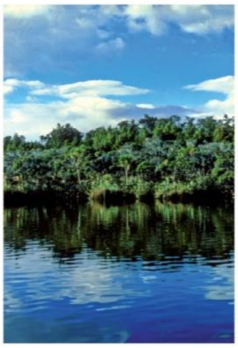

No possums, no TB

Animal Health Board R-10709

Landcare Research
Manaaki Whenua

No possums, no TB

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Landcare Research

Prepared for:

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July 2010

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Contents

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Summary

Project and Client

- A series of trials to investigate the efficacy of pre-control possum detection surveys using chewcards, followed by ground control at detection sites, for reducing or eliminating low-density possum populations were undertaken by Landcare Research, Lincoln, for the Animal Health Board (AHB), between May and November 2009.

Objectives

- To demonstrate a low-cost alternative to repeat aerial poisoning for achieving and confirming rapid TB eradication in low-density possum populations by:
    - demonstrating the efficacy and cost-effectiveness of using an extensive detection-and-mop-up strategy based on chewcards to nearly eliminate already low-density possum populations in continuous forest, and
    - determining the detection-and-mop-up effort required to achieve 99% confidence TB is absent.

Methods

- Possum abundance was surveyed in a 1430-ha area in Pureora Forest, Western Hauhungaroa Range, using chewcards set for 6 nights, in May and October 2009. The area was divided into five blocks, three surveyed with chewcards on transects 250 m apart and two with cards 500 m apart. Cards were spaced either 25 or 50 m apart on alternating transects throughout all study blocks.
- Possum trapping and cyanide poisoning (mop-up) was undertaken at sites within 50 m of all chewcard sites detecting possums in one block with 250-m line spacing and one block with 500-m line spacing, immediately after both chewcard surveys.
- Four of the five blocks were leg-hold-trapped in November 2009, to determine relative possum abundance in possum mop-up and untreated areas at the end of the study.
- Percent reduction in possum abundance during the study in the two mop-up blocks was determined using the May chewcard survey to index initial possum density and the November trapping data to index possum abundance at the end of the study.
- Costs were collated to calculate the cost of the detection and mop-up operations.
- All captured possums were necropsied to determine their TB disease status, with suspicious lesions and pooled lymph node samples from all animals cultured for *Mycobacterium* infection.
- Detection, mop-up and residual trap-catch data were modelled to estimate the probability that resident possums were TB free.

Results

- The mean possum chewcard index was 18.9% (±2.2%; 95% CI) in May, far higher than the expected range of 5–10%.

- Possum chewcard indices were low in the mop-up (treatment) block with 500-m spacing; less than 30% of those in the untreated blocks in both surveys. Possum mop-up removed 14 possums from this block, yet November trap-catch indices indicate there was a relative increase of 85% during the study, suggesting either major sampling error and/or some problem with the monitoring methods used.
- Relative possum abundance declined by 65% between May and November in the mop-up block with 250-m spacing, and is estimated to have declined by 36% and 48% due to the May and October mop-up operations respectively.
- Chewcards spaced at 25-m intervals detected 27% more centres of possum activity than did cards at 50-m intervals.
- Tissue samples were taken from 148 possums during the study. All cultured negative for *Mycobacterium*.
- Each detection and mop-up operation cost a mean of ~$16 and ~$39per hectare for the mop-up block with 500-m and 250-m spacing, respectively. Total costs were split c. 1:3 between detection and mop-up.
- Using the prototype detection-and-mop-methods used here (i.e.; chewcards and leg-hold trapping) couple with possum necropsy, it would cost about $147/ha to confirm with a high degree of confidence that TB had been eliminated from a forest possum population that was initially at about 5%RTCI. However, if more cost-effective mop up tools are developed, if the strategy is deployed at much lower initial possum densities (1% RTCI), and if additional information streams on TB status (sentinel and detection data) are incorporated, the cost would be far lower. If that can be achieved adoption of this strategy immediately after the second of two intensive aerial poisoning operations is likely to be faster and as (or more) cost-effective in confirming TB freedom than would the default approach of conducting a third aerial poisoning operation.

Recommendations

The AHB should consider using a detection-and-mop-up strategy for rapidly confirming with a high degree of confidence where TB has been eliminated from possums. At present, we suggest that the DMU approach would best be applied when possum populations have been under good control for at least five years and just after (within one year of) a whole-area control operation has reduced possum numbers to very low levels.

The prototype DMU approach trialled here should be refined by:

- Measuring the possum detection probabilities of chewcards for a range of transect spacings, card intervals, and placement duration, to determine the optimal detection design. In the interim we recommend that chewcards should be placed at 25-m intervals on transects during possum detection surveys in forest.
- Investigating alternative methods (other than leg-hold trapping) for cost-effective mop-up of possums at detection sites needs investigation. This should include determination of optimal devices, possum behaviour at low density, device-placement patterns, and timing of mop-up operations.

1 Introduction

A series of trials to investigate the efficacy of pre-control possum detection surveys using chewcards, followed by ground control at detection sites, for reducing or eliminating low-density possum populations were undertaken by Landcare Research, Lincoln, for the Animal Health Board (AHB), between May and November 2009.

2 Background

Possums are the main wildlife vector of bovine TB in New Zealand native forests (Coleman & Caley 2000). The proposed strategy for eliminating TB from possums over extensive tracts of forest is to conduct three aerial-broadcast 1080 poisoning operations at intervals of c. 5 years (AHB 2009), but the strategy is expensive (costed at $36 per hectare (including monitoring) per operation; Nugent et al. 2008) and is encountering increasing public opposition (Hansford 2009). The effectiveness of broad-scale possum control is now usually so high that it may be possible, with appropriate follow-up tools and strategies, to cost-effectively achieve local elimination of possums over large tracts of land (Morgan et al. 2006; Nugent et al. 2008). This requires the development of two tools, one to locate the few foci of surviving possums, and a second to eliminate all surviving possums at these foci.

The current standard possum monitoring tool, the residual trap-catch technique (RTC; NPCA 2008) is ineffective at providing cost-effective comprehensive spatial information on possum distribution because the leg-hold traps are bulky, heavy, and (most importantly) require daily visits. Therefore, Landcare Research (with co-funding from AHB and FRST; Nugent et al. 2008) has developed a possum detection device (chewcard) as a cost-effective alternative to leg-hold traps, to map residual possum populations over extensive areas of continuous forest (Sweetapple & Nugent 2008, 2011).

Chewcards are small, lightweight, interference devices that work on the same principle as WaxTags® (Thomas et al. 2003), but incorporate highly palatable foods inside the channels of a plastic coreboard card, to increase the likelihood that cautious feeders will bite the device. They are typically deployed at fixed intervals (20−50 m) along transects that span the entire surveyed area. They are more sensitive to the presence of possums than WaxTags® (unpublished data) and are at least 29 times more cost efficient at detecting low-density possums than standard RTC monitoring (Sweetapple & Nugent 2009). They, therefore, have considerable utility as a low-cost possum detection device. In a recent trial most possums (80–93%) bit chewcards placed nearby, although only c. 40% of the possums present were trapped over 6 nights (Sweetapple & Nugent 2008).

We assume that one of the fastest ways of achieving certainty that TB has been eradicated from possums in an area would be to eliminate the possums themselves and confirm that they are absent, A possum population cannot carry TB if there are no possums! This study therefore aimed to demonstrate in a mainland area of native forest that if possums have already been reduced to very low densities, the remaining possums, and thus TB, can be eliminated from a mainland area of native forest using a two-stage ‘Detection and Mop-Up’ (DMU) strategy. This DMU strategy involves a chewcard detection survey for mapping where survivors are present, followed by targeted possum mop-up of those survivors.

The strategy was trialled in part of the western Hauhungaroa Range during 2009. The area was last aerially poisoned with 1080 in 2005, and was presumed to still contain very low possum densities (Sweetapple & Nugent 2009). Two transect spacings and two card intervals were trialled to investigate their effect on detection-survey sensitivity. Possum mop-up methods were intensified, in an attempt to increase the proportion of possums killed, compared with previous attempts (e.g. Sweetapple & Nugent 2008).

Against expectations from previous research, possum densities in the study area turned out to be higher than the level (identified by Nugent et al. (2010)) at which modelling suggests a DMU strategy would most cost-effective. Despite that, the data gathered were used to assess the cost-effectiveness of this two-step strategy for controlling low-density possum populations compared with aerial poisoning and, with necropsy details from captured possums, to calculate the effort required to eliminate TB from the possum population.

3 Objectives

- To demonstrate a low-cost alternative to repeat aerial poisoning for achieving and confirming rapid TB eradication in low-density possum populations, by:
  - demonstrating the efficacy and cost-effectiveness of using an extensive detection-and-mop-up strategy based on chewcards to virtually eliminate already low-density possum populations in continuous forest, and
  - determining the detection-and-mop-up effort required to achieve 99% confidence TB is absent.

4 Methods

4.1 Study area

The study was undertaken in the Maramataha catchment in the Western Hauhungaroa Range. The study area comprised 1430 ha of undulating terrain between 600 and 850 m above sea level, between the north and south branches of the Maramataha River, west of the main range crest of the Hauhungaroa Range (Fig. 1). Forests were podocarp–hardwood associations dominated by tawa (*Beilschmiedia tawa*) in the canopy with frequent emergent rimu (*Dacrydium cupressinum*), tōtara (*Podocarpus hallii*), miro (*Prumnopitys ferruginea*), mataī (*Prumnopitys taxifolia*) and kahikatea (*Dacrycarpus dacrydioides*).

