston are, we believe, likely to benefit from a higher sowing rate than this, because they used a bigger bait (and hence lower frequency of individual baits available to possums), there is probably loss of baits held up in the canopy of the heavy scrub and gorse present (and unavailable to possums; Pracy pers. comm.) and in the deep litter existing under ‘old man’ gorse, and possums may have restricted movement (and thus likelihood of encountering a bait) in such food-poor and very dense habitat. Thirdly, no pre-feed was used despite both common practice and growing evidence in its favour (Coleman et al. in prep., AHB Contract R-10610), and such evidence indicates future aerial baiting operations should be pre-fed with identical non-toxic bait to induce all animals present to eat the novel food. Finally, the cinnamon levels used in bait manufacture were initially high enough to cause some reduction in bait acceptance by possums (Henderson & Frampton 1999), but we believe baits probably lost sufficient cinnamon during storage to negate this concern. An evaluation of cinnamon levels in bait immediately prior to sowing would seem to be warranted if 1080 in baits is masked at such high levels in future operations.

Further aerial baiting is planned for 2006. While operational plans for this baiting are at an early stage, the job will be put out to tender free from any baiting or strategic constraints apart from clearly defined operational RTCI targets (Grant Crawford, GWRC, pers. comm.). Thus, while the baiting strategies likely for this operation are unknown, we see value in some changes to that carried out in earlier years, with the successful tenderer being encouraged to increase the toxic bait sowing rate by 50% (to 3 kg/ha), sowing a pre-feed, and changing to a 6-g bait with lower initial levels of cinnamon present. We also believe that flight path data should be downloaded directly from the aircraft by the contractor, rather than recovered several days later. This would guarantee ‘clean information’, and permit any immediate infilling (baiting) of missed areas.

The techniques used by the GWRC and their justification in past aerial control are thus adequate to achieve target kills (despite needing modification in future control), but the same cannot be said as strongly for ground-control strategies and techniques. Timms traps are the ‘trap of choice’ used across most farmland at Featherston, even though they are not widely used by contractors controlling tuberculous possum populations elsewhere, being bulky and less catch-efficient than the more commonly used Victor leg-hold traps (B. Warburton, pers. comm.). Equally surprisingly is the wide variety of techniques and strategies used locally for controlling possums, and such variation appears to be driven overly by the need to obtain public acceptance of control programmes, rather than the need to use the most efficient tools for the job. As two examples of this logic, the postponement of control in Lake Domain during the duck-shooting season and of ground-based possum control in HR1 in 2004/05 during the ‘roar’ clearly reflected the perceived significance of the hunter lobby over local possum control. Both actions may have been tactically correct but the outcome was delayed control, and in HR1, inadequate control. Finally, accessing land about Featherston for pest control is not helped by either the very large number of ‘hobby farmers’ who do not farm cattle and thus have little to gain from providing access to possum and ferret control teams, or by several large landowners within the VCA being generally obstructive to any planned control or monitoring on their land or immediately behind it. Unless all land likely to carry infected possum and ferret populations is brought into the control programme, and at times that allow for the use of the most effective tactics and tools to complete the task, local Tb eradication seems unlikely.

The use of stream beds as the main and often only routes of poison baiting and trapping lines for possum control in Crown and NZFT lands is based around the belief by control staff that such control will effectively reduce all local possum populations. Stream beds are the major areas of native woody vegetation present and as such are believed to be the key feeding sites of local possums and hence contain more of them (G. Lewis, pers. comm.). By comparison, the large areas of intervening gorse are believed to be food poor, carry few possums, and any possums living there will eventually be caught on control lines along the forest streams. This hypothesis is apparently based on limited RTCI data from the Featherston Crown Area and does not take account of areas of palatable native vegetation scattered across hillside ridges and faces throughout the large patches of gorse present and the largely fixed home ranges of adult possums within them (Cowan & Clout 2000).

