Animal Health Board Project No. R-10610

Costs and Benefits of Pre-feeding for Possum Control

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Project and Client

The cost and immediate effectiveness of pre-feeding possums before aerial 1080 baiting operations was compared with that of aerial 1080 baiting without pre-feeding by Landcare Research between July 2003 and December 2005 for the Animal Health Board (AHB Project R-10610).

Objectives

To determine the costs and benefits of pre-feeding possum populations before aerial 1080 poisoning, by:

- Comparing the dollar costs of routine aerial 1080 control operations undertaken using cereal and carrot bait, with and without pre-feeding;
- Comparing the Trap Catch Indices (TCIs) before and after routine aerial 1080 control operations undertaken using cereal and carrot bait, with and without pre-feeding;
- Estimating the time for possum densities to recover to levels that exceed predetermined performance targets within each treatment;
- Evaluating the increased risk, if any, to selected forest birds of pre-feeding compared with no pre-feeding when using carrot bait.

Results

- The costs, exclusive of labour, in the two carrot and two cereal-based operations monitored ranged from $10.41 to $13.07 for the no-pre-feed treatment and from $17.21 to $24.76 for the pre-feed treatment.
- Of 90 recent aerial 1080 operations undertaken for conservation benefit, we obtained useful data from the Department of Conservation (DOC) for 84. Of these, 93% (26/28) of pre-feed operations achieved the operational target (Residual Trap Catch Indices (RTCIs) of <5%), compared with 70% (39/56) of no-pre-feed operations.
- Of 126 aerial 1080 operations undertaken for Tb control by regional authorities, about half were pre-fed. All but one met the operational standard, indicating that Tb control operations are usually successful regardless of whether they were pre-fed or not.
- RTCIs taken from four intensively monitored paired study replicates were on average about two-thirds lower in pre-fed blocks compared with RTCIs taken from no-pre-feed blocks, irrespective of bait type. A combined analysis of the data from all four replicates revealed a highly significant effect and one consistent with existing data from both paired and unpaired treatments.
- Pre-feeding extended the time to recovery over no pre-feeding of controlled possum populations to pre-control levels by 4–7 years in the four study replicates, and to operational targets in the two successful operations by c. 5 years.
- Counts and densities of male tomtits in the single replicate monitored increased from the pre- to post-poison surveys in both the pre-feed and no-pre-feed blocks, and significantly so in the pre-feed block.

Conclusions

- The increased costs of pre-feed over the no-pre-feed option require substantial increases in the percent kill and/or prolongation in the time of recovery of the population to both targeted and pre-control levels to be worthwhile.
- Historical aerial 1080 operations undertaken by DOC provide circumstantial evidence that pre-feeding results in more reliable achievement of target densities. This trend contrasts with historical data from regional authorities and, although the reasons are unclear, may reflect the real differences in baiting strategies used by the agencies. It also contrasts with earlier published material.
- In contrast with the historical material examined here, the four replicates monitored provided strong evidence that supports the hypothesis that pre-feeding produces higher possum kills than no pre-feeding.
- In these replicates, even where high kills of possums were achieved, the prolongation of population recovery to target levels by a factor of 2–3 associated with pre-feeding appeared to warrant the expense of the additional bait sown.
- The benefits of pre-feeding revealed in our field studies are clear-cut, but appear greatest where poorer kills are achieved, irrespective of bait type. In these situations, pre-feeding may reduce the degree of failure and hence should be considered a form of operational insurance.
- Pre-feeding appeared to have no major adverse effect on the tomtit population relative to no pre-feeding. Without replication, it is not possible to generalise and argue that pre-feeding never affects tomtit kills, but this trial indicates that at least sometimes it does not. A considerable number of replicates would be needed to prove pre-feeding widely adversely affects tomtit populations.

Recommendations

- Pre-feeding should be used in all operations for Tb possum control, regardless of bait type, and particularly so where there is reason to believe an operational failure is probable.
- The mechanisms of how pre-feeding may lead to higher possum kills should be investigated further through studies of possum behaviour likely to lead to higher rates of encountering baits and to higher rates of bait consumption.

1. Introduction

The cost and immediate effectiveness of pre-feeding possums before aerial 1080 baiting operations was compared with that of aerial 1080 baiting without pre-feeding by Landcare Research between July 2003 and December 2005 for the Animal Health Board (AHB Project R-10610).

2. Background

Although unconfirmed by quantitative studies, the weight of opinion amongst vector managers (VMs) responsible for local possum control is that pre-feeding before aerial sowing of toxic bait for possum control produces better kills than no pre-feeding. Additionally, higher kills provide a longer period of protection before possum numbers exceed Tb threshold densities, thereby reducing the likelihood of transfer of Tb from possums to livestock. Previous comparisons of the effectiveness of aerial control with and without pre-feeding in paired trials (Fraser & Knightbridge 1995; Fraser & Lorigan 1995) and in unpaired trials (Brown & Urlich 2004) have produced contradictory results confounded by factors such as initial possum densities, differences in toxin concentration, bait type, bait sowing rate, and patterns of weather following baiting.

The case for pre-feeding has been bolstered recently by the results of a study focused on the Hokonui Hills, Southland (Coleman et al. 2003), in which a new control strategy based on two pre-feeds and an increased bait sowing rate was designed and field tested against possums argued by control contractors to be both bait- and trap-shy. Using this new strategy, an aerial control operation was undertaken in 2004 over 7794 ha of forest and scrub in the same area and resulted in an exceptional reduction in the local possum population: approximately 1 month after the control, no possums were trapped on 58 standard Residual Trap Catch Index (RTCI) population monitor lines (M. Hunter, Environment Southland, pers. comm.). Further monitoring of this population approximately 6 months later to check this result revealed very few (47) possums inside the area baited (i.e. c. 1 possum/307 nights of trapping). In mid-2005, a second possum control operation based on this same strategy was undertaken over 100 000 ha in the Hauhungaroa Range in the central North Island. Post-control population monitoring there indicated a similar result: seven possums were taken off 15 358 trap nights from 512 post-control monitor lines (R. Lorigan, EPRO, pers. comm.). Both recent control operations and the underpinning research trial in the Hokonui Hills provide new evidence that pre-feeding may dramatically reduce possum populations to previously rarely achieved levels, thereby shortening the time required for Tb to self-eliminate from possum populations and ultimately from livestock.

It has been assumed by some contractors working in the possum control industry (e.g. R. Lorigan, EPRO, pers. comm.), but again unproven, that the extra costs associated with pre-feeding are justified by the achievement of the purported, and in some cases proven, greater kills. To date, there has been no comprehensive quantitative comparison of the true costs, immediate benefits, and risks (e.g. dollar costs, level of possum control achieved, and risks to non-target species especially native birds) or of the time to achieve Tb eradication through pre-feeding and no pre-feeding.

In terms of risk, just as it is assumed by control contractors and researchers that possums may be ‘conditioned’ by pre-feeding to take toxic baits more readily, the same arguments should hold for populations of non-target species resulting in them suffering unacceptably increased mortalities. However, there has been no formal comparison of the effects of pre-feeding and no pre-feeding on bird deaths following 1080-poisoning operations. Few populations of bird species have suffered detrimental effects from 1080-poisoning, with or without pre-feeding (Spurr 1994, 2000). One notable exception is the tomtit (*Petroica macrocephala*), for which pre-fed possum control operations using aerially sown carrot bait have been shown to adversely affect populations (Spurr 1981, 1994; Powlesland et al. 1998, 2000; Westbrooke & Powlesland 2005).

If pre-feeding before aerial control with either cereal or carrot bait (the only bait types currently available for such work) is shown to cost-effectively produce significantly greater kills of possums, its use as an integral element in routine control operations will be vindicated. However, any potential economic or control-related benefits associated with the use of this tactic will need to be balanced against any increased threats perceived by the public to non-target native and exotic species, and the need to ensure that any *actual* negative impacts on non-target species, particularly native birds, are minimised.

