Comparison of three methods for maintaining possums at low density

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ABSTRACT

This study aimed to determine the cost-effectiveness of three options for maintenance control of possums (*Trichosurus vulpecula*): repeat aerial applications of 1080 bait with changes in the bait used, bait-stations with 1080 in cereal baits, and ground-hunters primarily using traps. It also aimed to test a computer model for simulating population recovery. Seven 1.2-km^2 blocks were established in northern Pureora Forest, with the three treatments randomly allocated to two blocks each, and the seventh block kept as a non-treatment control. All blocks had initial possum residual trap-catches (RTCs) between 16% and 25%, and were to be maintained below 10% RTC. Control treatments were repeated only if trap-catch monitoring 12 months after control indicated that the population had increased to 10% RTC. All treatments effectively reduced possum numbers, but the bait-stations were the most cost-effective. Populations in all treatment blocks recovered to ≥10% threshold within the first 12 months and required the treatments to be repeated. All repeat treatments were again effective with trap-catches being reduced to lower levels than achieved from the first applications. The results showed that (1) in accessible areas bait-stations are the most cost-effective maintenance control option, (2) repeat aerial control did not appear to become less effective when the bait type was changed and pre-feed used, and (3) for small control areas immigration contributes significantly to rates of increase following control; managers need to optimise their control with respect to frequency and 'buffer' area treated.

Keywords: Aerial control, bait-stations, control strategies, maintenance control, population recovery, possums, rates of increase

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1. Introduction

Operations to control possums (*Trichosurus vulpecula*) have been conducted over large areas of New Zealand since the early 1960s (Morgan et al. 1997). During the last 5–8 years, the Department of Conservation (DOC) has attempted to extend the benefits obtained from the initial knockdowns by applying 'maintenance control' in an attempt to keep possum populations at low levels (DOC 1994). Maintenance control requires the development of strategies that can optimise the mix of variables such as the frequency and size of operations, as well as the sequencing of baits, toxins and traps to avoid behavioural and environmental problems. Landcare Research was contracted to assess the costs and potential problems of applying three different maintenance control regimes to keep possum populations at low levels for a period of 4 years from 1995 to 1999.

2. Background

This project started in 1994. At the time, a common strategy for protecting conservation values from possum damage was to reduce possum numbers by at least 80%, usually using an aerial poison bait drop, and then follow this initial reduction with maintenance control to keep the population below a threshold level to prevent unacceptable damage (Saunders 2000). The frequency and intensity of maintenance control, and the methods used, are presently up to the discretion of wild-animal managers with there being no one accepted cue for triggering repeat maintenance control (Parkes & Choquenot 1999). Typically, maintenance control has been carried out using either bait-stations with 1080 or brodifacoum baits, or contract hunters using traps and/or cyanide. A third option, until now untried, was to repeat aerial application of 1080 baits. Which of the available options is most cost-effective, or whether any one of the options is more suitable for use in a particular set of habitat characteristics, was not known.

The **frequency** at which maintenance control is applied depends on four factors:

1. The difference between the target density required (i.e. to achieve resource protection) and zero density. If the target density is close to zero, then maintenance control will have to be applied frequently because the population will quickly reach the required target.
2. The difference between the density required to protect a resource and the density achieved from the control method used. That is, if a population can only be reduced to a Residual Trap-Catch index (RTC) of 8%, and the population needs to be maintained below 10%, then this population will require more frequent control than one in which the residual population can be reduced to 3%, because it will recover from 8% to 10% sooner than from 3% to 10%.

3. The rate of population growth after control. If immigration or breeding rates are high, then the population will recover more rapidly, and maintenance control will be required more frequently.
4. The susceptibility and resilience of the resource, i.e. its ability to respond to changes in possum numbers. If a resource has the potential to recover rapidly when possum numbers are reduced, or if it does not decline immediately once possums recover, then possums could be left longer between control treatments.

Thus the best frequency of control as determined by the above four factors may impose constraints on which control method is used. For example, the frequent use of a single bait-type or toxicant may lead to behavioural aversions (O'Connor & Matthews 1999) and, consequently, managers will need to consider other methods if the required frequency of control is to be maintained.

This project applied three potential maintenance control techniques (repeat aerial 1080 application, repeat 1080 application in bait-stations, and contract hunters primarily using traps) to determine the relative effectiveness and efficiency of the three treatments and the potential problems generated by the frequent application of these treatments.

3. Objectives

1. To compare the effectiveness and efficiency of three maintenance control techniques, by:
   - measuring the frequency of application required to keep possum populations below a nominated density index
   - measuring the effort, cost, and percentage kill of the 'best practice' application of each control technique
   - relating the possum densities before and after each control operation and chosen threshold densities, to simple indices of possum impacts.