As one example of the consequences of this strategy, monitoring on randomly located lines following official possum control in part of HR1 in 2004 provided an RTCI of 0.3 ± 0.6% (see Section 5.1) and indicated a high level of control. Six monitor lines were located in the northern third of this stratum, and only one possum was taken from them. This result contrasted with that obtained from the first of our seasonal trapping and cyaniding surveys in the same block 2–3 weeks later, which produced a trap-catch of 6.2% and a poison catch of 4.1% over two nights. Even allowing for the shorter duration of our trapping and cyaniding (two nights instead of three) and our less rigorous selection of trap sites (on 'best sign'), our catch as a Rate Ratio (RR: Kirkwood & Sterne 2003) was 11.25 times higher than that recorded during the monitor and significantly different ($P = 0.0177$). The difference between these two results must be cause for concern, and appears to result from a combination of relatively few monitor lines falling into gorse habitat and from some allocated lines being relocated to habitat more accessible to human observers – one of 18 lines in the wider survey was switched to a more accessible area, and two of 18 were given alternative bearings due to cover judged impenetrable (J. Lambie, GWRC, pers. com.). Formal auditing of the monitoring conducted at this site would have identified this problem.

Subsequent catches of possums taken in three further seasonal samples in our immigrant-flow study (Section 5.3) offered some support for the broad ground-poisoning control strategy used in the NZFT lands in 2004, as most (75%) possums taken by us in this study were within 100 m of gullies and streams (and hence of official control lines). Our catch indicates that possums surviving control (and presumably those taken in formal control) do indeed favour (but not exclusively) the vicinity of local gully and stream bed sites over those of the drier more gorse-covered ridges and faces. However, our data indicate that even in such gully and stream beds, official control as practised is inadequate because it leaves significant patches of possums uncontrolled in an environment still containing Tb-infected wildlife.

The design and allocation of lines in all post-control possum population monitoring in the VCA is undertaken by the GWRC, with control targets based on pre-control monitor data and the stratum disease risk status (determined in conjunction with AHB). By comparison, population monitoring is now being undertaken by 'preferred contractors'. Such contractors are able to seek limited changes to predetermined monitoring plans, where monitor lines are allocated to apparently impassable habitat. The extensive areas of gorse on the hills west of Featherston make this a common occurrence. However, the relocation of RTCI lines once allocated, following site inspections, is clearly at odds with the intent of the latest monitoring protocol (NPCA 2004), which infers significant changes in location or direction of lines should occur only where there is no possum habitat present or where completing the lines would expose field staff to unacceptable physical risk – not from the presence of possum habitat that is difficult to negotiate. A possible outcome of the approach followed by the GWRC-contracted monitoring team in 2003/04 is that the monitor survey may have indicated an RTCI unrepresentative of the control achieved. Such an RTCI will fail to provide any useful feedback to control staff, and in the worst case, may provide misleading information. A monitoring strategy that more closely follows the monitoring protocol will produce more accurate estimates of residual possum density while the use of more monitoring lines in high-risk strata than is usually the case (as recommended in the latest monitoring protocol; NPCA 2004), and more frequent auditing of individual monitors (see below) may be warranted. Finally, monitors of control operations are normally undertaken within 1 month of the completion of the control job. This practice normally biases low any population index obtained (Coleman & Coleman 2000; Forsyth et al. 2003), and such monitors should be deferred for at least 3 months where possible. Unfortunately, better estimates of the optimal time post-control to undertake RTCIs await the results of ongoing research (D. Morgan pers. comm.; AHB contract R-10623).

A revised control strategy that sought to more comprehensively control possums throughout all large areas of gorse (and follow traditional strategies of total control coverage) would undoubtedly lead to better kills but also to significantly increased control costs. By comparison, possum control on farmland throughout the Featherston VCA had no such problems of physical access, with most farmland being well developed and free of forest and scrubland.

The question of 'who audits the auditors' has apparently not been addressed by the GWRC for the Featherston VCA. While a low but currently unspecified number of monitoring operations undertaken for AHB across all VRAs in New Zealand are expected to be formally audited each year, no such audits have been undertaken in the VCA during the period of this review (G. Butcher, pers. comm.). This would seem to be a serious shortcoming in the control package undertaken in the high-risk strata, and appears to stem from the lack of precise instructions for auditing from AHB to all vector managers. If such auditing had been undertaken as part of the Featherston VCA control programme, it would have identified some of the control and monitor concerns identified here.