Possums were first controlled in the area, by aerial application of 1080-poisoned baits, in winter 2001, but the kill achieved was probably poor as the RTCI within the core of the study area was 18.6% RTC in April 2004 (Nugent & Whitford 2006; middle section of Appendix 1). The 2004 trapping and subsequent follow-up surveying revealed that the local possum population still carried TB at that time (Nugent & Whitford 2006). Further aerial 1080 poisoning was undertaken in September, 2005. Cereal baits containing 0.15% 1080 were sown at 5 kg/ha following a single non0toxic prefeed. This operation reduced possum abundance to just 0.2% RTC (S. Littlefair, Qualmons, Taupo, pers. comm.). Low possum abundance following the 2005 operation was confirmed by a chewcard survey completed in December 2005, which detected possums on just 3.4% of cards (Nugent et al. 2008). The

2005 poisoning operation within the study area was part of a much larger operation (88,000 ha), with no part of the study area less than 5 km from the nearest uncontrolled terrain.

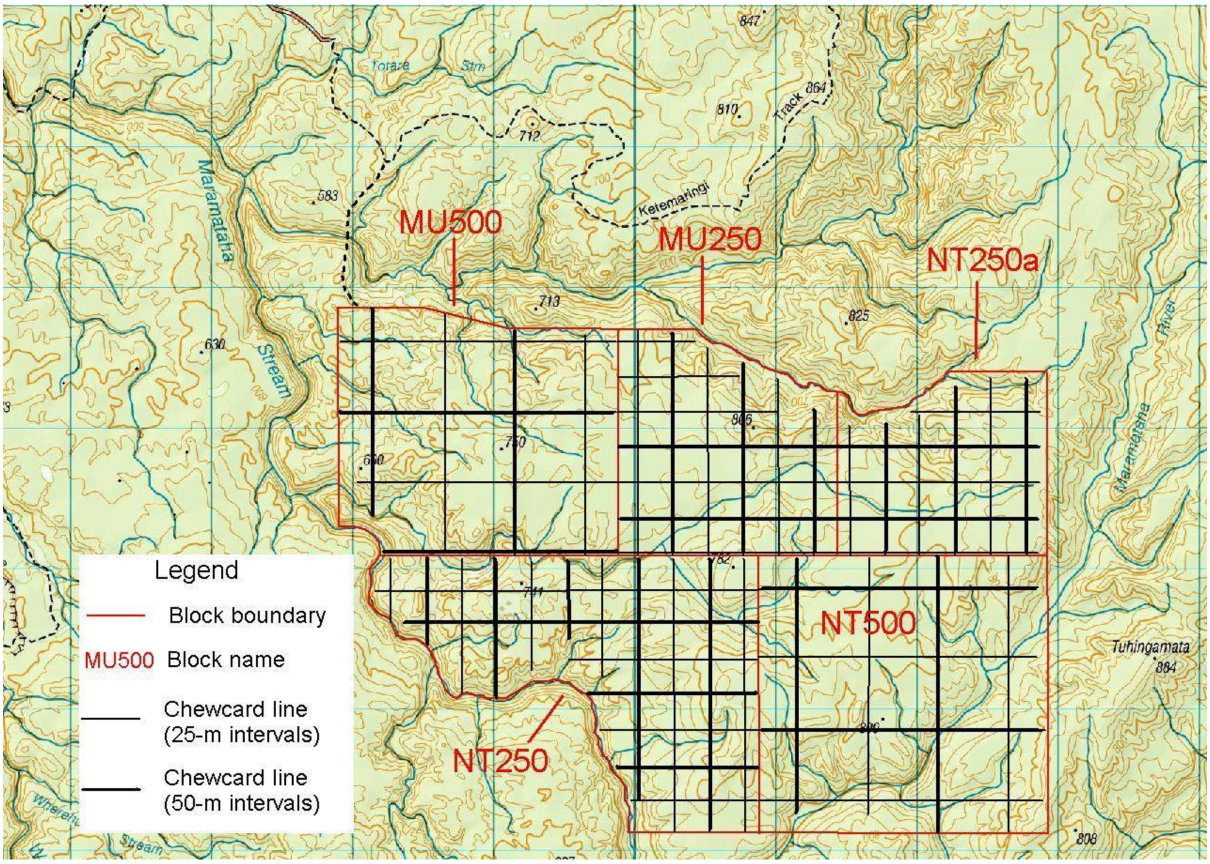

Figure 1 Maramataha study area showing location of the mop-up and non-treatment blocks, and chewcard transects. North–south transects were measured in May and east–west transects in October 2009.

4.2 Possum mapping surveys

The study area was initially divided into four c. 400-ha blocks, and detection or mapping surveys (using parallel lines of chewcards) were undertaken in all four. The two northern blocks were designated as treatment blocks, where ground control of possums was to be undertaken at possum-detection sites (possum ‘mop-up’). No mop-up was undertaken in the two southern areas designated as non-treatment blocks. In one mop-up and one non-treatment block the lines of chewcards were spaced 250 m apart, while in the other 500-m spacing was used. The treatment block with 250-m-spaced transects was further divided into two c. 200-ha blocks, one receiving possum mop-up (block MU250) and one receiving no mop-up (block NT250a; Fig. 1), because high numbers of possum detections there made it too expensive to attempt possum mop-up over the whole block.

All five blocks were surveyed in May 2009 and again in October 2009. On both occasions chewcards were placed at 25-m or 50-m intervals on alternating lines, and left for 6 nights before removal and assessment. All cards were baited with two baits, one a peanut-butter-based bait lured with icing sugar and ground lucerne pellets, and the second a ground-lucerne-based bait lured with peanut butter and eucalyptus oil. Canola oil was added to both baits as required to attain a soft paste consistency to permit easy bait penetration into the card flutes. The first bait is highly palatable to both possums and rodents while the second is palatable to possums but at least partially repellent to rats (P.S. unpubl. data), and was used to reduce the potential for rat interference to prevent possum detection. Cards were placed at sites of best sign within c. 10 m of their predetermined locations, and were attached to trees at 30 cm above the ground. October transects were placed at right angles to May transects (Fig. 1). The GPS location of each chewcard site was recorded.

4.3 Possum mop-up

Mop-up was attempted at all of the card locations in the MU500 and MU250 blocks at which possums were detected, commencing within one week of the chewcard surveys. In May, sentry bait stations (Pest Control Research, Christchurch) baited with c. 50 g of lucerne pellets were placed 30 cm above ground level at each possum-detection site for 3–6 days prior to setting leg-hold traps. These bait stations were deployed in an attempt to increase subsequent possum-capture rates compared with previous attempts (e.g. Sweetapple & Nugent 2008), by ‘prefeeding’ the detection sites before traps were opened. They were baited with lucerne pellets, believed to be unattractive to rats, so that rats did not rapidly remove the bait.

When bait stations were established, Cyanara50 cyanide paste (Connovation, Auckland) was placed inside an orange-oil-lured 50 × 40 mm sealed plastic bag with c. 2 g flour/icing sugar lure and stapled to a tree c. 2 m away, and at four other stations at c. 25-m intervals along the original chewcard line for 50 m in both directions from the detection site. Where multiple adjacent cards detected possums, poison stations were established at 25-m intervals along the length of the detection focus. Flour/icing-sugar-lured leg-hold traps were placed unset at each poison station at the time of poison laying. A handful of lucerne pellets was also scattered on the ground around each poison station. As a result of poor weather the traps, once opened, had to be run for c. 7 nights to achieve the minimum of two fine trap-nights required by the national trap-catch protocol (NPCA 2008). A chewcard was set 30 cm above each trap when first set, and were removed and checked when traps were removed. The GPS location of each trap and captured possum was recorded.

Possum mop-up after the October detection survey followed similar protocols to those in May, except that a mixture of lucerne and 2-g RS5 non-toxic baits (Pest Control Research, Christchurch) were placed in bait stations and on the ground, and poison/trap stations were placed at 50-m intervals in a cruciform pattern centred on sites of possum detection. Traps were run for 3 nights, and included at least two fine nights, at all locations.

4.4 Trap-catch assessment of residual possum abundance

A systematic leg-hold trapping programme was undertaken over much of the study area in November 2009 to assess the impact of the two possum mop-up operations. Traplines of five leg-hold traps spaced at 50-m intervals were trapped for 3 fine nights. Twelve traplines were run in each of the NT250 and NT500 blocks, with 20 and 24 traplines run in the MU250 and MU500 blocks, respectively (Fig. 2). All traplines were at least 200 m apart, and again the GPS location of each trap and captured possum was recorded.