   Note: At the end of Year 1, DOC agreed the third objective could be waived because all control was going to achieve similar possum reductions; therefore there would be no measurable differences in resource impacts that could be attributed to the different treatments. Consequently, the 'nominated density index' was the same for all blocks.
2. To investigate and report on the possibilities of using a possum-spatial model to apply maintenance control techniques in an integrated way.

4. Methods

The field trial ran from April 1995 to May 1999, with population monitoring carried out annually.

4.1 STUDY SITE

An area of lowland podocarp-tawa hardwood forest in northern Pureora Forest was chosen for the trials after discussion with Waikato Conservancy staff. Seven blocks, each 1200 m × 1200 m were established, and two of each of the treatments were randomly allocated to the blocks with the seventh block used as a non-treatment block (Fig. 1). The area had not received any possum control for at least 5 years (initial trap-catch estimates were in the order of 20%), and so the first control undertaken in this trial was equivalent to an initial knockdown.

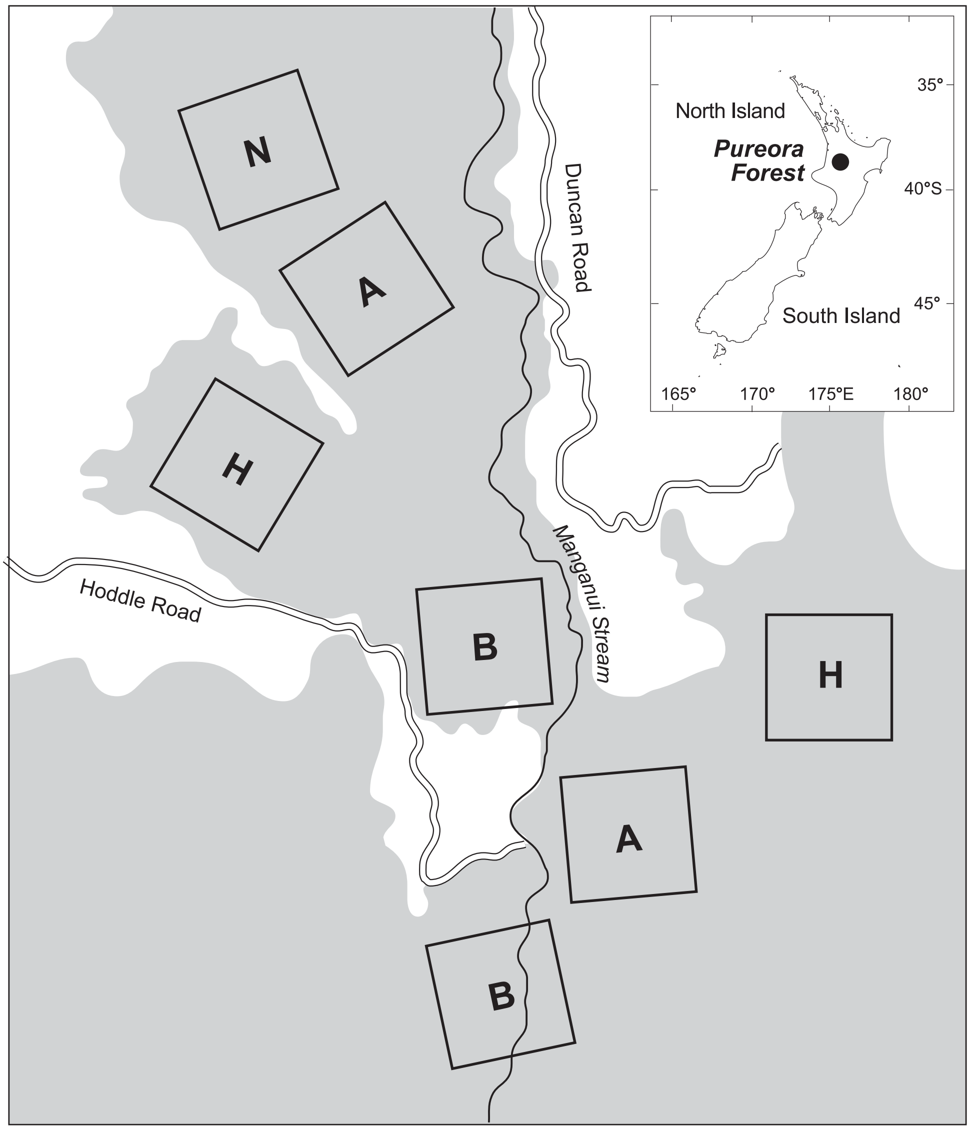


Figure 1. Layout of the 7 trial blocks in Northern Pureora Forest. A = aerial, B = Bait-station, H = hunter, and N = non-treatment. Shaded area is forest and white area is farmland.