Ferret control (and incidentally that of cats) within the VCA began far more recently than possum control. It has not been consistently applied across all areas or years, is patchy in nature, and targets the scrub margins and farmland within the VCA. Input monitoring of ferret control provides little useful data on ferret population size, except that it indicates little if any fall-off in catch over 1999/00–2004/05. As ferrets have high reproductive rates, their population densities are driven primarily by rabbit numbers (Byrom 2001), and rabbits are common about the VCA scrub-forest margin, ferrets surviving control are presumably well below densities likely to be limited by their primary prey and thus able to rapidly rebound from any control undertaken. Ferrets are now recognised as significant spillover hosts of Tb and may become maintenance hosts when their densities exceed 2.9/km^2 (Caley & Hone 2005). Catches of ferrets on Featherston farmland appeared much lower than this, with recent catches estimated at roughly 0.95/sq. km in 1999/00 and 2.0/km^2 in 2004/05. However, as infected ferrets were found in 2001, annual ferret kills show no sign of decline, tagged ferrets known to be still alive were not recovered in control operations in 2004, and Tb still present in other wildlife, ongoing control of their populations seems warranted. Such control would, of course, be dependent on greater resourcing.

In summary, public approval for local pest control, issues of gaining access onto private land, and the problems of traversing the dense vegetation present are clearly adversely affecting the strategies used and the overall uniformity and effectiveness of pest control undertaken in the VCA. While gaining access to private farmland is likely to remain the driving influence of the success of on-farm pest control, and will be improved only by ongoing public education programmes on the need for local pest control, public liaison, and the development of local 'working' groups, there appears to be a very strong case for more frequent use of aerial baiting for possum control on Crown and NZFT lands. Such an approach will reduce the difficulty of ground operators obtaining approval to access forest/scrub areas across farmland and eliminate the problems of control staff traversing large areas of gorse. It will not, of course, eliminate either of these problems for monitoring or auditing operations following control.

6.2 Mapping of pre-control possum density

Residual possum populations of c. 0.5 and 0.4/ha were estimated using Wax Tags in the northern and southern blocks, respectively, on the scrub-covered hillsides above Featherston, and were equivalent to RTCIs of approximately 5% and 4% (B. Warburton, pers. comm.). Surviving possums were patchily distributed. Their numbers were greatest in the least accessible scrub and on the uncontrolled faces above Boar Creek, and reflected patchy control.

Juvenile possums taken on Feratox baits were distributed evenly across the altitudinal gradient of both blocks, with the obvious exception of disproportionately high numbers within 200 m of the pasture–scrub margin. This should concern local possum managers, as juveniles disperse widely and those adjacent to pasture and presumably feeding on it may have originated from populations of unknown disease status located in deep, uncontrolled forest. Such distributions of juvenile and adult possums indicated a clear need for more consistent local control, more intensive control along the scrub–forest margin, and greater effort within the large areas of largely impenetrable gorse and native scrub.

Possum distribution and numbers in Lake Domain remain unknown to us, despite our best efforts to survey this outlying area (see Section 4.2). However, as control about and within the area has been intensified and recent monitor results indicate few possums, it seems that the very high numbers recorded there 3–5 years ago were a direct result of the limited control undertaken there at that time. Maintenance of current control pressure appears warranted.

6.3 Flow of immigrant possums as a source of Tb

Young immigrant possums sampled across the annually controlled hillside near Featherston were predominantly male. They occurred as a steady trickle of animals throughout the year, and at a rate over 12 months of approximately 4.5 possums/km of farm edge. As most of these animals originated from the presumed higher density deep-forest possum population (uncontrolled for 3 years), they should have been at greater risk of being infected with Tb than older more sedentary possums living in the annually controlled area. While we were unable to find any Tb in them, they still pose a greater risk to livestock than older possums surviving annual control. Curtailment of possum dispersal from deep, uncontrolled forest is therefore a key component in the elimination of Tb from on-farm livestock.

Patterns of young possums over the hillside in HR1 revealed in our immigrant-flow study thus contrast with that determined one year earlier in our mapping survey (where young possums were most common near the forest–pasture margin). Such differences appear to reflect the different timing of the two studies in relation to previous control, i.e. sampling was undertaken immediately before annual control (and during annual dispersal; Cowan & Clout 2000) and that of our immigration-flow study taken over 12 months following control, but do not overturn our concerns of this cohort being more likely carriers of Tb than older possums.

Our immigrant-flow study was clearly insufficient to eliminate the movement of deep-forest, relatively high disease risk animals dispersing out some 1200 m to farmland, perhaps because for most of the year no control tools were in place (our trial of long-life baits was ineffective).