This report compares the consistency with which monitored operations have met possum control targets, depending on whether or not the possums were pre-fed. We also measured in paired pre-feed and no-pre-feed trials whether pre-feeding increased possum kills and tomtit losses, and modelled the time-to-retreatment for possum control.

3. Objectives

To determine the costs and benefits of pre-feeding possum populations before aerial 1080 poisoning, by:

- Comparing the dollar costs of routine aerial 1080 control operations undertaken using cereal and carrot bait, with and without pre-feeding;
- Comparing the Trap Catch Indices (TCIs) before and after routine aerial 1080 control operations undertaken using cereal and carrot bait, with and without pre-feeding;
- Estimating the time for possum densities to recover to levels that exceed predetermined performance targets within each treatment;
- Evaluating the increased risk, if any, to selected forest birds of pre-feeding compared with no pre-feeding when using carrot bait.

4. Methods

4.1 Operational costs and benefits

To determine the likely benefits of aerial control operations against possums with and without pre-feeding, we canvassed Department of Conservation (DOC) conservancies and VMs for operational information (bait type, sowing rate, toxic loading, and RTCI data) from all aerial 1080 control operations using cereal and carrot bait applications within the last 5 years and formally monitored for success.

For our study replicates, we obtained the dollar costs of the materials, cartage, sowing, and field labour of each treatment from the VM involved. Because of the variation in costs between carrot and cereal bait, the relative proportion of the total costs comprising the pre-feeding component of the trial varied between the two bait types. The costs of the planning and consent procedures of each treatment, stated by VMs as ‘a considerable fraction of the total’ (R. Lorigan, EPRO, pers. comm.), was not made available to us, thus limiting our ability to compare total operational costs. The annualised cost of control for the two AHB operations was based on the costs obtained from operation managers and the predicted time to recovery to target levels (2%).

4.2 Paired trial design and data collection

Overall design

This project evaluated the costs and level of control likely to arise from the use of pre-feeding 1080-poison baiting operations for possums, when compared with no pre-feeding. The basic design consisted of a comparison of two in-forest cereal and two carrot replicate pairs of treatments, with one of each pair pre-fed and the other not. The experimental areas were all chosen in consultation with the AHB and local VMs from areas scheduled for operational aerial control of possums and free from any recent (within 5 years) control. They included two cereal bait operations (Copland–Karangarua and Waitohi–Okuku Gorge) and two carrot bait operations (Matakuhia and Whareorino–Moeatoa, Table 1), with the Copland–Karangarua and Whareorino–Moeatoa operations undertaken by DOC for protection of conservation values and the Matakuhia and Waitohi–Okuku Gorge operations undertaken by VMs for Tb possum control.

The minimum area considered for inclusion in this study was c. 2000 ha, to allow for the selection of two treatment blocks (i.e. pre-feed and no pre-feed) of c. 1000 ha. Where the control operation areas selected were significantly greater than 2000 ha, we limited our individual treatments and population monitoring to two discrete areas of c. 1000 ha within the larger site and separated by a minimum of 200 m.

The selection of the two treatment blocks in each replicate was done in consultation with the local managers overseeing the control operation. However, such selection was largely driven by the need to ensure close similarity of habitat, i.e. aspect, topography, vegetation, and the control history for each treatment pair. Also, apart from the use or omission of pre-feed, each treatment block was also assumed to receive identical bait quality and baiting tactics, i.e. bait sowing rate, and bait coverage.

Indexing possum populations

For each replicate, we undertook pre-control surveys of the possum population to establish baseline density indices (TCIs) in each pair of treatments. Following the control operation, we resurveyed the residual (survivor) possum populations to obtain indices of population change and of residual possum density in each treatment block (Table 1). All possum monitoring followed the accepted national protocol (NPCA 2002, 2004), except that it was undertaken at approximately twice the intensity of that used for routine operational performance monitoring to ensure a relatively high degree of precision around each TCI or RTCI estimate (compared with normal operational monitoring) and more robust comparisons between treatments. Landcare Research designed each survey and supervised each monitor to ensure a standardised approach across all replicates.

Table 1 Date of each pre- and post-control survey and number of trap lines monitored in each of four replicates and two treatments indexed for possum numbers.

Replicate	Treatment	Date of pre-control survey	Date of post-control survey	No. of paired lines
Matakuhia	Pre-feed	June 2003	September 2003	24
	No pre-feed	June 2003	September 2003	24
Copland–Karangarua	Pre-feed	October 2003	December 2003	24
	No pre-feed	October 2003	December 2003	23
Waitohi–Okuku Gorge	Pre-feed	April 2004	December 2004	18
	No pre-feed	April 2004	December 2004	18
Whareorino–Moeatoa	Pre-feed	September 2004	December 2004	24
	No pre-feed	September 2004	December 2004	24

Up to 24 standard trap lines of 10 traps set at 20-m intervals were randomly located in each of four pairs of treatment blocks before and after control (Table 1). All lines were monitored where possible for three consecutive fine nights between 2 and 4 weeks before and again after the sowing of the toxic bait. The field plan for each monitoring survey ensured that traps and field staff were allocated randomly to each treatment to minimise any potential trap or observer effects. TCIs for each trap line monitored before control and RTCIs monitored after control were calculated using Landcare Research's trap-catch estimator – 'PestCalc' (version 1.2). For each replicate, we used the non-parametric Mann–Whitney U test and Fishers exact test to compare mean TCIs between treatment blocks, as the TCIs were not normally distributed. Where the variation in mean TCIs between replicates (i.e. operations) or between pre-control treatments was considered to be high, we also calculated the mean difference in TCIs between pre- and post-control for each pair of treatments using Linear Mixed Models (Pinheiro & Bates 2000) and tested this against the null hypothesis that 'pre-feeding will not significantly reduce the mean percent kill of possums compared to no-pre-feed treatments'.

Predicting population recovery

We used the theta-logistic growth equation (Barlow & Clout 1983) to 'model' population recovery within each treatment area. The annual change to the population, based solely on in situ breeding, is given by:

$$dN / dt = r_m * N (1 – [N / K]^{\theta})$$

where: N = population density at time t, r_m = intrinsic rate of population increase, K = carrying capacity(~equilibrium density), and θ = exponent determining the shape of density dependence. Such modelling allowed us to estimate the time required for the population to recover to exceed the operational control target (<2% RTCI) and to reach pre-control density. For each pair of treatment blocks in each replicate, we used the pre- and post-control TCIs to represent K and N, respectively, a θ value of 2 (Barlow & Clout 1983), and intrinsic rates of increase of 0.36 (Hickling & Pekelharing 1989) for these calculations. The model makes no allowance for immigration, which due to the size of our replicates (c. 2000 ha), the size of the surrounding controlled areas, and the time to post-control monitoring (< 6 months), we assumed would initially be minimal and thereafter equal to the outflow of possums.

4.3 Indexing tomtit populations

Unfortunately there is no standard protocol for monitoring changes in bird populations following toxic baiting for possum control. A variety of techniques have been used including 5-minute counts (Spurr 1991, 1994), territory mapping (Powlesland et al. 1998, 1999), strip-transect counts (Westbrooke et al. 2003; Westbrooke & Powlesland 2005), potential resighting banded birds (Powlesland et al. 1998, 1999, 2000), distance sampling (Westbrooke et al. 2003), and radio-telemetry (Powlesland et al. 1998). In the light of this plethora of techniques, and because of the known risk of 1080 baiting to tomtit populations, the AHB requested that we use the strip-transect method of Westbrooke et al. (2003) to monitor the effects of pre-feeding compared to no pre-feeding for possum control on populations of tomtits.

Tomtit populations were monitored in one carrot operation only, using the strip-transect and distance sampling methods of Westbrooke et al. (2003). Within each pre-feed and no-pre-feed treatment block, we established 36 transect lines, each 250 m long, on parallel compass bearings in a grid of six rows of six transect lines. The transect lines were 100 m apart within rows and 200 m apart between rows. Each line was marked with numbered plastic cruise tape at 10-m intervals to assist with distance estimation.