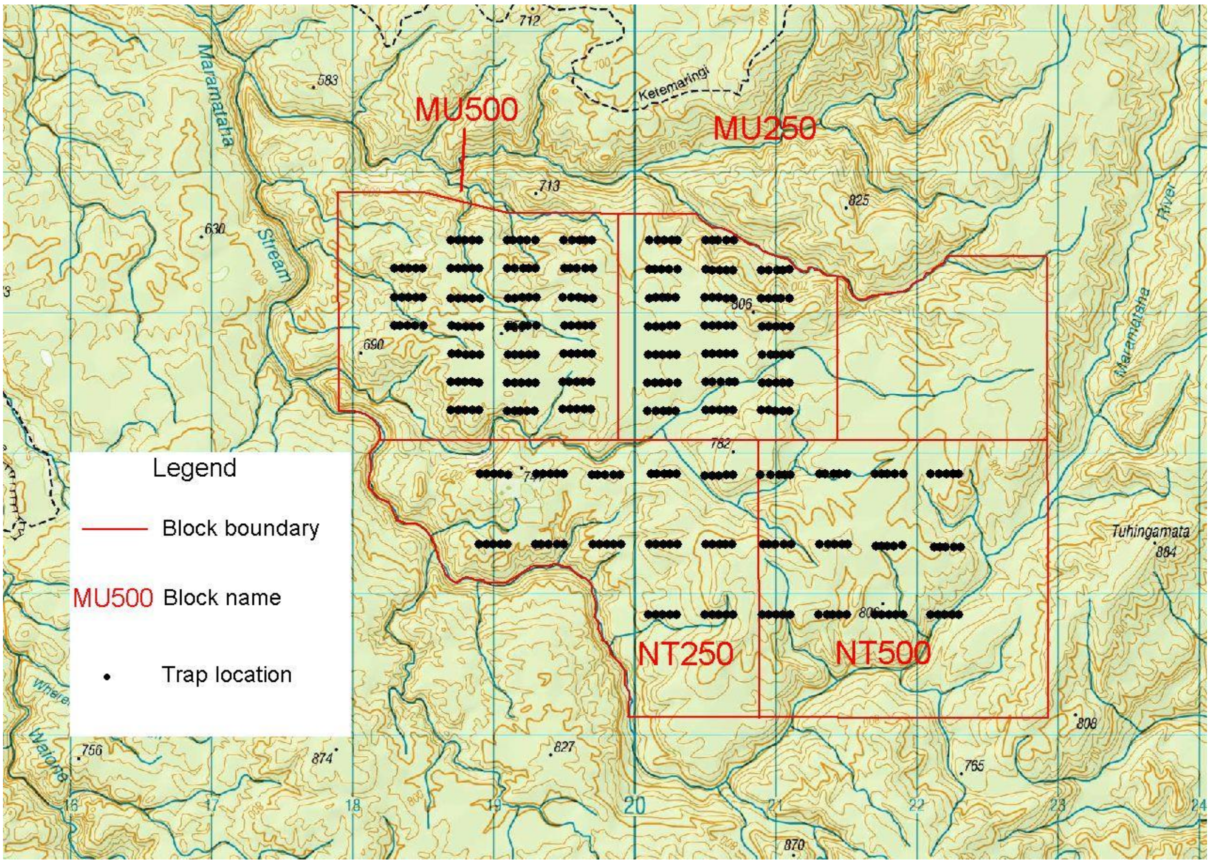

Figure 2 Leg-hold trap locations in the November 2009 residual trap-catch programme in the Maramataha study area. Intervals between traps within transects was 50 m.

4.5 Possum necropsies

All possum carcasses from the mop-up and residual possum trapping operations were necropsied for demographic parameters and the presence of TB-suspicious lesions. Any suspicious lesions were sampled, and axilliary and inguinal lymph nodes from all apparently uninfected animals were pooled (10–20 animals per pool). All tissue samples collected from possum carcasses during mop-up and residual trapping were cultured for *Mycobacterium bovis* at the Infectious Disease Laboratory, Wallaceville.

4.6 Data analysis

Population reduction

Chewcard indices (CCIs) for each block and survey were calculated for possums (and rats) by dividing the number of detections by the total number of chewcards retrieved. Residual possum trap-catch rates (RTCs) from November trapping were calculated for each trapline by dividing the number of possums captured by the total number of trap-nights, adjusted downwards for possum escapes, sprung-but-empty traps, and non-target capture as per the national protocol (NPCA 2008). The CCIs recorded in May were used as baseline possum-abundance estimates and November RTCIs provided residual possum abundance estimates.

These data were used to estimate the possum population reductions in the mop-up blocks during the study using a non-parametric resampling (bootstrap) approach as follows (see Appendix 1 for more details):

The reductions were estimated from

$$\Delta N(\%) = \left(1 - \left(\frac{CCI_{NT}}{CCI_{MU}} \times \frac{RTC_{MU}}{RTC_{NT}}\right)\right) * 100$$

where $\Delta N(\%)$ is the possum population reduction expressed as a percentage of the predicted uncontrolled November population, *CCI* are May chewcard indices, *RTC* are November trap-catch indices, *MU* is a mop-up block and *NT* are the non-treatment NT250 and NT500 blocks combined. Only chewcard data from the area trapped and a 200-m buffer around it (Fig. 2) were used.

Effect of chewcard spacing on detection sensitivity

The effect on detection sensitivity of placing chewcards at 25-m rather than 50-m intervals on transects was compared using data from the 25-m transects. Foci of possum activity (defined as single or multiple detections not more than 100 m away from adjacent detections) were counted, and the length of each activity focus measured (distance between first and last detection + 100 m), on each transect to assess sensitivity of 25-m spacings. The same parameters were measured on the same transect with odd-numbered cards excluded to simulate sensitivity of 50-m spacings. The two sets of parameters were then compared using paired *t*-tests. The validity of this comparison is dependent on there being similar levels of contagion on cards spaced at 25-m and 50-m intervals. Therefore, the presence of contagion (increased encounter rate at closer device spacing due to the closer spacing inducing active searching for devices; Bamford 1970) was tested for by comparing possum detection rates on 25-m and 50-m transects.

DMU cost projections

Total costs of each stage of the operation (detection survey, possum mop-up, RTC monitoring) were calculated using a contractor charge-out rate of $325/person/day, two days of travel to and from the study area per person and $2,500 helicopter hire in each of the May, October and November operations, $0.60 per kilometre of vehicle travel and $0.25 per baited chewcard. Fixed costs (labour and expenses travelling to and from the study area) were assigned to tasks in proportion to the time spent undertaking them.

Cost of confirming TB freedom using DMU

We used the combined data to: (1) quantify the probability of TB freedom in the 250-m and 500-m experimental blocks following the two mop-up sessions; (2) predict the probability of freedom over subsequent hypothetical mop-up sessions; and (3) explore the impact of the higher than desirable trap-catch rates encountered in the study on the cost-effectiveness of the DMU. Specifically, we predicted the number of mop-up sessions that would be necessary to achieve a median and lower 95% confidence interval for the posterior probability of TB freedom greater than 0.99 and 0.90 respectively given that all surveys were negative for TB. This is the threshold at which we arbitrarily would claim successful disease eradication. The reader, of course, can adjust this threshold and use the results to determine the expected effort necessary to achieve success. For simplicity, we assumed the mop-up sessions were immediately sequential, with no population increase between them, so this is an estimate of what it would cost to immediately achieve TB freedom.

To estimate the probability of TB freedom after each mop-up session, we began with an estimate of the prior belief TB had been eradicated given the level of control applied in 2005, and, as proposed by Nugent at al. (2007), used Bayesian updating to calculate a 'posterior' probability that incorporated the new data on the numbers of possums (and the absence of TB in them) removed during each DMU session and also an underlying probability of disease introduction with each temporal update (Appendix 1). For this a hypergeometric model was used to estimate the probability of detecting TB in the population, which incorporates estimates of population size, proportion caught, and test (necropsy and culture) sensitivities. Uncertainties in these estimates are incorporated in the modelling and propagated through to the confidence intervals of the resulting predictions of the probability of freedom.

The Bayesian approach requires a prior probability of disease infection in the population. For this analysis we used a spatially explicit, individual-based model (Ramsey & Efford 2010) to predict the probability of TB presence in the population prior to the onset of the present study. In this simulation, we assume that the May 2005 population density was equivalent to 20% TCI with a TB prevalence of 2%. A single control episode in winter 2005 was simulated that resulted in an RTCI of 0.2%. Population dynamics were then simulated for 4 years (till 2009) with an intrinsic rate of population growth equal to 0.5. We ran 1000 simulations. None of these predicted TB persistence in 2009. However, this prediction is based on a number of unverified assumptions, including uniform application of control, and no reintroduction of TB from outside the area or from other species. Thus, despite the prediction of a zero probability of TB persistence, we therefore elected to use an extremely 'conservative' (i.e. likely to be higher than reality) prior probability of TB persistence for the purposes of this study. Our prior distribution followed a beta distribution with the mean equal to 0.1 (a 10% chance that TB was present at the start of this study; $\alpha = 6$ and $\beta = 54$).

5 Results

5.1 Detection surveys

Combined totals of 1174 and1238 chewcards were deployed across the 1477-ha study area in May and October, respectively (178–340 per block in each survey). Mean possum CCI throughout the study was 18.7 ± 2.3% (95% CI). Possum CCI was 6.3% in the MU500 block in May, significantly lower than in the other four blocks where 17.2–26.8% of cards were bitten by possums (non-overlap of 95% confidence intervals; Figs 3, 4a). Mean possum CCIs declined between May and October by 26.6% in the MU250 block and increased by 33.9% in the NT250a block, but none of these changes were statistically significant. Details of operational parameters and results, by block, are given for each operational activity in Appendix 2.