The value of placing long-life toxin baits along such lines thus remains unclear, but should result in fewer young possums appearing on forest margins. The question then becomes one of cost effectiveness, with the establishment of seasonally baited deep-forest control lines using long-life toxic baits likely to be considerably more expensive than season-baiting using standard toxic baits along the forest margin.

Possums taken in our surveys were very largely located in or within 100 m of streambeds, and were taken less frequently on hillside faces and ridges. This indicates that on the hillsides at Featherston, minor streams are used as dispersal routes or places to settle by possums. However, such catches may also well reflect the vegetation present in such sites, with streams and gullies containing many forest plants eaten by possums, while many ridges and faces were dominated by extensive low-palatability stands of gorse. Possum-habitat mixed hardwood forested hillsides elsewhere in New Zealand do not show the same patchiness of vegetation, or the same sharply patchy possum distribution (Coleman et al. 1980).

6.4 Pigs, deer, and possums as potential sources of Tb

Pigs are generally thought to be spillover hosts hosts for Tb (McInerney et al. 1995) that occasionally act as link hosts (through the scavenging of their carcasses; Nugent et al. 2003), and only rarely as maintenance hosts ((Parra et al. 2003). Tb was formally identified in the VCA in three aged boars and one aged sow. As pigs have home ranges in gorse/scrub and pasture habitats about kill sites averaging approximately 1100 ha (Nugent et al. 2003), clearly all four pigs would have had access to both deep-forest and pasture-edge carrion. Further, all four infected pigs were at least 30 months old when captured and comprised four of the seven old pigs necropsied. As none of the 17 younger pigs were infected, it appears that the level of infection in species scavenged by pigs now must be lower than that of 2–3 years ago. This may well reflect the increasing intensity over the last 2–3 years of local control of possums and ferrets by the GWRC. Such infection in pigs may also indicate an earlier infection in the local possum population, as they appear the most likely source of Tb in pigs. Ferrets, the other wildlife species previously infected in the VCA, confine their activities very largely to scrub–pasture margins (as revealed in our radio-tracking study, see Section 5.6). Even when available, ferret carcasses are apparently rarely eaten by scavenging pigs (Byrom 2004). Likewise, pigs rarely scavenge other pigs (Yockney & Nugent 2003), providing one reason for their absence from our video film shot over pig heads. Finally, even though all four infected pigs examined were taken several kilometres from one another, it appears likely that some of the four infections arose from joint scavenging events involving either a sow and litter or litter mates.

A wide range of wild animals, livestock, and birds interacted with the video-monitored pig heads. The only mammals filmed scavenging the heads were several rats and a cat, and these animals, along with livestock sniffing and licking heads, appeared to pose the greatest risk of Tb transmission in this part of our study. Cats are confirmed spillover hosts of Tb (Coleman & Cooke 2001), and their observed behaviour reflects an obvious route of transmission. In contrast, the visit by two cattle to one head indicates a clear route of Tb transmission, but such behaviour probably occurs very infrequently in the VCA, as pig heads are normally discarded by hunters in areas inaccessible to cattle. However, our observed behaviour of cattle was not surprising, as it parallels the response of cattle and deer to ill-disposed possums in other field situations (Sauter & Morris 1995).

The generally low numbers of mammals interacting with all heads presumably reflected the low density of local possums, ferrets, and cats as a consequence of their ongoing control, as well as of the location of the video cameras. Video footage certainly did not rule out a role for these species in the maintenance of Tb at Featherston. The low level of scavenging at our Abbots Creek video site was most surprising, particularly as the site is littered with pig carcass remains in various states of decay, and both a ferret and wild cat were trapped nearby during official control soon after our filming. However, our video observations indicate that the *current* role of possums, ferrets and cats in Tb transmission to livestock or to other wildlife at Featherston is limited. In contrast, rats were frequently observed to scavenge from pig heads and do carry Tb, but as the disease is rarely identified from them, they are presumably rarely involved in its transmission (Coleman & Cooke 2001).

Given the frequency of the visits by ferrets to pig heads set out in similar studies elsewhere (Yockney & Nugent 2003), the low level of interest in our pig heads by ferrets was unexpected, as many ferrets were caught locally during the radio-collaring phase of this study and in the ferret control programme that followed our video-monitoring. Perhaps the low interaction by ferrets reflected the location of the heads and cameras inside the scrub margin (to avoid human interference) and 100–200 m away from pasture, where our ferret movement data indicate ferrets rarely ventured.