Pre-poison surveys were undertaken in late September – early October 2004, 2–3 weeks before the control operation; post-poison surveys were undertaken in early November 2004, 2 weeks after the control operation (Appendix 1). The two treatment blocks (pre-feed and no pre-feed) in each operation were surveyed on different days, and observations were made only when the weather was fine with little or no wind. Within each block, each of the two observers surveyed each transect line once, completing two lines per day for 3 days. For each tomtit detected, observers recorded the distance in metres from the start of the transect line to the observer, the distance from the observer to the tomtit, the compass bearing from the observer to the tomtit, whether the tomtit was male or female, adult or juvenile, and whether it was first encountered visually, heard singing (territorial song), or heard calling (non-territorial song). Westbrooke et al. (2003) stated that they recorded only territorial males in full song, but it is likely they also recorded males seen. We included all males heard and/or seen.

From the distance measurements and compass bearings recorded above, and the compass bearings of the transect lines, the exact location of each tomtit was calculated. All males that were detected within a strip 50 m wide on either side of the transect line (i.e. an area of 2.5 ha/transect) were included in the subsequent analysis of transect count data. As noted by Westbrooke & Powlesland (2005), the strip-transect method does not require identification of all male tomtits within the strip, but does assume that the proportion of them identified over time is consistent in each treatment area. Changes in bird behaviour over time may affect the number of birds identified, but this will not affect the analysis of the treatment impact in our trial provided any changes in behaviour over time are similar in each block.

The change (if any) in the number of male tomtits counted from pre- to post-poison was calculated separately for each treatment block, from A minus B, where A = the median pre-poison count and B = the median post-poison count. The 95% CI of this change was calculated using a bootstrap procedure with 100 000 iterations (Crawley 2002). The statistical significance of any change in time or block effects, and their interaction, was estimated from analysis of the raw data in a linear mixed-effects model (Pinheiro & Bates 2000), using observer as a random effect (n = 288).

The right-angle distances from the transect lines of all male tomtits detected were calculated from the distance measurements and compass bearings outlined above, and analysed in the program DISTANCE (Buckland et al. 2001) to produce an estimate of male tomtits per hectare. We used the half-normal hermite polynomial for all estimates (pre-feed and no-pre-feed blocks, before and after poisoning), and truncated the most distant 10% of measurements. This resulted in sample sizes of 99 pre-poison and 184 post-poison records in the pre-feed block, and 57 pre-poison and 94 post-poison records in the no-pre-feed block. Despite the length of the transects used, they provided insufficient records within treatment blocks to allow us to determine the statistical significance of any differences between blocks or times. Transect lengths sufficient to provide significantly different bird counts between blocks would have needed to be much greater, given the density of birds present.

5. Results

5.1 Operational costs and benefits of routine operations

Costs of experimentally monitored operations

The costs arising from both treatments monitored varied with each replicate, due in considerable part to the bait type used and to the variation in sowing rates of both the pre-feed and toxic bait. Costs were, of necessity, always greater for pre-feed than no-pre-feed operations due to the increased amount of bait sown (Table 2), and impact on the overall benefits of either baiting strategy.

Costs per hectare for the Matakuhia operation for the bait (carrot), its cartage, and its sowing were $13.07 for the no-pre-feed treatment and $24.76 for the pre-feed treatment (K. Nicholas, EPRO, pers. comm.; an increase of 89%), and were the highest recorded from any of our replicates (Table 2). Labour costs for both planning, obtaining operational consents, and field work were, however, low at $2.97and $4.14 for the no-pre-feed and pre-feed treatments respectively. While there are economies of scale in these labour costs, due to the large size of the Matakuhia operation, the data were difficult to extract from the early records and should be accepted with caution.

By comparison, costs per hectare for the Copland–Karangarua operation for the bait (cereal), its cartage, and its sowing were lower at $10.41 for the no-pre-feed treatment and $17.21 for the pre-feed treatment (G. Woodhouse, DOC, Fox Glacier, pers. comm.; an increase of 65%), presumably at least partly because of the lower sowing rates used (Table 2). Total labour costs, including those of operational planning and consent applications, were not available, although costs of labour on the sowing strip were minimal and estimated by DOC as approximately 7c and 14c/ha for the no pre-feed and pre-feed treatments respectively.

Operational costs per hectare for the Waitohi–Okuku Gorge operation (cereal) exclusive of labour were $12.23 and $20.17 for the no-pre-feed and pre-feed treatments respectively and were similar to those of Copland–Karangarua, despite a further reduction in the sowing rates of both the pre-feed and no-pre-feed treatments (Table 2). Costs were again 65% higher for the pre-feed treatment. Labour costs in this replicate (although unable to be broken down) were c. $11/ha, regardless of the treatment used (S. Gooding, Target Pest, Christchurch).

Finally, costs per hectare for the Whareorino–Moeatoa operation (carrot) exclusive of labour were $10.53 and $17.44 for the no-pre-feed and pre-feed treatments respectively, and were similar to those of both Copland–Karangarua and Waitohi–Okuku Gorge (Table 2; K. Nicholas, EPRO, pers comm.). Costs were again 65% higher for the pre-feed treatment. Labour costs inclusive of planning, operational consents, and field work for Whareorino–Moeatoa were similar to those of Matakuhia, but again should be accepted cautiously.

Overall, the sowing rates of bait for both the pre-feed and no pre-feed were sufficiently similar such that we were unable to demonstrate any relationship in our replicates between sowing rate and operational success.

Table 2 Sowing rate and costs of pre-feed and no-pre-feed treatments in each replicate control operation.

Operation (& bait type)	Treatment	Sowing rate (kg/ha)	Cost bait, cartage, sowing (Ex. GST)	Cost labour/ha
Matakuhia (carrot)	Pre-feed	3 + 5	$24.76	$4.14
	No pre-feed	5	$13.07	$2.92
Copland–Karangarua (cereal)	Pre-feed	2 + 3	$17.21	NA
	No pre-feed	3	$10.41	NA
Waitohi–Okuku (cereal)	Pre-feed	1.44 + 2.5	$20.17	c.$11
	No pre-feed	2.5	$12.23	c.$11
Whareorino–Moeatoa (carrot)	Pre-feed	2 + 3	$17.44	$5.75
	No Pre-feed	3	$10.53	$3.66

NA = Not available

Historical conservation-based operations on Crown lands

Operational details: Between 1999/00 and 2003/04 inclusive, eight of the 13 DOC conservancies undertook 1080 aerial operations for the control of possums for conservation benefits (Table 3). All 90 operations were primarily in indigenous forest. The remaining five conservancies (i.e. Auckland, Tongariro/Taupo, East Coast/ Hawke's Bay, Canterbury, and Otago) did not aerially sow bait for possum control over this period.

Pre-feed was, in all instances, sown at a rate of 2 kg/ha, irrespective of the sowing rate of the toxic bait. However, pre-feeding was an operational strategy favoured by only a few conservancies, with Northland (1/1), Waikato (9/10), and West Coast (14/37) most consistently sowing pre-feed bait and other conservancies rarely or never sowing pre-feed (see Table 3).

Operational success: The operational performance target of all aerial operations was set in terms of the nationally recognised RTCI. Of the 84 operations undertaken with known RTCI targets and outcomes, 69 had targets of <5%, but were generally greater than those set for most operations aimed at controlling Tb possums (see below). Fifteen DOC operations had RTCI targets of <3%. In all, 65 of the 84 operations exceeded the performance targets set for control (i.e. mean RTCIs of 2.16% and 2.9% for pre-feed and no-pre-feed operations respectively), including 93% (26/28) of pre-fed operations and 70% (39/56) no-pre-feed operations, and provided circumstantial evidence of higher rates of success arising from pre-feeding. However, the Conservancy-based variation in operational details (see Appendix 2), especially sowing rate of both pre-feed and toxic bait, bait size, and bait type, curtailed further analyses.

Table 3 Number of carrot and cereal-based aerial baiting operations undertaken against possums for conservation benefits by DOC conservancies, number pre-fed/not pre-fed, and toxic loading used: 1999/00–2004/05. Baiting details of these operations are summarised in Appendix 2.