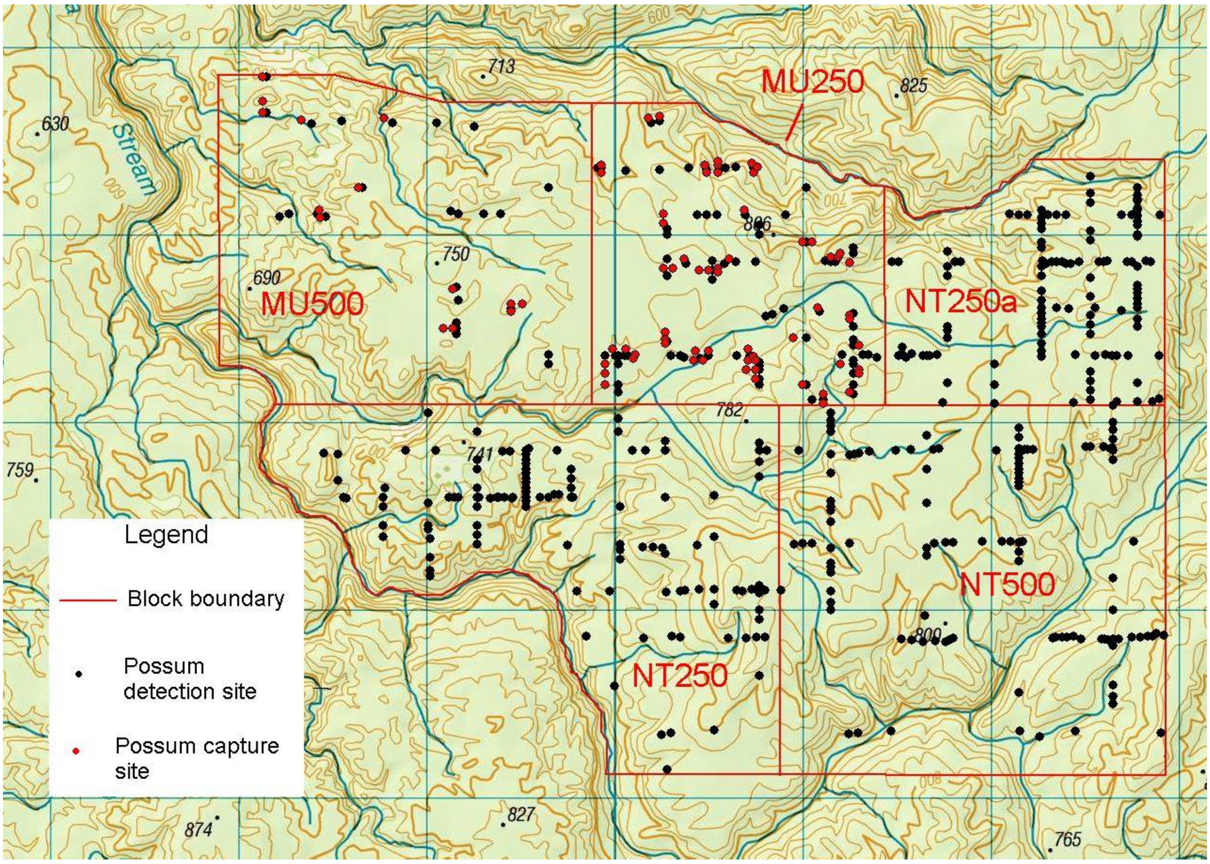

Figure 3 Possum detections by chewcards, and possum captures, during May and October, 2009, detection and mop-up operations in the Maramataha study area.

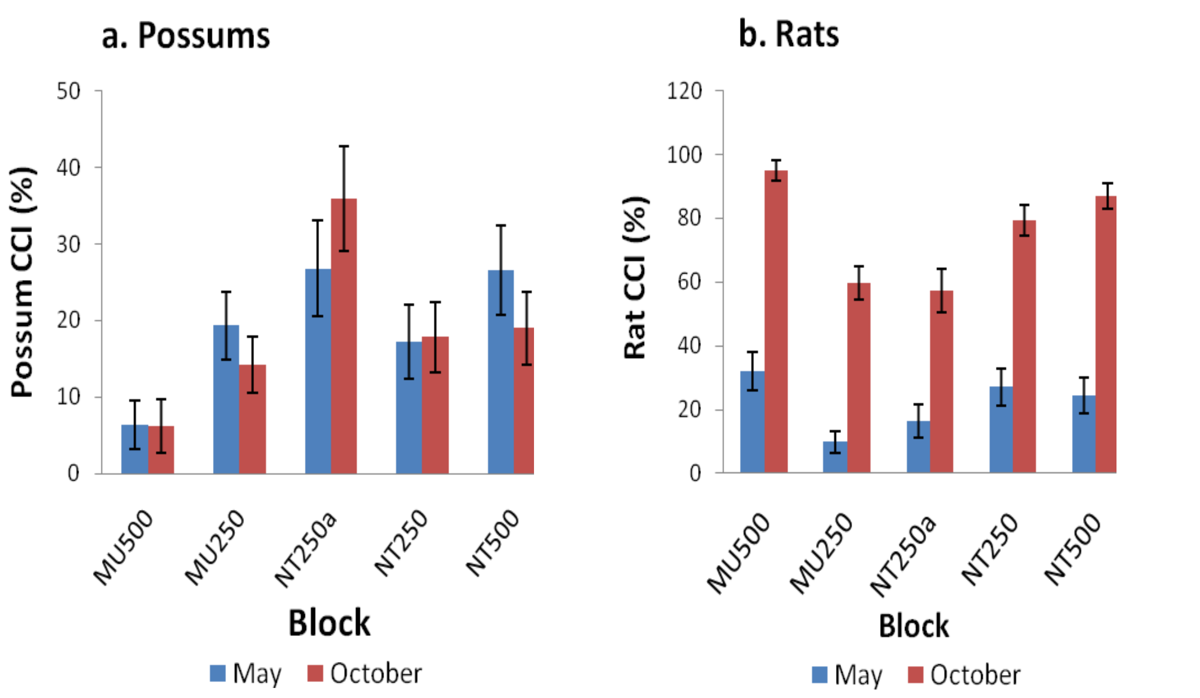

Figure 4 Chewcard indices of (a) possum abundance and (b) rat abundance during the two chewcard surveys in the Maramataha study area in May and October 2009. Error bars are 95% binomial confidence intervals.

Rat CCIs ranged from 9.9% to 32.0% (mean = 22.3 ± 2.3%) during the May detection survey and climbed significantly in all blocks to 57.3−94.9% (mean = 76.1 ± 2.5%) during the October survey (Fig. 4b). Poisson transforming the rat CCIs to compensate for device saturation (Hone 1988) indicates that October rat activity was c. 2.5 times greater in the MU500, NT250 and NT500 blocks than in the other two blocks, and 5.4 times greater than May rat activity in the non-treatment blocks.

In May, the possum CCI on cards that did not detect rats (all blocks) was 68.7% higher than on the cards that did detected rats (2×2 contingency tables: $\chi^2_1 = 13.1$, $P < 0.001$). This difference was even greater in October (3.5 times higher on 'non-rat' cards; 2×2 contingency tables: $\chi^2_1 = 117.9$, $P < 0.001$). These data demonstrate a negative interaction between rat and possum interference on chewcards. The similar possum CCI in non-treatment blocks in May and October (means = 23.8% and 24.2%, respectively) despite the marked increase in rat CCI over this period indicates that (assuming no marked seasonal change in possum detectability) much of this interaction was due to possums excluding rat interference from cards, as opposed to the other way around.

The mean CCIs (both surveys combined) on transects with cards spaced at 25-m intervals was 18.13± 1.9%, similar to the mean of 20.1 ± 2.8% recorded for transects with cards spaced at 50-m intervals. The lack of a significant difference between these two estimates means that contagion (as defined by Bamford 1970) was absent or of similar levels at both card spacings.

On transects with 25-m card spacing, even-numbered chewcards (50 m apart) detected 51 of the 70 (72.9%) possum activity foci detected. Cards spaced 25 m apart detected a greater mean length of possum activity per line (625 m) than did 50-m spaced cards on the same transects (425 m; paired *t*-test: $t_{24} = 5.45$, $P < 0.001$). During mop-up operations 3.7 and 2.5 possums/km were caught on transects with 25-m and 50-m card spacings, respectively, although this difference was not significant (two-sample *t*-test: $t_{19} = 0.91$, $P = 0.373$).

5.2 Possum mop-up

A total of 49 possum-detection foci were poisoned and trapped across the two treatment blocks during the two mop-up operations, deploying 111 bait stations and 282 traps and poison baits (Table 1, Fig. 3). Seventy-six possums were caught; most (81.6%) in the smaller 224-ha MU250 block, reflecting the greater possum detection rate and consequently greater mop-up effort there (Table 1, Figs 3, 4a).