The role of Australasian harriers in Tb transmission from offal to livestock is unclear, but this and other studies (e.g. Byrom 2004) indicate that they are frequent scavengers of pig and possum carcasses. Harriers may also open up wildlife carcasses and make sub-dermal tissue more available to other scavenging species (G. Nugent, unpubl. data). *M. bovis*, the causative agent of Tb, does not normally survive in birds, although recent laboratory studies have indicated some birds may disperse *M. bovis* organisms over brief periods following their exposure to it (Fitzgerald et al. 2004). Although we think it unlikely, the organism could be distributed away from scavenging sites by disturbed birds taking carrion with them.

Overall, the presence of ongoing infection in old pigs only, the low level of interest in pig offal by key scavenging wildlife vectors, and the absence of any recently described infection in their populations, indicate an ongoing but declining infection in local wildlife, and one that is likely to be eliminated by the maintenance of possum and ferret populations at low levels. Having said that, there is a case for an official pig control operation in the VCA to rapidly reduce the number of infected pigs present, thereby reducing both the chances of scavengers picking up the disease and the level of *M. bovis* in the environment (as advocated by Nugent et al. (2003)). Such an action would be anathema to local pig hunters, who could then be expected to hinder future local pest control. Alternatively, there is a case for the encouragement of local hunters to either place heads in freezer chests held by authorised collection agents/sites for necropsy, or to place pig heads in scavenger-proof containers, particularly at the Twin Bridges site over Abbots Stream, where many heads are discarded. Such a programme could, if managed properly, and based on a modest bounty, source reliable data from hunters. It would, in the first instance, provide a means of collecting additional information on the level of Tb in the local pig populations, and in the second, help reduce the suspect dumped offal available to wildlife.

No Tb was identified in any of the 139 possums necropsied from our mapping and immigrant-flow studies. Such a sample taken over approximately 320 ha of scrubland could be expected to identify infection prevalence of 2% or less (G. Forester, pers comm.). Disease in possums in HR1 in the VCA is therefore near to or at zero.

Possum carcasses set out in front of our video cameras were scavenged by pigs and possibly by a hedgehog, although other mammals (possums and rats) spent time sniffing and inspecting the carcasses, and blackbirds apparently ate invertebrates associated with the decaying carcasses. Possums, when grossly infected contain huge numbers of *M. bovis* and are highly infectious, and the consumption or licking of their carcasses provides a significant opportunity for inter-mammal species transmission of the disease, with pigs being the greatest risk. The consistent approach to each possum carcass by the scavenging sow and her litter demonstrated (a) an obvious pathway for the disease in both adult and juvenile pigs, (b) the likely amplification of the disease through communal feeding on a single carcass, and (c) the most likely current source of the Tb demonstrated in pigs during this study.

6.5 Ferrets as a source of Tb

Our modest samples do not rule out the likelihood of local populations of either ferrets or cats being infected, particularly as our ferret trapping was limited to farm–scrub margins of the study site accessible to us (some farmers excluded us from their properties). Further, 17 of the 59 ferrets necropsied by us were in their first year of life and, as such, were significantly less likely than older animals to be infected (Lugton et al. 1997). Assuming typical prevalence rates of <10% for ferrets taken from foci of infection for this species, where possum trap catch rates are low (Caley 1998) and even less for cats (Cowan 1994), at least 28 animals would need to be examined to be 95% sure of identifying the presence of at least one infected animal of any of these species. Ferret carcasses recovered during control operations should therefore continue to be necropsied wherever possible, particularly those of adults, to provide ongoing confirmation of their disease status and, where infected, of likely foci of infection in their and in other wildlife populations.