Conservancy	Total no. operations	Carrot	Loading 1080	Pre-feed	Cereal No. 7	Cereal RS5	Loading 1080	Pre-feed
Northland	1				1		0.15	1
Waikato	10	1	0.08	1	9		0.15	8
Bay of Plenty	4	2	1 @0.15 1 @ 0.08	1 1	2		0.15	0
Wanganui	11				11		0.15	1
Wellington	5				5		0.15	0
Nelson/ Marlborough	15	1	0.15	1		14	0.15	0
West Coast	37				37		0.15	14
Southland	7				7		0.15	0
TOTAL	90	4		4	72	14		24

Historical Tb-based operations on Crown lands

Operational details: Seven regional authorities supplied us with operational data covering 126 aerial Tb possum control operations undertaken under AHB funding on Crown lands between 1999/00 and 2003/04 (Table 4). Such data were not available from Waikato, Taranaki, Bay of Plenty, Hawke's Bay, or Auckland (regional councils), and no Tb-based aerial operations were undertaken in Northland. Data collected from Horizons.mw, Tasman District Council, Marlborough District Council, and Environment Canterbury were incomplete and of limited value, and data from the one operation undertaken during our survey period in Southland was excluded from this summary as the baiting strategy employed there was experimental.

Pre-feed was sown in 54 of the 76 operations fully documented (Table 4), and appeared to be part of standard operations carried out by the Greater Wellington, Tasman, and Otago regional concils, and generally omitted from operations conducted in the West Coast (apart from its use with two operations using carrot bait).

Operational Success: The operational targets set by each authority were similar, being lowest for Otago (2%), but similar for Tasman (2–4%), West Coast (3–4), Greater Wellington and Environment Canterbury (2–5%), and highest in Marlborough (3–5%). Performance monitoring results indicated that apart from one failure by Wellington Region when the toxin was washed out by heavy rain, all operations met the target specified, and RTCIs for pre-feed (1.4%) and no-pre-feed (1.16%) operations were similar.

Table 4 Number of carrot and cereal-based aerial baiting operations undertaken against possums by local authorities for the control of Tb, number pre-fed/not pre-fed, and toxic loadings used: 1999/00–2003/04. Baiting details of these operations are summarised in Appendix 3.

Authority	Total no. operations	Carrot	Loading	Pre-feed	Cereal No. 7	Cereal RS5	Loading	Pre-feed
Horizons.mw	6					1[a]	0.08	
Greater Wellington RC	20				20		0.15	20
Tasman DC	15					15	0.15	15
Marlborough DC	22	4	0.08			18[a]	0.08	
Environment Canterbury	18[b]					13[a]	0.08	?
West Coast RC	27	2		2	25		0.15	
Otago RC	18[b]	2		2		15	0.15	15
TOTAL	126	8		4	45	30		50

? No data obtained   RC = regional council, DC = district council

[a] Unspecified cereal bait

[b] Includes additional operations using unspecified bait

5.2 Comparison of pre- and post-control TCIs of possums on the experimental sites

(Monitoring results are compared graphically in Appendix 4.)

Matakuhia (carrot)

Pre-control monitoring produced mean (± 95% CIs) TCIs of 16.2±4.5% and 13.3±4.3% in the pre-feed and no-pre-feed treatment blocks, respectively, and were not significantly different (Mann–Whitney test: $U = 231.0$, $P = 0.238$). Post-control monitoring produced mean RTCIs of 0.14±0.29% and 0.97±0.77% in the pre-feed and no-pre-feed treatment blocks, respectively. The actual reductions achieved indicated mean percent kills of 99.1% (95% CI: 97.4–100.0%) and 92.7% (87.5–97.9%) in the pre-feed and no-pre-feed treatment blocks, respectively, and below the operational target set for both blocks. An overall comparison of the difference between the pre- and post-control surveys of both treatments indicated that although 20 of 21 lines in the pre-feed treatment were reduced by 100% compared with 18 of 24 lines in the no-pre-feed treatment, *the difference between treatments was not statistically significant* (Fisher exact test, $P = 0.101$).

Copland–Karangarua (cereal)

Pre-control monitoring produced mean TCIs (± 95% CLs) of 20.4±6.8% and 8.8±3.0% in the pre-feed and no-pre-feed treatment blocks, respectively, and were significantly different

(Mann–Whitney test: $U = 150.0$, $P = 0.007$). Post-control monitoring produced mean RTCIs of 2.30±1.53% and 5.80±3.17% in the pre-feed and no-pre-feed treatment blocks, respectively (cf. an RTCI target of 5%). The actual reductions achieved indicated mean percent kills of 88.7% (95% CI: 80.3–97.2%) and 34.0% (−7.5% to 63.5%) in the pre-feed and no-pre-feed treatment blocks, respectively, and provided evidence that *the percent kill in this replicate was higher in the pre-fed block* (Fisher exact test, $P = 0.048$).

Waitohi–Okuku Gorge (cereal)

The pre-control monitoring surveys in both treatment blocks in this replicate were completed in April 2004. However, the post-control monitoring surveys were not completed until December 2004 due to a combination of deep snow, unavailability of suitable contractors, and farm management issues (lambing) preventing access to both blocks. The pre-control survey produced mean (±95% CLs) TCIs of 18.2±4.6% and 19.2±5.6% in the pre-feed and no-pre-feed treatment blocks, respectively, and these data were not significantly different (Mann–Whitney test: $U = 160.5$, $P = 0.96$). Post-control monitoring produced mean RTCIs of 0.0% (i.e. no possums trapped from 530 trap nights) and 0.6±0.6% in the pre-feed and no-pre-feed treatment blocks, respectively. The mean percent kills were 100% and 97.1% in the pre-feed and no-pre-feed blocks, respectively, and indicated very successful operations well under the typical performance targets set for Tb possum control in this area. However, there were *no significant differences between the two treatments for the reductions achieved* (Fishers exact test, $P = 0.229$).

Whareorino–Moeatoa (carrot)

Pre-control surveys produced mean (± 95% CLs) TCIs of 28.5±5.1% and 22.4±3.8% in the pre-feed and no-pre-feed treatment blocks, respectively, and were not significantly different (Mann–Whitney test: $U = 199.5$, $P = 0.07$). The post-control surveys produced mean RTCIs of 6.0±1.7% and 15.6±2.9% in the pre-feed and no-pre-feed blocks, respectively, making this replicate the least successful of all four replicates monitored. Despite the fact that both treatments fell well short of the operational performance target (3% RTCI or less), the residual possum density was significantly lower in the pre-fed block (Mann–Whitney test: $U = 53.5$, $P < 0.001$). The reductions achieved, indicated mean percent kills of 79.0% and 30.5% in the pre-feed and no-pre-feed blocks, respectively, providing further strong evidence that *the reduction achieved was highest in the block where pre-feeding was used* (Mann–Whitney test: $U = 65.5$, $P < 0.001$).

Analysis of the TCI and RTCI data from all four replicates together using linear mixed models (Pinheiro & Bates 2000) revealed that pre-feeding had a highly significant effect on the overall residual possum catch when compared with no pre-feeding (90.82% vs 50.68%; $t_{167} = 4.07$, $P < 0.0001$). The analysis also revealed some exceptional outlier data points arising from the two operations that produced low kills (Copland–Karangarua and Whareorino–Moeatoa), but the removal of these data separately or together had no effect on the overall conclusions of the analysis.

5.3 Recovery times for controlled possum populations

In each of the four replicates, irrespective of the bait type used, the model used predicted that pre-feeding should prolong the period taken by the residual possum population to recover to pre-control levels (Fig. 1) compared with no pre-feeding. When the percent kill achieved was high (>90%), as was recorded in the Matukuhia and Waitohi–Okuku Gorge replicates (baited with carrot and cereal respectively), recovery was likely to be slowest, taking 20 years in both pre-feed blocks, and 13 and 16 years respectively in the no-pre-feed blocks. In comparison, where the percent kill achieved was modest or poor (<90%), as recorded in the Copland–Karangarua and Whareorino–Moeatoa replicates (baited with cereal and carrot respectively), population recovery was predicted to be more rapid, taking 12 and 10 years respectively for the pre-feed blocks and 5 and 6 years respectively for the no-pre-feed blocks. However, within-replicate comparisons of the pre-feed and no-pre-feed treatments for the Copland–Karangarua and Whareorino–Moeatoa replicates are confounded by the markedly different pre-control possum densities and/or the poorer kills obtained (e.g. kill in Copland–Karangarua pre-feed treatment block was 88.7% compared with 30.5% in the no-pre-feed block, Fig. 1).