Despite being deployed up to a week before traps were actually opened, the bagged cyanide-paste baits caught fewer possums (10) than did leg-hold traps (66; $\chi^2_1 = 40.26$, $P < 0.001$). Most baits were dry and intact when retrieved. Possums were caught on 67.3% of detection foci. Although the proportion of foci at which possums were killed was consistently higher in the MU250 block and during the second mop-up operation (Table 1), neither comparison was statistically significant (2×2 contingency tables; $\chi^2_1 < 2.40$, $P > 0.05$).

Nightly catch rate declined rapidly over three successive nights of trapping during the October mop-up, with 59.4% (15.0% RTC) of the 32 trapped possums caught on the first night and just 6.5% (1.6% RTC) caught on the third night. Persistent wet weather prevented calculation of a meaningful nightly catch rate in May, but most of the trappable possums present appear to have been caught early in the extended trapping session as only three possums were caught on the last (seventh) trap-night, when the weather was completely fine.

Lucerne pellets appeared unattractive to possums. There was no obvious reduction in lucerne volume in bait stations during the mop-up operations (P.S. pers. obs.).

During mop-up trapping, possums were detected on six of the chewcards placed above traps even though no possum was trapped at that site. This included three foci where the whole array of five or more traps did not capture any possums. Five of these six cards were in the MU500 block in May, resulting in the detected-but-not-captured rate for possums there (41.6%) being significantly higher than for the MU250 block (0%; 2×2 contingency table: $\chi^2_1 = 13.4$, $P < 0.001$). The sixth such detection was from the MU250 block in October.

Table 1 Details of devices used and possum captured during the two possum mop-up operations in the Maramataha study area, May−October 2009

Parameter	First mop-up (May)		Second mop-up (October)		Total
	Block MU250	Block MU500	Block MU250	Block MU500	
No. of possum foci detected	19	10	13	7	49
No. of bait stations set	52	14	34	11	111
No. of traps + poison baits set	105	50	92	35	282
No. of possums trapped	27	7	26	6	66
No. of possums poisoned	4	0	5	1	10
Total no. of possums caught	31	7	31	7	76
Percent of foci catching possums	68.4	40.0	84.6	71.4	67.3

5.3 Residual possum trapping

A total of 72 possums were captured during November RTCI trapping (Table 2) with the non-standard RTCIs ranging from a low of 3.4% in the MU250 block to a high of 11.2% in the combined NT250/NT500 block (Fig. 5). As this trapping was undertaken on transects of the same length but with half the number of traps specified in the national protocol (NPCA 2008), the equivalent or standard protocol RTC values would be lower, perhaps as low as 1.7−5.5%.

Table 2 Demographic details of possums caught in the Maramataha study area during the mop-up and residual trapping operations, May−November 2009

Parameter	First mop-up (May)	Second mop-up (October)	RTC Trapping (November)	Total
Adult females	22	14	31	67
Adult females with pouch young	21	11	31	64
Adult males	8	16	27	51
Juveniles	8	8	14	30
Juveniles < 1.5 kg	6	7	14	27
Total	38	38	72	148

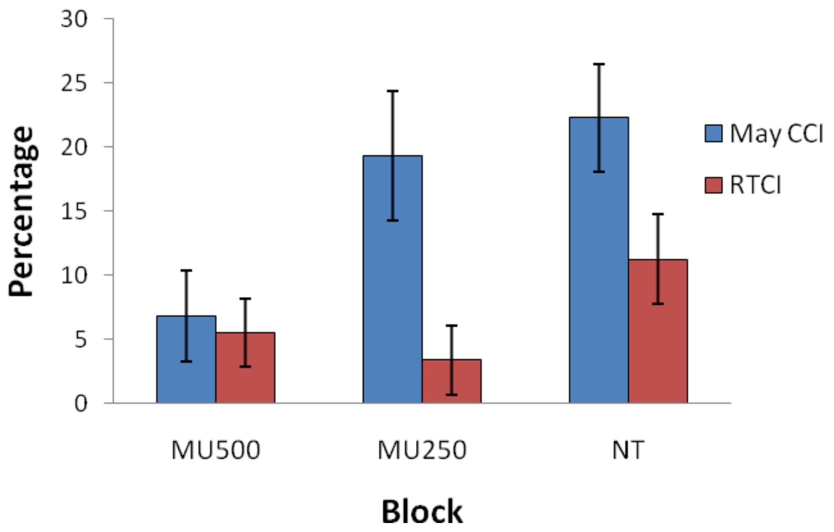

Figure 5 Residual trap-catch indices (RTCI) and May possum chewcard indices (CCI) for the two mop-up blocks and the combined 250–m and 500-m non-treatment blocks. Only chewcard data from within a 200-m buffer around the RTC lines is presented. Error bars are 95% confidence intervals.

Mean nightly catch declined from 37.5% (RTC = 7.9%) of trapped possums caught on the first and second nights to 25.0% (RTC = 5.3%) on the third fine night. This pattern of nightly declines in possum captures did not differ significantly between mop-up and non-treatment blocks (2×3 contingency table: $\chi^2_2 = 3.91$, $P > 0.05$), indicating that the different RTC-transect spacing in these two areas did not affect trap-catch rates.

However, comparing the declines in catch rate between the October mop-up operation and the November RTCI trapping indicated that targeted placement of traps in mop-up blocks caught possums significantly faster than did untargeted systematic placement of traps (χ^2_2 = 7.94, $P < 0.05$). To compare the speed of the declines, negative exponential regression equations were fitted to the nightly decline in trap-catch during October mop-up and November RTC trapping respectively, then solving for 'y = 0.05(night 1 RTC)' predicts that nightly trap-catch would have declined to an arbitrary 5% of the first night's catch after 3.8 and 16.3 nights during October and November trapping, respectively. In other words, targeted mop-up trapping reduced possum abundance by a specified amount more than four times faster than did systematic placement of traps.

5.4 Possum necropsies

The sex ratio of adult possums caught in May differed significantly from parity (χ^2_1 = 6.54, $P < 0.05$) with females outnumbering males 22:8 (Table 2). The sex ratio of adults captured in October and November combined did not differ from parity (χ^2_1 = 0.05, $P > 0.1$). Most female possums reach sexual maturity at about one year of age (Efford 2000), and appear to do so in the study area as the heaviest immature female was 1.45 kg (n = 13). Nearly all adult female possums (those with a fully developed pouch) bred in both autumn and spring during the study with 95% and 100% carrying pouch young in May and November, respectively (Table 2). Therefore, it appears likely that nearly all adult females bred as one-year-olds.

Seven of the 38 possums (18.4%) captured during the second mop-up operation were juveniles less than 1.5 kg in weight, indicating significant recruitment of newly independent possums between the two mop-up operations.

Necropsies revealed only a single non-TB-typical lesion in the lung of an October-captured possum. This sample, and all 13 pooled lymph node samples, cultured negative for *Mycobacterium bovis*.

5.5 Possum population reduction

For both mop-up operations combined, the estimated changes in possum density during the study were a 65.0% (95% CI = 27.3−88.8%) decline in the MU250 block (62 possums removed), and an 85.4% (95% CI = 287−-19.1%) increase in the MU500 block (where only 14 possums were removed).

An overall reduction in possum abundance of 65% equates to c. 40% reduction in each mop-up operation in the MU250 block. However, the same number of possums was removed from this block in each mop-up operation, so the percentage removed will have been higher in October than in May. A total of 95 possums were accounted for in the MU250 block at the end of October, based on the number known to have been removed plus the number estimated to still be alive. Subtracting the 31 possums captured in October suggests 64 possums were present immediately before that mop-up operation. Five of the 31 possums (16%) captured in October were juveniles recruited since May. Accounting for the juveniles that were recruited into the population between May and October that were not killed in October, we calculate that just c. 85 possums (95 − (64*0.16)) were present at the start of May. The 31 possums removed in each of May and October, therefore, equate to population reductions of 36.4 and

48.1%, respectively. Ten possums were captured in the MU250 block during November RTC trapping, which equates to a further 29.9% population reduction.

5.6 Possum detection and mop-up costs

Mean total cost for each detection-and-mop-up operation was $38.53 and $15.55 per hectare for the 250-m and 500-m blocks respectively (Table 3). These totals were comprised of $5.32−$8.36 per hectare for detection surveys and $8.93−$34.84 per hectare for possum mop-up. Mop-up costs in May were 38% greater than in October due to persistent wet weather extending trapping to c. 7 nights at each trap site. October mop-up was also hindered by bad weather, forcing the closure of traps for 2 nights, mid-session. Overall, 84.8% of the total cost was for labour and the remainder for operational expenses, mostly travel (Table 3). Costs for the RTC trapping in November were $13.22 and $24.14 per hectare in the non-treatment and mop-up blocks, respectively.

Table 3 Mean operational costs for the two detection-and-mop-up operations undertaken in the Maramataha Catchment, May–October 2009.

Activity	**250-m blocks ($/ha)**	**500-m blocks ($/ha)**	**Average ($/ha)**
Detection survey:			
Labour	7.01	4.40	5.71
Travel (vehicle + helicopter)	1.00	0.74	0.86
Chewcards	0.27	0.14	0.21
Other supplies	0.08	0.04	0.06
Total for detection surveys	8.36	5.32	6.84
Possum mop-up:			
Labour	25.64	8.97	17.31
Travel (vehicle + helicopter)	4.36	1.21	2.78
Other supplies	0.17	0.05	0.11
Total for mop-up	30.17	10.23	20.20
Total	38.53	15.55	27.04

5.7 TB eradication probability

As a result of our inability to obtain a meaningful estimate of the reduction resulting from removing 14 possums from the 500-m block (see population reduction section above), we could not make useful predictions on the probability of disease freedom in the 500-m treatment block. The results presented here are therefore for the MU250 block alone.