Young radio-collared ferrets dispersed relatively small distances in this study (median 0.63 km) compared with comparable datasets from the South Island. In those studies, median distances dispersed by ferrets were 1.2 km on North Canterbury farmland (Caley & Morriss 2001); 2.5 km in the Marlborough high country (Byrom 2004); 5.5 km in the Mackenzie Basin (Byrom 2002), and 6.2 km in North Canterbury (Young 1998). In our study, young ferrets largely confined their range movements to forest/scrub–pasture margins, and were never recorded more than approximately 100 m into gorse/scrub-covered hillsides. Such dispersal provides no evidence of the likely transportation of infection by this species from the pasture–scrub margin about Featherston out of the VCA. However, these data should be treated cautiously; our sample was small and we radio-tracked animals for a maximum of 7 months. Elsewhere in New Zealand, young ferrets typically have lower prevalences of Tb than adult animals, but often become infected within 3 months of weaning and during dispersal (Byrom 2004). Thus, while other wildlife species at Featherston remain infected, the possibility of dispersing ferrets scavenging infected wildlife and transporting the disease to new areas must be a realistic possibility. Against this, the low ferret numbers caught in our own and in official trapping operations, and the zero prevalence of infection recorded for this species, indicate that ferrets currently play little if any role in maintaining Tb in wildlife in the VCA. In addition, the estimated population density of ferrets at Featherston was c. 2/km^2, and below the putative threshold for maintenance of bovine Tb (2.9/km^2 ; Caley & Hone 2005).

6.6 Revisiting our hypotheses

Of the four hypotheses identified as possible ‘drivers’ of Tb in livestock in the VCA (see Section 2), the first hypothesis – transmission to livestock directly from possums – appears a realistic possibility. Although we did not identify any grossly infected possums, our samples were modest and restricted to less than half of the scrub and forest (the primary possum habitat) in the VCA. However, within the area sampled, sampling theory indicates a small but non-zero likelihood of our samples missing infected possums. Instead, we believe that the typical clustered distribution of possums infected with Tb demonstrated elsewhere in New Zealand (making their identification difficult, Coleman et al. 2002; Fraser & Coleman 2004), the modest and patchy ground control undertaken in the VCA leaving many surviving possums, the improved possum control concomitant with a fall in infection in livestock in recent years, and the infection recorded in aged local pigs distant from livestock (and most likely to have been infected by scavenging possums, Nugent et al. 2003), together support the possibility of a infection (pre-2002) in possums but one probably now eliminated.

Our second hypothesis – direct transmission from ferrets – appears equally plausible, with our reasons for believing this possibility very similar to our reasons for arguing the involvement of possums in local herd infections. However, in contrast to that of possums, the limited area sampled for ferrets for Tb surveys and the modest size of the samples necropsied give us little confidence that the absence of Tb in ferrets sampled necessarily reflects the greater population. Instead, we believe the demonstrated mobility of this species about scrub margins, and in one instance, out on to farmland, the patchiness of recent ferret control, their known role as scavengers (Nugent et al. 2003) despite observations in this study, and the presence of Tb in two pigs on the forest margin (and within the range of local ferrets), indicates that ongoing infection in ferrets may be a realistic possibility. However, given that ferrets in the VCA are below the putative threshold density for intraspecific disease transmission (Caley & Hone 2005), if infected their populations must be picking it up from other wildlife or livestock.

Our third hypothesis – transmission directly from pigs or deer – is unsupported by any evidence gleaned in this study despite the identification of infection in pigs and is therefore dismissed. What is apparent is that there are no obvious behaviours of either species likely to lead to their close interaction with livestock, that deer are rare, that neither deer nor pigs regularly forage out on pasture alongside livestock in this area, and that infected pigs are not readily able to transmit Tb to herbivores or to other pigs (Nugent et al. 2005).

Our final hypothesis – within- and between-herd transmission – was dismissed because of the dispersed location of the infected herds and lack of any known contact between them, and the proven continued presence of infected wildlife. Data collected during this study support such a rebuttal: latest herd-testing results indicate all local herds are now free of Tb infection, even though Tb still exists in at least one wildlife species – pigs – and perhaps in others. Such infected individuals are clearly capable of providing a source of *M. bovis* for any livestock grazing within normal vector foraging or dispersal distance through their inspection of any carcasses present. The few non-musterable and thus untested cattle in Lake Domain are of concern, particularly as the last herd to come off movement control about Featherston (in 2003/04) was grazed in the domain.