More importantly, the time taken for the possum population in both successful operations monitored to exceed the operational target (2% RTCI) now used for many Tb possum operations was approximately 10 years for the pre-feed treatments and roughly half that in no-pre-feed treatments. By comparison, both the replicates considered to be failures never achieved this target for either the pre-feed or no-pre-feed treatments.

Considering each replicate separately in terms of the population recovery to target levels (Fig. 1), for Matakuhia the model predicts that the possum population in the no-pre-feed block would have exceeded the 2% operational target within 2–3 years, whereas that in the pre-feed block would have taken 10–11 years, i.e. the time to retreatment was likely to be three times longer, reducing the average annual cost of control by c. 66%. For Copland–Karangarua, where the target was 5% RTCI, retreatment would be required immediately for the no-pre-feed block as the target was not achieved, while the model predicted recovery to target levels in 3 years for the pre-feed block, and a major cost saving. Monitoring results for Waitohi–Okuku Gorge were very similar to those of Matakuhia, and the model predictions are thus also very similar. Of particular note, however, is the predicted recovery at this site of the possum population in the pre-feed block from an RTCI of zero. This occurs because we accepted that the absolute eradication of possums from the block and zero immigration into it was extremely unlikely and so set the kill for modelling purposes at 99% rather than the 100% indicated by the monitor. Finally, for Whareorino–Moeatoa, because both treatments failed to achieve the RTCI target, both areas needed immediate retreatment and the additional expense of pre-feeding was largely wasted. Here, even in the pre-feed block, the significantly greater reduction achieved (6% RTCI) compared with that in the no-pre-feed block is likely to have had only a modest effect on local Tb levels.

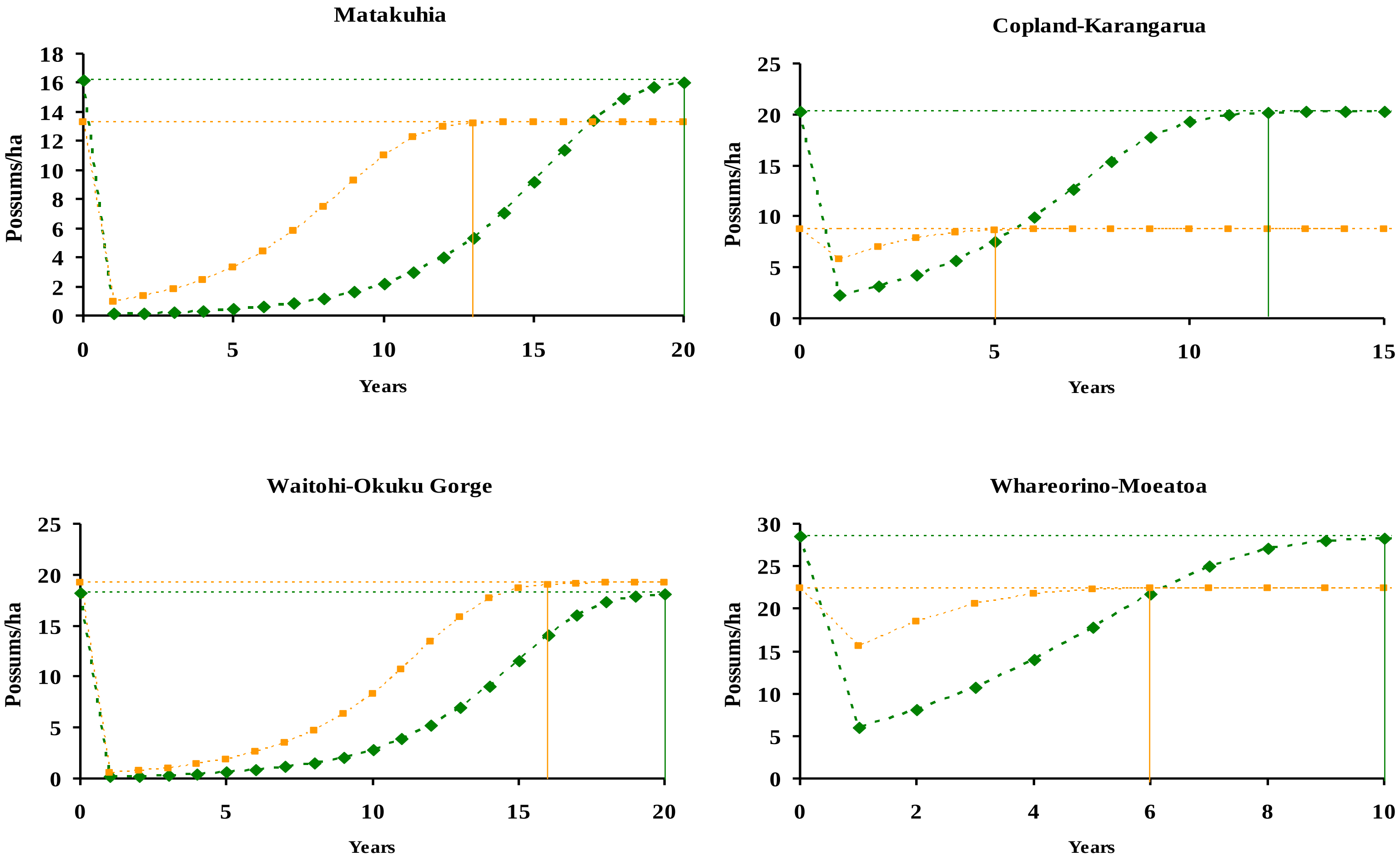


Fig. 1 Predicted rates and times of recovery from immediate post-control levels to pre-control densities for each treatment for pre-feed (green) and no pre-feed (orange) treatments on the four replicate sites, based on the population growth equation of Barlow & Clout (1983). Time to recovery to pre-control levels for each treatment is indicated by the vertical orange lines.

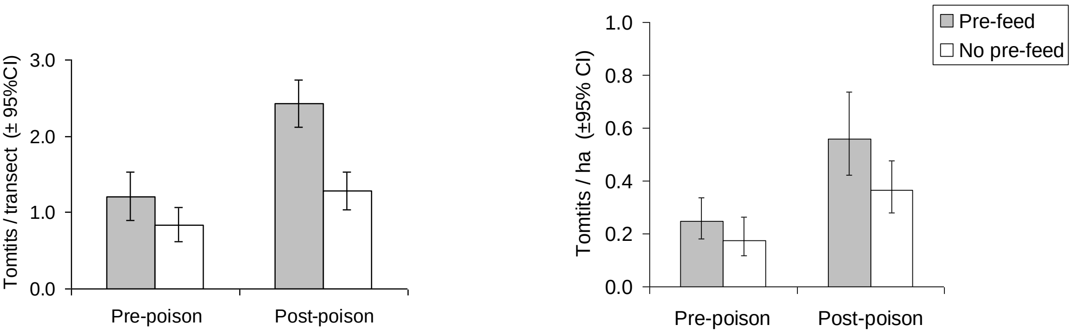
5.4 Comparison of pre- and post-control tomtit populations

Transect counts

Counts of male tomtits roughly doubled between pre and post-poison surveys in both the pre-feed and no-pre-feed blocks in the Whareorino–Moeatoa carrot-baited replicate (Fig. 2). The increase in the pre-feed block (201%) was significantly greater than in the no-pre-feed block (154%) (t_{283} = 3.187, P = 0.002).