Assuming a prior probability of TB persistence in this block of 0.1, the posterior median probabilities of TB freedom after the May and October mop-up operations were 0.93 and 0.95 respectively (Table 4). Confidence intervals were wide due to the multiple sources of uncertainty in the analysis ($N_{i,b}$, priors, *P(Intro)*, test sensitivities, and proportion captured).

Under this conservative scenario, and assuming a 40% population reduction during each operation, eight mop-up operations were required to achieve a median and lower 95% confidence interval of the posterior probability of TB freedom equal to 0.99 and 0.90 respectively. We estimate that this would have cost a total of $146.70 per hectare (Table 4).

Table 4 Posterior probability of freedom from TB calculated by using the percentage of the population removed (and found to be TB free) in two actual and 10 simulated successive detection and mop-up operations. The prior probability of TB freedom is conservatively assumed to have been 0.1, and the initial population size is the median value from the bootstrap analysis. Simulations assume all carcasses recovered are TB free.

	Median	0.025 CI	0.975 CI	Pop. size	Cost ($/ha)	Total cost ($/ha)
1. May	0.932	0.863	0.973	94	38.53	38.53
2. September	0.948	0.893	0.980	63	38.53	77.06
3. Simulation 1	0.951	0.890	0.984	32	20.00	97.06
4. Simulation 2	0.952	0.880	0.999	19	11.87	108.93
5. Simulation 3	0.959	0.876	0.999	11	10.39	119.32
6. Simulation 4	0.999	0.880	0.999	7	9.65	128.97
7. Simulation 5	0.999	0.893	0.999	4	9.10	138.07
8. Simulation 6	0.999	0.915	0.999	2	8.63	146.70
9. Simulation 7	0.999	0.968	0.999	1	8.54	155.24
10. Simulation 8	0.999	0.999	0.999	1	8.54	163.78
11. Simulation 9	0.999	0.999	0.999	0	8.36	172.14
12. Simulation 10	0.999	0.999	0.999	0	8.36	180.50

The specified posterior probabilities of freedom were achieved far more quickly if we assumed more efficient mop-up operations in which 75% of the population was caught in each operation. Under this scenario, only three mop-up operations, at a total cost of $60 per hectare, were required to meet the designated target (Table 5).

Table 5 Posterior predictions of the probability of freedom using a distribution of the proportion of the population captured with a mean of 0.75 (i.e. 75% of residual possums captured each mop-up operation). A conservative prior (0.1) is also used in this analysis. Population size is the median value from the estimated population size from bootstrap analysis.

	Median	**0.025 CI**	**0.975 CI**	**Pop. size**
May	0.975	0.929	0.995	94
Simulation 1	0.982	0.932	0.999	24
Simulation 2	0.999	0.952	0.999	6
Simulation 3	0.999	0.999	0.999	1
Simulation 4	0.999	0.999	0.999	0
Simulation 5	0.999	0.999	0.999	0
Simulation 6	0.999	0.999	0.999	0

6 Conclusions

6.1 Efficacy of detection and mop-up operations

The two-stage DMU strategy explored here was developed primarily as a potential alternative to periodic (usually 5-yearly) aerial 1080 poisoning operations as a cost-effective way of attaining and maintain near-zero possum densities after initial control (Nugent et al. 2008). While previous research has demonstrated that chewcards provide the requisite low-cost high-sensitivity tool needed for the detection stage of the strategy (Sweetapple & Nugent 2008, 2009, 2011), this was the first attempt at actually eliminating a forest-dwelling possum population using a DMU approach. We did not achieve that. Despite conducting two DMU operations, possum abundance in the most intensive treatment block (transects at 250-m intervals) was reduced by just 65% relative to the untreated blocks, at a cost of $77 per hectare. The single most successful single DMU operation reduced possum abundance by c. 50%.

Although costs were much lower in the 500-m block ($31 per hectare) there was no measurable reduction in possum numbers there. This may reflect low possum detectability (which will have resulted in lower trapping input than desirable into targeted mop-up stage). We suggest the 85% increase in RTCI in the 500-m treatment block (relative to the non-treatment blocks) was not likely to represent mass immigration of possums into that block between October and November. Rather we suggest that in May and October possums were less detectable by chewcard in that block than elsewhere. Whatever the reason, we are unable to draw any quantitative inference about the reduction in possum numbers in the MU500 treatment block other than that any reduction is likely to have been small given the small number of possums removed (14) and the number of possums suggested present by the November RTCI of 5%.

For the MU250 block, the modest reduction recorded could reflect:

1. Low detection sensitivity because of low chewcard attractiveness. This seems unlikely given that in previous studies elsewhere in the Hauhungaroa Range similar chewcard surveys using similar bait have detected >80% of possums and (because the possums were usually clustered in groups) almost all of the groups of possums to be targeted (Sweetapple & Nugent 2008, 2009).

2. Low detection sensitivity because of rat interference. This also seems unlikely given that possum kill was higher in October (48%) than in May (36%) when the rat CCI was also highest (60% cf. 9%).

3. Low detection sensitivity because the chewcard transects were spaced too far apart. The 250-m spacing should have ensured chewcards were placed within the annual home ranges of most possums as their home ranges in forest are usually c. 2–4 ha (80–113-m radius; Cowan 2005) , or even larger (c. 10 ha) in low density populations (Pech et al. in press). However, the area used by a possum within the 6-day chewcard assessment period may sometimes be much smaller than this. Recent GPS-based analysis of possum home range use indicates that some have very localised activity patterns with most activity recorded in just 2–3 locations that were each just a few metres in diameter (Nugent et al. 2010). Such possums are more likely to have been missed using a 250-m spacing.

4. Low detection sensitivity because the chewcards were spaced too far apart along transects. Cards spaced 50 m apart detected only three-quarters of the foci detected by cards 25 m apart. Sixty per cent (by length) of chewcard transects in the 250-m treatment block had cards spaced at 50-m intervals indicating that only c. 82% of possum activity was detected compared with total detected activity had all transects used 25-m card spacing. Higher levels of contagion (as defined by Bamford 1970) on the more closely spaced cards does not explain this result as we found no evidence for it. If all transects had cards at 25-m intervals then we estimate that total possum kill in the 250-m block would have been c. 59% in October.

5. Ineffective mop-up by poisoning. Cyanide paste baits in plastic bags were clearly ineffective at killing possums during mop-up as they accounted for only 13% of possums killed despite longer deployment than the traps placed at the same sites.

6. Insufficient intensity of mop-up trapping. This seems unlikely as the rapid decline in nightly catch rate during October mop-up suggests that the trap density was sufficient to catch most trappable possums present during the 3 nights trapped.

7. Low trappability of possums. The proportion of possums present that were not trapped during mop-up operations is unknown. As few as 40−50% of possums were trappable at any one time during previous attempts to trap low density populations

(Morgan et al. 2007; Sweetapple & Nugent 2008). Our data are consistent with a high possum detection rate followed by a c. 40% capture rate during mop-up. There is some indication of variation in trappability between seasons, as proportionately far fewer adult males were caught in May than in October (Table 2). This sex bias was also observed from Pureora Forest in May 2010 (unpubl. data), and elsewhere (N. Philpott pers. comm.). If males are less trappable in late autumn, they may also be less detectable with chewcards, lowering detection sensitivity.

On balance, we suggest that the achievement of only modest reductions reflected lower than expected detection sensitivity as a result of card spacing and the seasonal timing of the first operation, and low trappability of detected possums. We hypothesise that both of these could reflect patterns of highly localised home range use by possums that are able to access all of their food and shelter in just a few places. It is important to note that we used traps and an acute poison in this study deliberately, in order to obtain carcasses for TB necropsy, but other ground control methods using long-life baits might provide more effective mop-up (but no TB data).

The overall 18.9% possum CCI recorded in May 2009 was almost six times higher than the 3.3% recorded in the same area in December 2005, at a time of similar rat abundance (Nugent et al. 2008). That suggests a very high exponential rate of annual increase of 0.50 p.a. This increase is unlikely to reflect immigration because the study area is deeply embedded within an 88 000 ha-area poisoned in 2005. Such rapid population growth could reflect the high breeding rates observed in both autumn and spring. If real, this suggests that the population has access to abundant food supplies, which may in turn make them more difficult to detect and trap than higher density populations.

6.2 Cost of possum detection and mop-up

Mapping possum distribution across a forested landscape, using transects 250-m apart costs c. $8.40 per hectare, regardless of card spacing along the lines. Because the mostly gentle terrain and vegetation enable relatively fast travel through the bush, and because the contractor used (Bushwork Contracting, Kati Kati) has a reputation for high productivity, this cost will be at the low end of what is likely to be usual.

Mop-up cost will vary greatly between operations. In this study costs were higher than expected because of (1) the pre-control RTC (c. 5%) was far higher than the 1% expected and (2) poor weather, particularly in May, which greatly extended trapping effort. The additional effort to prefeed trap sites also increased costs.