In summary, we believe that the infection in aged pigs recorded in this study and the historical infections recorded in possums, ferrets, and livestock, indicate a residual infection now confined very largely to pigs. Provided possum control is ongoing and numbers reduced to and kept below nationally targeted levels for Tb control throughout the VCA (i.e. 2% RTCI), and ferret control targets all ferrets across the VCA, Tb is likely to disappear from local pigs as the infected aged animals die and no new infection enters the pig population. Further patchy control of both possums and ferrets, and their scavenging on infected pig offal recorded in other studies (e.g. Nugent et al. 2005), could however lead to the re-emergence of Tb in both these species.

7. Recommendations

- Because ground control is difficult we recommend greater use of aerial poisoning in the Featherston VCA to ensure all possums in the dense scrub find baits and eat them. Future aerial control should be upgraded by increasing the sowing rate to 3 kg/ha and sowing a pre-feed to encourage all possums in the dense scrub find baits and eat them. Based on outcomes from other studies cinnamon essence should be applied to bait at standard operational rates as a mask to 1080, to ensure possums encountering baits find them palatable
- Strategies for ground control of possums should be revised to ensure complete coverage of all possum habitat.
- Monitoring of possum abundance should conform to the national protocol and, at least in high-risk strata (e.g. HR1), be followed by independent audits of compliance. An increase in the number of monitor lines in high-risk strata is warranted to increase the precision of the density indices generated and to meet the requirements of the latest Monitoring Protocol for 50% more monitor lines in high-risk strata (based on both the need for better line coverage and on increases in monitor costs deemed acceptable to Vector Managers).
- Where contract agreements permit it, post-control monitors should be delayed for at least 1 month and preferably 3 months, to help overcome some of the bias inherent in population monitoring undertaken immediately after control.
- Senior managers involved in local pest control should continue to work to improve the acceptance of this programme by the key Featherston landowners and residents opposed to its implementation, through programmes of increased public information, liaison, and buy-in via the development of local ‘working’ groups.
- The annual ‘control’ of ferrets should be formally structured as disease surveillance, and focus primarily on the forest–pasture margin where the risk of Tb reintroduction is greatest.
- The economics of controlling possums dispersing from uncontrolled deep forest, using lines of long-life toxic baits across hillsides, compared with such control along the pasture margin, needs further study as our research failed to properly evaluate this strategy.
- As long as the pig population remains infected, pig hunters and the local pig-hunting club should be encouraged to participate in a surveillance programme of age-specific prevalence and distribution of Tb in pigs. This programme should be structured so as to ensure the collection of pig heads in either freezer chests held by collection agents or scavenger-proof collection boxes for pig offal at key offal discard points and their clearance following weekend hunting. Incentives to ensure hunter participation should include a modest bounty for each head recovered, and a clear understanding that while no

formal pig control is currently planned, pig samples are required and will be collected with or without hunter involvement.

- If pig hunters are not prepared to become involved in a pig surveillance programme, the case for an immediate one-off pig control operation across the VCA should be investigated further, to rapidly reduce the number of infected pigs present.
- Non-musterable cattle living in Lake Domain should be shot as their disease status is unknown and they may pose a threat to nearby cattle herds.

8. Acknowledgements

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Appendix 1 Trap and cyanide data (nights) and catch of possums from the immigrant-flow study.

Season	Trap	Catch	Cyanide	Catch	Feratox	Catch	Total
Winter	320	19	217	8	427	1	28
Spring	480	11	524	5	-	-	16
Summer	480	13	440	2	-	-	15
Autumn	545	17	319	3	-	-	20

Appendix 2 Scavenging about pig heads: camera operation times and species involved.

Camera site	Total operational time (days)	Species visited
Boar Gully	1.0	No visits
D J cam 1	4.92	Harrier, rat
D J cam 2	10.97	Dog/hunter, Harrier
D J cam 3	6.75	Harrier
D J cam 4	2.64	Cat, Harrier
Twin Bridges 1	13.76	Rat
Twin Bridges 2	8.56	No visits
Twin Bridges 3	12.64	No visits
Twin Bridges 4	13.08	Bird, hedgehog, rabbit, rat
Twin Bridges 5	12.95	Rat, stoat
Twin Bridges 6	12.80	Ferret, rat
Lake Meadows 1	1.0	No visits
Lake Meadows 2	11.63	Cattle, harrier, hedgehog, possum
Lake Meadows 3	3.85	No visits

Appendix 3 Scavenging of possum carcasses by (a) a sow, and (b) her litter.
Note full video footage of this sequence of activities is available from the authors.

(a)

(b)