Distance measurements

The number of male tomtits per hectare estimated by distance sampling increased from pre- to post-poison in both the pre-feed and no-pre-feed blocks (Fig. 2). The increase in the pre-feed block (225%) appeared to be greater than in the no-pre-feed block (207%), as for the transect counts, but because it was not possible to estimate density separately for each transect within treatment blocks (see section 4.3) we could not determine whether the difference was statistically significant.



(a) (b)

Fig. 2 (a) Male tomtits per transect (median ± 95% CIs), and (b) per hectare from distance sampling (mean ± 95% CIs), in pre-feed and no-pre-feed blocks before and after 1080-poisoning, Whareorino–Moeatoa replicate.

6. Conclusions

6.1 Operational costs and benefits of routine operations

The operational costs exclusive of labour of pre-feed treatments in this study were 65% greater than the costs for no-pre-feed treatments in three out of four of the replicates monitored and 89% greater in the fourth replicate. Comparison of the labour cost of each treatment was more difficult, as only part of each operational cost was available to us. Despite this limitation, labour costs for pre-feed operations are unlikely to be significantly different to no-pre-feed operations, as the large costs associated with operational planning and obtaining operational consents is largely the same regardless of the treatment used. Regardless, the documented overall increased costs of pre-feeding presumably can only be justified where the pre-feed treatment achieves significantly greater operational success (kill) or a significant extension of possum population recovery times. These issues are dealt with in sections 6.2 and 6.3.

Aerial control operations undertaken by DOC conservancies for conservation benefits over the last 5 years mostly used Wanganui No. 7 cereal bait, and only infrequently used either RS5 cereal bait or carrot bait. The tactic of pre-feeding sowings of toxic bait was used by few conservancies. Pre-feeding was confined to all operations using carrot bait and to approximately one-third of operations using Wanganui No. 7 bait, and was never used for any operations using RS5 cereal bait. As the latter is thought to be the most palatable of the two cereal baits employed (Henderson & Frampton 1999), its exclusion from RS5 bait-based operations seems reasonable. Thus, pre-feeding, as practised by DOC conservancies, appeared to be driven by local tradition with three of the 13 conservancies commonly applying the tactic, particularly to carrot bait, or by bait palatability (RS5 bait is more palatable than Wanganui No. 7 bait). Patterns of use or of non-use of pre-feed do not appear to follow any nationally held belief or evidence from DOC-based control operations of its positive benefits or unnecessary costs, but rather from staff experience, with those that have used the strategy favouring its continued use and vice versa. That said, the data provide good circumstantial evidence that pre-feeding results in the more reliable achievement of operational targets and, as such, the strategy deserves wider use. In addition, the results observed in this project provide strong evidence that pre-feeding does result in better % kills and longer return times, thereby strengthening the case for pre-feeding overall.

Aerial control operations undertaken by regional authorities for Tb-possum control were also based largely on Wanganui No. 7 cereal bait, and most operations undertaken by most authorities that we have adequate documentation for were pre-fed. Despite operational targets (RTCIs) for Tb possum control traditionally being lower than operations undertaken for conservation benefits, 119 of 120 Tb-based operations appear to have achieved their targets, irrespective of whether pre-feed was used or not. Thus, historical data from regional authorities on the achievement or otherwise of operational targets, provided no evidence of improved control arising from the use of pre-feed in aerial operations, but little against it either. Finally, the reasons for the better overall achievements by VMs of Tb control operations compared with managers of DOC operations is unresolved. Anecdotal evidence suggests that DOC-run operations follow NPCA monitoring protocols (NPCA 2002, 2004) less assiduously, but we have no data to support this suggestion.

6.2 Comparison of pre- and post-control TCIs of possums

Overall, the four replicates monitored provide strong evidence to support the belief that pre-feeding produces greater possum kills than no pre-feeding irrespective of whether Wanganui No. 7 cereal or carrot bait is used (i.e. % kills of 90.8% vs 50.68%, $P < 0.01$, see section 5.2) and results in RTCIs that are, on average, about two thirds lower than in the absence of pre-feeding (Fig. 3). Taken separately, surveys of two of our replicates produced significantly higher possum kills when pre-fed (Copland–Karangarua and Whareorino–Moeatoa) and two produced higher but non-significantly different kills (Matakuhia and Waitohi–Okuku Gorge). These results are consistent with those from a previous paired trial at Takorakuri in 1995 (Fraser & Knightbridge 1995; Fig. 3). A comparison of the mean percent RTCI obtained from 10 possum control operations undertaken by DOC without pre-feeding (1.7%) with the results of 30 possum operations undertaken with pre-feeding by the Greater Wellington Regional Ccouncil (0.83%) reflect a similar pattern (Brown & Urlich 2004), although these results were not derived from the same paired trial design followed in the current study and thus provide only circumstantial evidence of lower RTCIs. Therefore, we caution against assuming this difference is purely a pre-feed or no-pre-feed treatment effect.

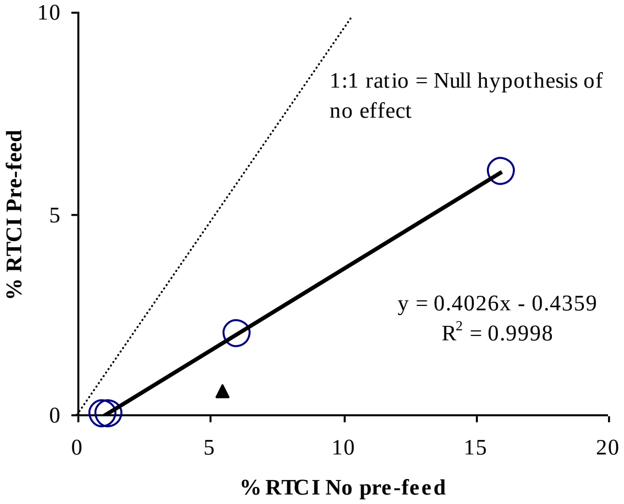


Fig. 3 Correlation between % RTCIs in the four paired control-operation trials with and without pre-feeding (open circles) monitored in this study. The black triangle shows the result from a previous paired trial at Takorakuri in 1995.

In the five paired-treatment trials monitored using leg-hold trapping (i.e. this study and that of Fraser & Knightbridge 1995), consistently higher kill rates have been recorded in the blocks where pre-feeding was undertaken. The likelihood of this happening if pre-feeding had no effect on kill rates is extremely low ($P = 0.031$). Similarly, while the overall results are variable, the likelihood of all four replicates in the current project trending in the same direction by chance alone is only about 7% and thus unlikely.

From both the comparison of the historical DOC and Greater Wellington Regional Council data examined by Brown & Urlich (2004) and our trial data, there appears little doubt that pre-feeding generally results in better possum kills, but the effectiveness is mitigated by:

- The overall level of success (or otherwise) of the operation. Two of our replicates (Matakuhia and Waitohi–Okuku Gorge) achieved the operational targets set, whereas the other two (Copland–Karangarua and Whareorino–Moeatoa) failed to meet the operational targets set. In the case of the two successes, there would appear to be little immediate benefit for the AHB in pre-feeding, based solely on achieving RTCI targets, since the operational targets were also met without pre-feeding.
- The intermediate-term benefit – with time to recovery of the population to target levels and hence the need for retreatment directly dependent on the overall absolute level of success (see 6.3 below). In the case of the two failing operations, there is clearly some benefit in pre-feeding as the no-pre-feed treatments produced significantly poorer kills than the pre-feed treatments.
- The numerous operational baiting variables – that even within traditionally run operations produce kills of possums that vary unpredictably. Pre-feeding appears to partly overcome such variation, and substantially improves the population reduction (i.e. percent kill) achieved as well as reduces the risk of operational failure.