We estimate that for a possum population in similar habitat but at c. 1% RTC (instead of c. 5% as in this study) and using a similar approach in fine weather but without prefeeding, mop-up alone would cost c. $12 per hectare, and detection and mop-up $21 per hectare. Non-toxic prefeed could instead be achieved at little extra cost by scattering baits on the ground at possum-detection sites while checking chewcard lines.

The DMU costs could be greatly reduced by development of a toxin-only mop-up protocol if carcass retrieval was not required. Under these conditions, toxic baits could be sown at possum-detection sites at the same time as chewcards are read. This would obviate the need for multiple return visits to those sites. Use of possum kill traps is another, albeit more expensive, option. Kill traps are bulky (i.e. few can be carried), and require deployment for up to 10 days to achieve a similar kill to leg-hold traps (Sweetapple et al. 2006). They may also be less effective in the presence of abundant rats which may rapidly remove most of the lure and bait.

The utility of the detection and mop-up trapping strategy compared with blanket trapping is highlighted by the rapid possum capture rate following the October detection survey compared with the November trapping results. This would have been due to the targeted placement of traps where possums were located, and the prefeeding effect of non-toxic baiting and the presence of chewcards before and during trapping. By comparison a blanket trapping strategy, prefeeding trap sites a week before opening traps for 3 nights at 50-m intervals on transects 250 m apart, would cost c. $52 per hectare. This latter strategy may be less successful than targeted mop-up trapping because traps will not be deployed 50 m either side of transects, or benefit from any prefeeding effect of the presence of chewcards.

6.3 Probability of freedom from TB

Using a DMU strategy with low kill rates to achieve and confirm TB freedom from a possum population initially at about 5% RTCI would be expensive. Under the assumptions applied here we predict that it would require eight DMU operations (at a total cost of c. $149 per hectare) in quick succession to achieve the arbitrary ‘freedom’ target set. If those operations were spread over several years, the apparently high possum population growth rate would add substantially to the number of operations required. However, if the efficiency of mop-up can be improved to produce a 75% reduction per operation, achieving the desired confidence of TB freedom would require just three operations at a cost of about $60 per hectare.

Alternatively (or in addition) costs would be further substantially reduced if a DMU approach was applied immediately after a conventional ‘whole-area’ control operation that reduced possum RTCIs to under <0.5%, 90% lower than in this study. In that context confirming TB freedom at the level we have arbitrarily set would require only two DMU operations even with inefficient mop-up – the equivalent of simulations 4 and 5 in Table 4.

Further, in this study we have used only the population reduction and TB prevalence data to update the probability of TB freedom. However, once very low possum densities are achieved (either by conventional control or by previous DMU operations), some parts of the area are free of possums, so must also be free of TB-infected possums. Nugent et al. (2010) show that possum monitoring data (specifically spatially explicit trapping data showing sites where no possums were detected) can be used as another source of data to demonstrate TB freedom. Developing that concept for chewcard data was beyond the scope of this project, but once that development has been done, each detection survey showing large areas with few or no possum detections would add greatly to confidence that TB is indeed absent. Likewise, collection of data from sentinel species such as pigs and deer could (if available) also increase confidence that TB is absent from possums.

For the study area, the possum densities that prevailed before the 2005 aerial 1080 poisoning operation were moderately high and TB was still present in possums in the area in May 2005 (Nugent & Whitford 2006). That operation could therefore be regarded as the first of the three such operations currently regarded as being needed to eliminate TB from a deep forest area (AHB 2009). Using the possum-TB model developed by Ramsey & Efford (2010) to simulate the impact of three such operations seems certain to predict a very high probability of TB freedom. However, it assumes that there are no gaps or errors in control coverage and it also assumes that there is no spillback of TB from other hosts or reintroduction of TB by immigrant possums. As quantifying those risks will always be extremely difficult, there is always likely to be some unknown (and possibly unknowable) level of certainty around the quantitative predictions of the model. It therefore appears likely that even where three aerial poisonings have been applied there will still be a need to empirically ‘validate’ those predictions. At present, this empirical ‘proof of freedom’ validation is likely to be attempted via surveys of sentinel species. We conclude that even though mop-up was only moderately effective, the DMU approach used here (i.e. with carcass recovery for necropsy) does offer an alternative way of validating that possums are free of TB. We further suggest that it has the potential to be as or more cost effective than the approach currently adopted.

We consider that the most cost effective way of using the DMU (and necropsy) approach would be to apply it soon after a second aerial poisoning operation. The additional population reduction would increase the likelihood of quickly eliminating any residual possums and also quickly, empirically, and quantitatively provide a high degree of confidence that TB freedom has indeed been achieved. If the density of possums remaining after the second whole-area poisoning was very low, the cost is likely to be much the same as that of the default approach involving a third whole-area poisoning and subsequent surveys of sentinel species. We also consider that there is substantial potential to markedly improve the efficiency and cost-effectiveness of mop-up. Further, using the non-detection data from the detection surveys to provide another major information stream for estimating the probability of possum (and therefore TB) absence is likely to add greatly to statistical power in calculating the probability of TB freedom.

7 Recommendations

The AHB should consider using a detection-and-mop-up strategy for rapidly confirming with a high degree of confidence where TB has been eliminated from possums. At present, we suggest that the DMU approach would best be applied when possum populations have been under good control for at least five years and just after (within one year) a whole-area control operation has reduced possum numbers to very low levels.

The prototype DMU approach trialled here should be refined by:

- Measuring the possum detection probabilities of chewcards for a range of transect spacings, card intervals, and placement duration, to determine the optimal detection design. In the interim we recommend that chewcards should be placed at 25-m intervals on transects during possum detection surveys in forest.
- Investigating alternative methods (other than leg-hold trapping) for cost-effective mop-up of possums at detection sites needs investigation. This should include determination of optimal devices, possum behaviour at low density, device-placement patterns, and timing of mop-up operations.

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1 Appendix 1 Approach used to model the probability of TB freedom

In all of our analyses we incorporated probability distributions to account for uncertainty in the inputs of our prediction models, which are then propagated into the uncertainty of the resulting probability of TB freedom. It is therefore critical to consider not only the median posterior prediction but also the 95% confidence intervals. We calculated the posterior probability of TB freedom after each of the two mop-up trapping sessions in the 250-m-spacing treatment blocks. The priors for each subsequent trapping session were updated by combining the posteriors from the preceding session and a low probability of introduction. We then predicted the probability of freedom following each of up to 10 subsequent hypothetical trapping sessions, updating the priors following each session.

For convenience, we describe the data modelling procedure in terms of the calculation of the probability of TB persistence $P(Tb^{+}_{i,b} \mid S^{-}_{i,b})$ given that none of the possums necropsied were found to be infected, at time *i* in treatment block *b*. The posterior probability of TB freedom, given those negative TB necropsy results, ($P(Tb^{-}_{i,b} \mid S^{-}_{i,b})$), is then calculated as the complement ($1 - P(Tb^{+}_{i,b} \mid S^{-}_{i,b})$). The $P(Tb^{+}_{i,b} \mid S^{-}_{i,b})$ was calculated as a function of the sensitivity of detecting TB within the defined area given infection is present in possum population ($SeP_{i,b}$). Recognising that $1 - SeP_{i,b}$ is the probability of not finding TB in possums $(P(S^{-}_{i,b} \mid Tb^{+}_{i,b}))$, and assuming that false positive results are not possible (we cannot 'find TB' if there is none there), we used Bayes' theorem to estimate the posterior distribution of $P(Tb^{+}_{i,b} \mid S^{-}_{i,b})$ within the extent of interest:

$$P(Tb^{+}_{i,b} \mid S^{-}_{i,b}) = \frac{(1 - SeP_{i,b}) * P(Tb^{+}_{i,b})}{(1 - SeP_{i,b}) * P(Tb^{+}_{i,b}) + (1 - P(Tb^{+}_{i,b}))} \qquad (1)$$

where $P(Tb^{+}_{i,b})$ is the prior probability distribution of TB persistence in the possum population, and $SeP_{i,b}$ is the probability of detecting TB given that the population is infected (sensitivity). The priors followed a beta distribution with the mean equal to 0.1 ($\alpha = 6$ and β 54; Figure 6).

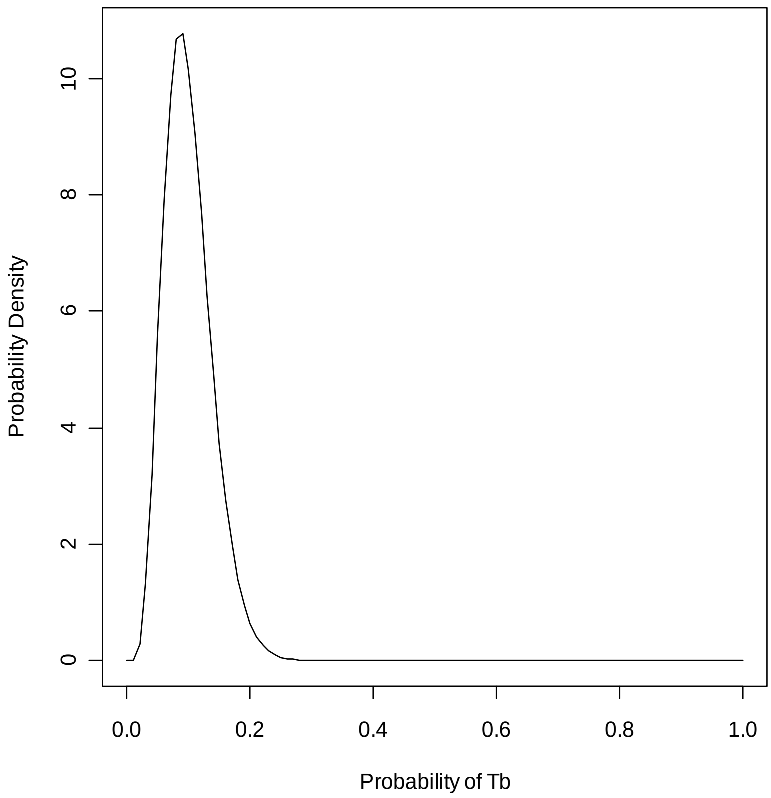

Figure 6 Prior distribution of the probability of TB persistence at the onset of the study followed a beta distribution with the mean equal to 0.1 (α = 6 and β = 54).

The initial prior distributions were applied to the first trapping session, and the posterior distribution ($P(Tb^{+}_{i,b} \mid S^{-})$) for that session was used as the prior distributions for the subsequent trapping session. The priors were updated by combining the posteriors from the preceding years with a probability of disease introduction (*P(Intro)*):

$$P(Tb^{+}_{i,b}) = P(Tb^{+}_{i-1,b} \mid S^{-}_{i,b}) + P(Intro) - (P(Tb^{+}_{i-1,b} \mid S^{-}_{i,b}) * P(Intro)) \qquad (2)$$

The *P(Intro)* was arbitrarily defined to follow beta distribution with a mean of 0.01 (α = 0.15, β = 14.85). The $SeP_{i,b}$ at time *i* in block *b* was calculated using a hypergeometric model, which requires an estimate of the population size ($N_{i,b}$):

$$SeP_{i,b} = 1 - (1 - SeU \cdot PROP_{i,b})^{P^{*} \cdot N_{i,b}} \qquad (3)$$

where P^{*} is the design prevalence (Martin et al. 2007), $PROP_{i,b}$ is the proportion of the population trapped and tested for TB, *SeU* is the unit- or animal-level sensitivity. The calculation of the $SeP_{i,b}$ is based on the assumption that TB is present within the possum population. The probability of detecting TB in this area depends on a minimum expected prevalence, or design prevalence. The P^{*} is not related to actual prevalence as it becomes relevant only when no TB is being detected. In practical terms, the level of the P^{*} determines the amount of surveillance necessary to achieve the eradication goal. As the level of P^{*} decreases, the amount of surveillance must increase, and the level set for P^{*} defines what is meant by eradication. In this analysis we set the P^* equal to 0.01, which is a conservative level and makes it relatively difficult to obtain a pre-set threshold probability of eradication.

We used a bootstrap procedure of the data used to calculate $\Delta N(\%)$ to obtain a distribution of the estimated population size at each mop-up trapping session. This was done by sampling 10 000 times with replacement of the presence/absence chewcard data and the RTC estimates for each transect. This resulting distribution of population size was used in the hypergeometric model (eq. 3) and contributed necessary uncertainty in the posterior probability of freedom (eq. 1).

The unit-level sensitivity in eq. 3 (*SeU*; the probability of detecting TB in a possum given it was infected) was calculated according to the employed parallel testing with gross-lesion inspection and tissue cultures. The gross-lesion test sensitivity followed a beta distribution with a mean of 0.60 (α = 9, β = 6), and the tissue culture had a mean of 0.98 (α = 24.5, β = 0.5). The total *SeU* was calculated as the following:

$$SeU = 1 - (1 - Beta(9,6)) * (1 - Beta(24.5, 0.05)), \quad (4)$$

which results in a distribution with a very high *SeU* (Figure 7).

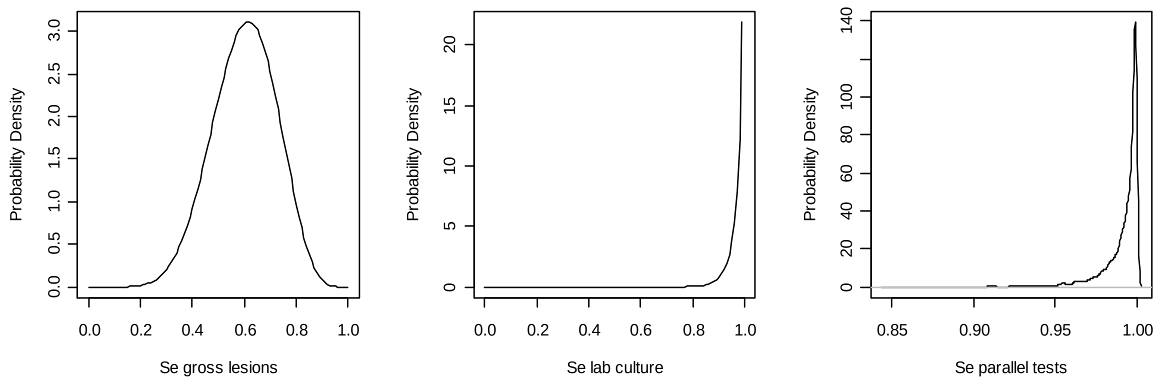

Figure 7 Distributions for gross-lesion, lab culture, and combined test sensitivities.

In the prediction modelling of 10 additional mop-up operations we did not have actual trap catch data so we assumed a distribution for the proportion of the population captured. Again, using a distribution acknowledges and incorporates appropriate uncertainty into our results (posterior distributions). Given the trap-catch record in this study, we used a beta distribution with a mean of 0.4 (α = 18.2 and β = 7.8). Lastly, we explored a scenario in which trapping efficiency was greatly improved. This was accomplished by using a beta distribution for the proportion of the population captured with each mop-up operation with a mean value equal to 0.75 (α = 19. 5 and β = 6.5).

Appendix 2 Chewcard survey, possum mop-up and trap-catch details, May-November 2009.

Event	Dates	Parameter	Block					
			MU500	MU250	NT250a	NT250	NT500	All
First chewcard survey	5-16/5/09	Hectares	320	224	178	349	406	1477
		Transect spacing (m)	500	250	250	250	500	
		Transects with 25-m CC spacing	2	2	2	3	2	9
		Transects with 50-m CC spacing	2	5	3	4	2	14
		No. chewcards retrieved	222	233	190	303	226	1174
		No. possum-chewed cards	14	45	51	52	60	222
		Possum chewcard index (%)	6.30	19.31	26.84	17.16	26.55	18.91
		Rat chewcard index (%)	32.00	9.87	16.32	27.06	24.34	22.32
First possum mop-up	13-24/5/09	No. of trap-nights	350	735	0	0	0	1085
		No. cyanide bait bags set	50	105	0	0	0	155
		No. possums trapped	7	27				
		No. possums poisoned	0	4				

Event	Dates	Parameter	Block					
			MU500	MU250	NT250a	NT250	NT500	All
First possum mop-up		Cost ($/ha)	11.52	34.84				
Second chewcard survey	22/9-4/10/09	Transects with 25-m CC spacing	2	3	3	5	2	15
		Transects with 50-m CC spacing	2	3	3	6	2	16
		No. chewcards retrieved	178	240	192	365	263	1238
		No. possum-chewed cards	11	34	69	65	50	229
		Possum chewcard index (%)	6.18	14.17	35.94	17.81	19.01	18.50
		Rat chewcard index (%)	94.94	59.58	57.29	79.73	87.07	76.09
		Change from May possum CCI (%)	-1.9	-26.6	+33.9	+1.04	-28.4	-2.17
Second possum mop-up	1-10/10/09	No. of trap-nights	105	276	0	0	0	381
		No. cyanide bait bags set	35	92	0	0	0	127
		No. possums trapped	6	26				32
		No. possums poisoned	1	5				6

Event	Dates	Parameter	Block					
			MU500	MU250	NT250a	NT250	NT500	All
Second possum mop-up		Cost ($/ha)	8.93	25.50				
Detection and mop-up	05-10/2009	Total no. possums trapped	13	53	0	0	0	66
(May and October)		Total no. possums poisoned	1	9	0	0	0	10
		Total no. possums removed	14	62	0	0	0	76
		Total no. possums necropsied	14	62	0	0	0	76
		Total no. gross TB lesions	0	0				0
		Mean cost of both operations	15.55	38.53				
Trap-catch survey	9-21/11/09	Transect spacing (m)	200	200		200-500	200-500	
		No. transects/adjusted trap-nights	24/355	20/295		12/174.5	12/175	68/1020
		No. possums caught	23	10		13	26	72
		No. possums necropsied	23	10		13	26	72
		No. gross TB lesions	0	0		0	0	0

Event	Dates	Parameter	Block					
			MU500	MU250	NT250a	NT250	NT500	All
Trap-catch survey		Estimated change in abundance since May	+85%	-65%				
		Estimated change in abundance since Oct.	+87%	-48%				
		Residual trap-catch index (%) (non-standard index; see methods)	6.48	3.39		7.45	14.86	7.06
		Cost ($/ha)	19.44	23.11		8.90	7.65	11.92