6.3 Recovery times for controlled possum populations

The theta-logistic growth equation (Barlow & Clout 1983) used in this study to model population recovery within each of the treatment blocks, based solely on in situ breeding in our four replicates, produced clearcut results. In the two operations classed as successes (see above), modelling of both the no-pre-feed and pre-feed treatment blocks indicated the time taken for the residual possum populations to recover to pre-control levels (as distinct from operational target levels) was 13–16 and 20 years respectively and the benefit associated with pre-feeding (i.e. of baiting control areas twice) based on this parameter is modest. Conversely, in the operations classed as failures, modelling of population recovery to pre-control levels of the pre-feed treatment blocks indicated prolonged recovery periods of only 10 and 12 years, while that of no-pre-feed blocks did not (i.e. 5 and 6 years), indicating the benefits arising from pre-feeding such operations is proportionately more clear-cut. Thus, as with the achievement of operational RTCI targets (section 6.2), the overall operational benefits of pre-feeding possum populations prior to control are probably greatest where there is good reason to believe control operations undertaken without pre-feed are likely to fail.

6.4 Comparison of pre- and post-control tomtit populations

The survey of tomtit numbers in the Whareorino–Moeatoa operational area indicates that pre-feeding had no major adverse effect on the tomtit population relative to no pre-feeding. The increase in tomtit abundance in both blocks from pre- to post-poison presumably reflects the increased conspicuousness of tomtits as a result of changes in behaviour (e.g. increased singing) from late September/early October to early November, as the breeding season progressed. The significantly greater increase in tomtit abundance in the pre-feed block compared to the no-pre-feed block could have been a consequence of the higher possum kill (and presumably higher rat kill) reducing predation on tomtits in the pre-feed block. Non-operational factors such as habitat or weather differences between the two treatment blocks may have also contributed. Because there was no non-treatment block (to keep costs down), we cannot tell whether either treatment (poisoning with or with out pre-feed) had any adverse impact on the tomtit population.

Without replication (i.e. without monitoring other operations), it is not possible to generalise with statistical confidence and say that pre-feeding never affects tomtit kills, but given the outcome of this trial it would now require several more replicates to confirm that this alternative hypothesis is invalid. Such replication could provide a similar result to this trial and further evidence to suggest no difference in impact between pre-feed and no pre-feed carrot 1080-baiting operations, thus supporting the continued use of 1080. Alternatively, an opposite result would indicate adverse outcomes are sometimes possible, but would be unlikely to provide sufficient insight about the likely size of any adverse effect and its probability of occurrence.

Evidence from previous trials indicates that the adverse effects of pre-feeding 1080 carrot on tomtit populations are less at bait application rates of 3–5 kg/ha than at 10–15 kg/ha (Powlesland et al. 1998, 2000; Westbrooke & Powlesland 2005). The low bait application rate of 2 kg/ha of pre-feed and 3 kg/ha of toxic feed in the Whareorino–Moeatoa operation would have reduced any potential impact on tomtit populations, and also may have reduced the contrast between poisoning with and without pre-feeding.

6.5 Comparisons of costs and benefits of pre-feed versus no pre-feed

As we were unable to demonstrate any increased risk to tomtits arising from the use of pre-feed relative to no pre-feed, the costs and immediate benefits of both treatments for possum control is dependent solely on the costs of each treatment, the kill achieved, and the subsequent rate of population recovery to levels requiring retreatment. For the two successful operations monitored in this study, both treatments reduced the populations to below the standard operational target of 2% RTCI. However, pre-feeding relative to no pre-feeding was predicted to roughly treble the time taken by these populations to recover to and exceed this level for a cost increase of 89% for Matakuhia and 65% for Waitohi– Okuku Gorge. As both treatments for these replicates had similar rates of recovery to target levels (see section 5.3), the annualised costs of control, based solely on materials, bait delivery, and field labour, equate to between \$2.75 and \$2.97 for the pre-feed option and between \$6.39 and \$9.29 for the no-pre-feed option, i.e. annual savings of between c. \$3.50 and \$6.30. However, these figures take no account of the high planning costs accrued and must therefore be treated only as rough approximations of real cost differences.

For the two replicates that failed to achieve target levels, a different argument applies, with the additional cost of pre-feeding relative to no pre-feeding being justified solely on the increased likelihood of pre-feeding achieving operational targets. The fact that the successful and unsuccessful replicates each included one cereal- and one carrot-based operation, or that the historical data from conservation and Tb-based operations analysed by us show no clear advantages of either treatment (in contrast to that published earlier; Brown & Urlich 2004), does not affect this conclusion.

7. Recommendations

- Pre-feeding should be used in all operations for Tb possum control, regardless of bait type, and particularly so where there is reason to believe an operational failure is possible.
- The mechanisms of how pre-feeding may lead to higher possum kills should be investigated further through studies of possum behaviour likely to lead to higher rates of encountering baits and to higher rates of bait consumption.

8. Acknowledgements

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10. Appendices

Appendix 1 Tomtit counting routine

before (late September – early October 2004) and after (early November 2004) aerial possum control, Whareorino–Moeatoa.

	Date		Observer 1	Observer 2
Block	Pre-poison	Post-poison	Transects	Transects
Pre-feed	26 Sep	7 Nov	A1–6	C1–6
			B1–6	D1–6
	27 Sep	8 Nov	C1–6	A1–6
			D1–6	B1–6
	29 Sep	9 Nov	E1–6	F1–6
			F1–6	E1–6
No pre-feed	1 Oct	2 Nov	A1–6	E1–6
			B1–6	F1–6
	2 Oct	3 Nov	E1–6	A1–6
			F1–6	B1–6
	3 Oct	4 Nov	C1–6	D1–6
			D1–6	C1–6

Appendix 2 Details of historical conservation-based operations on Crown lands

The bait used in the operations detailed in Table 3 included all three bait types registered for aerial use against possums in New Zealand — 86/90 operations used cereal baits and four operations used carrot bait. Of the two cereal baits available, Wanganui No. 7 baits were favoured by nearly all conservancies (72/86 cereal bait operations), with RS5 baits used only and almost exclusively by Nelson/Marlborough Conservancy (14/15 operations).

Other operational baiting statistics were more variable. Most operations (62/90, 69%) consisted of a single sowing of toxic bait (Table 3). All other operations (28) consisted of a single sowing of non-toxic pre-feed bait followed by a single sowing of toxic bait of the same bait type. Pre-fed operations included all those using carrot bait (4/4), one-third of those using Wanganui No. 7 bait (24/72), but none of those using RS5 baits.

Sowing rates of the toxic bait varied between 4 and 12 kg/ha. Most operations (77) in all conservancies except Bay of Plenty sowed toxic bait at 3 kg/ha or less. Of the remainder, seven operations sowed bait at 4–5 kg/ha, while two operations in Waikato and one in Bay of Plenty sowed bait at exceptionally high rates, i.e. 10–12 kg/ha or greater.

The size (mean weight) and type of pre-feed and toxic baits sown was always the same in each operation using this baiting strategy. About half (40/82) of all operations undertaken used 12-g cereal baits and the remaining operations for which we have such data (42) used 6–8 g cereal or carrot baits. Conservancies varied in their choice of bait size: Southland and Wanganui used 6-g baits exclusively, while Waikato, Westland, and Nelson/Marlborough showed a preference for 12-g baits.

Finally, with the exception of one carrot-based operation, baits for all operations across all conservancies were loaded with 1080 at 0.15% wt:wt (Table 3).

Appendix 3 Details of historical Tb-based operations on Crown lands

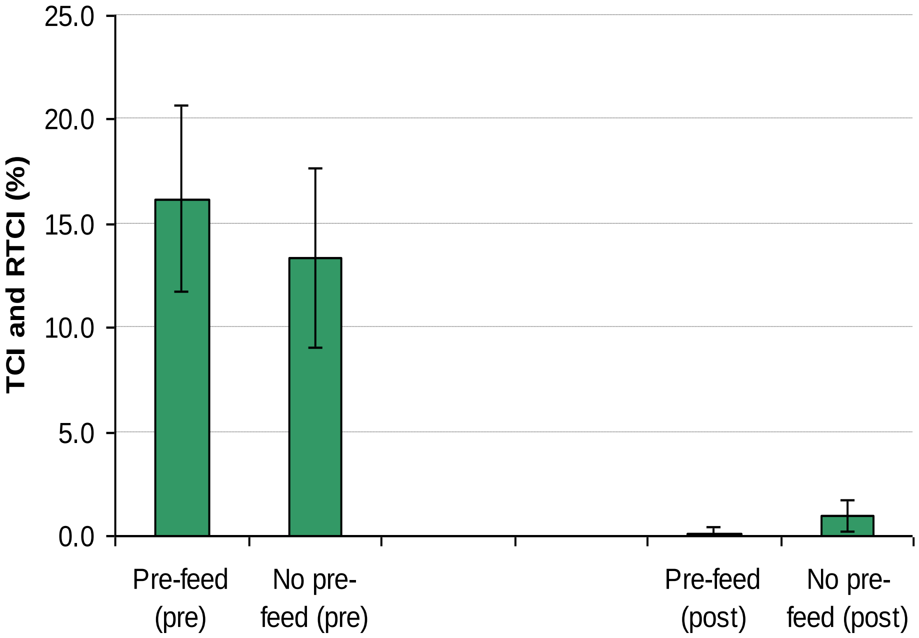
The operations listed in Table 4 used the full range of bait types registered for aerial use in possum control. For operations adequately detailed, 46 used Wanganui No. 7 cereal bait, 30 used RS5 cereal bait, and eight used carrot bait. Wanganui No. 7 bait was the sole bait used by Greater Wellington and almost so by West Coast, RS5 the sole bait used by Tasman, and almost so by Otago, and carrot bait was infrequently used by Marlborough, West Coast, and Otago, and only by Otago in the last 5 years.

Data on bait size and sowing rates indicated strong regional preferences: 12-g baits were favoured by Greater Wellington, and 6-g baits by West Coast and Otago. Pre-feed bait was in all instances the same size as the toxic bait, with the intent clearly to present to possums identical pre-feed and toxic bait, apart from the inclusion of 1080 in the latter. Sowing rates of toxic bait were typically lowest in Greater Wellington (1–2 kg/ha), intermediate in Otago (2–4 kg/ha) and Tasman (3 kg/ha), and generally highest in West Coast (3–5 kg/ha). Pre-feed bait was sown at identical rates in Greater Wellington, but at 2 kg/ha in Otago.

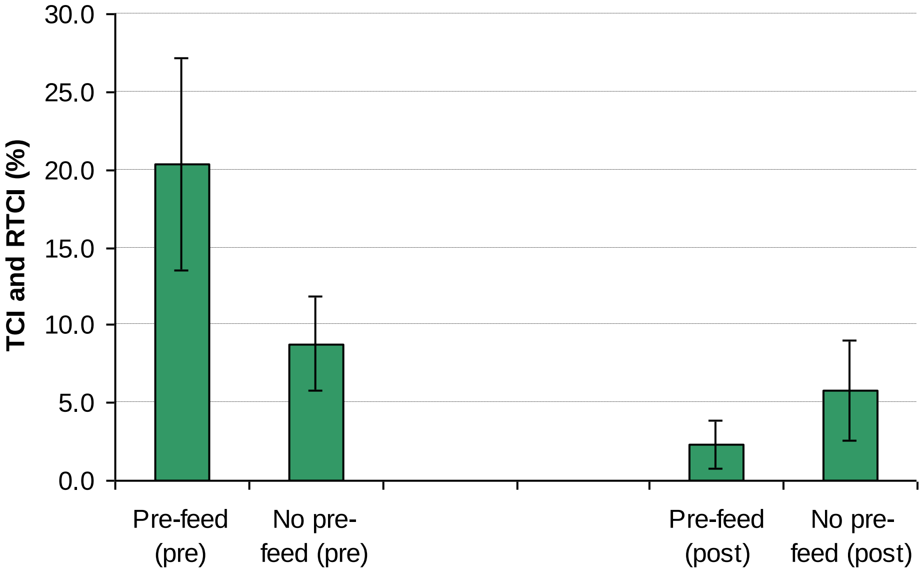
All toxic baits were loaded with 1080 at 0.15% wt:wt in all operations apart from a single operation undertaken by Horizons.mw, one early carrot-based operation undertaken by West Coast, and all operations detailed by Environment Canterbury and Marlborough.

Appendix 4 Graphs of pre- and post-control TCIs and RTCIs of possums from four study replicates

(a) carrot

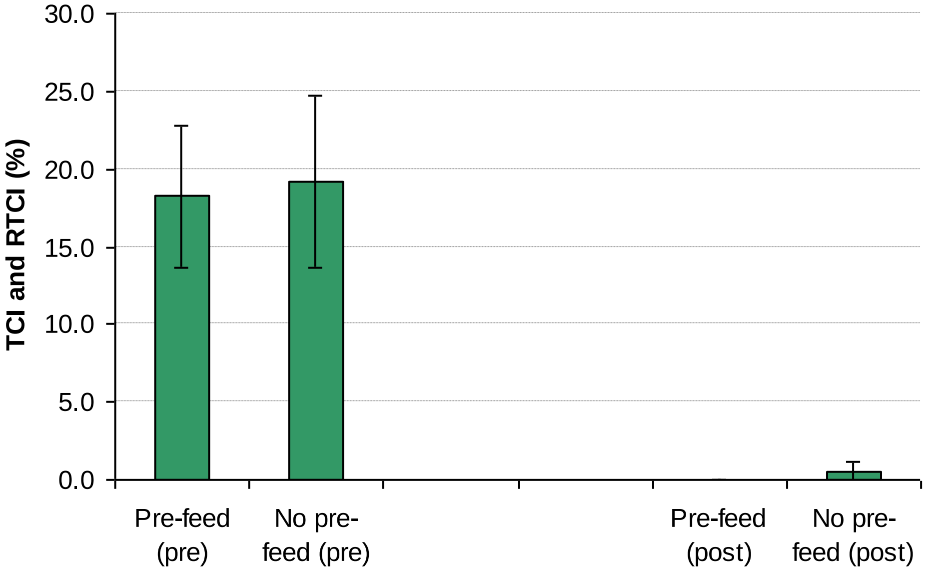


(b) cereal

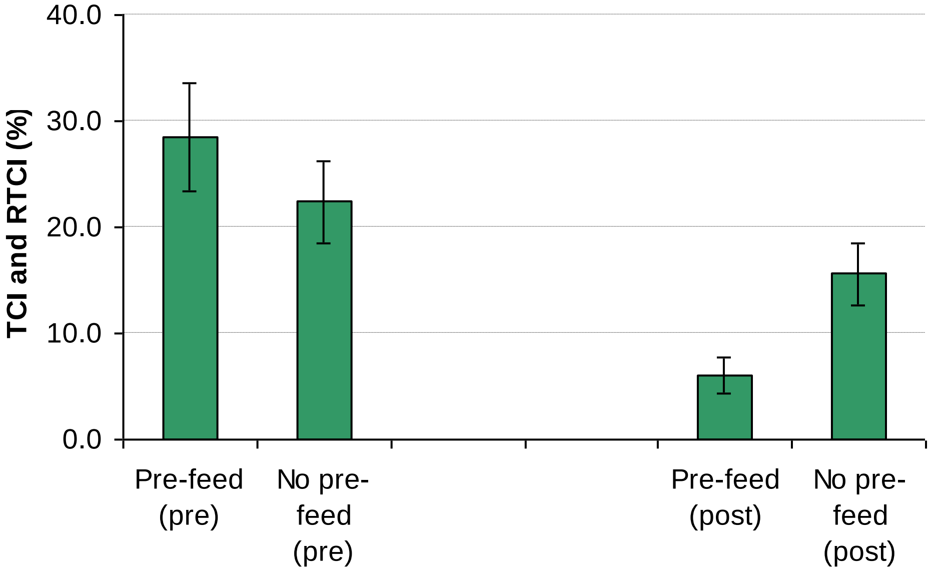


Pre- and post-control TCIs and RTCIs (± 95% CI) for the pre-feed and no-pre-feed treatment blocks for the (a) Matakuhia, (b) Copland–Karangarua replicates.

(c) cereal



(d) carrot



Pre- and post-control TCIs and RTCIs (± 95% CI) for the pre-feed and no-pre-feed treatment blocks for the (c) Waitohi–Okuku Gorge and (d) Whareorino-Moeatoa replicates.