4.2 POPULATION MONITORING

Each block was initially monitored both before and after control with four lines of 20 traps. Because of the high between-line variation in catch, the number of lines was doubled and 10 traps instead of 20 were used on each line. Traps were set for 2 nights instead of 3 to minimise the impact of the monitoring on the possum population. For each repeat survey, start points of the monitoring lines were selected at random, although the need to keep lines at least 150 m apart resulted in the lines being spaced relatively consistently throughout the block in any one survey. All possums trapped were killed. All blocks were monitored each year, and those blocks having an RTC estimate above 10% were subject to maintenance control followed by a second (post-control) trap-catch survey.

4.3 CONTROL TREATMENTS

Two aerial control operations were carried out by Environment Waikato. The first operation used one sowing of 0.15% 1080 in RS5 cereal pellet bait at 5 kg/ha. This operation was carried out specifically for this project and was carried out to our specifications. In the second operation carrot was pre-fed then the area was sown with 0.08% 1080 at 15 kg/ha. The first aerial operation was restricted to the trial blocks allocated for aerial treatment, but the second operation was part of a large-scale Tb control operation for the Animal Health Board, and the aerial treatment blocks and all the surrounding forest (excluding the other treatment blocks) was sown (i.e. the treatment blocks in year 1 and year 2 are likely to have had different rates of immigration). The change from cereal to carrot bait was chosen to minimise the risk of control failure due to any aversion problems if the same bait type had been used. The costs of aerial applications were obtained from Environment Waikato and a general cost was used rather than the specific cost of treating these blocks, because the small block size meant the high fixed costs (e.g. ferry time) were apportioned across a small area, resulting in unrealistically high per hectare costs.

The bait-station blocks were marked out in grids (150 m × 150 m) and Kilmore bait-stations were sited at each 150-m intersection (a total of 81 (9 × 9) bait-stations). Bait-stations were pre-fed twice (at weekly intervals) with non-toxic RS5 cereal baits and then followed with 500 g of 0.15% 1080 RS5 baits and left for a further week before any remaining toxic bait was removed. Both pre-feed and toxic RS5 baits were lured with 0.1% cinnamon. The cost of the bait-stations and bait used was recorded as well as the time taken to service the stations. Each repeat bait-station control operation followed the above application protocol. That is, no attempt was made to tailor the amount of bait delivered to changes in population abundance.

The contract hunter blocks were controlled by two experienced possum hunters using primarily traps with a small amount of cyanide paste being used to supplement their trapping effort. Each hunter was allocated $25/ha to achieve as large a reduction in possum numbers as they could. Each hunter kept a daily work diary reporting what effort of trapping and poisoning was applied.

4.4 THRESHOLD DENSITY INDEX

We endeavoured to achieve the maximum population reduction with each control treatment and then decide whether maintenance control was necessary, based on the trap-catch index having reached or exceeded 10%. If this trigger level was reached within 10–12 months, then the treatment was repeated, otherwise the block was left a further 12 months before being reassessed. Although a 5% possum catch or lower threshold is often used now for triggering maintenance control, a 10% threshold was chosen for this project because we needed a threshold that was sufficiently different from what was achievable by the control treatments to enable increases in capture rates to be detected by the monitoring method.

Because the treatment blocks had relatively large edge-to-area ratios, it was expected that in Year 1 immigration would contribute significantly to the rate of population recovery. In contrast, in Year 2 (after the large-scale poisoning of the surrounding possum population) it was predicted that rates of population increase following control would be slowed because of the reduction in the number of potential immigrants in the surrounding forest.

4.5 MODEL OF POPULATION RECOVERY

A simple deterministic diffusion model was developed in MS Excel using a step-wise approximation of a continuous density gradient in a circular control area. It was assumed that possum density was at carrying capacity at the edge of the control area (set at a percentage catch of 20%) and reduced to selected levels within the block (a 90% kill was assumed). The proportion of animals available for dispersing (i.e. emigrating down the density gradient) was determined using the difference between current density (N) and carrying capacity (K). That is, we calculated population productivity (r_m – in situ mortality = HN), then 'dispersed' the proportion of this productivity that corresponded to N/K. Thus total productivity dispersed when N was very low, with progressively less dispersal as N approached K. The proportion of productivity that did not disperse died. It was assumed that the surrounding population (at carrying capacity) bred and all 'surplus' offspring emigrated. The number of possums immigrating and settling into any 500-m step along the density gradient was added to the residual population plus the annual *in situ* recruitment. It was assumed that animals entering into a 500-m step settled there. The rate of population increase from *in situ* breeding was set at 0.3 (Clout & Barlow 1982). The model simulated 10–15 years of breeding and migration to determine the time required for the population to recover to carrying capacity at the centre of the control area.

4.6 STATISTICAL ANALYSES

Because the mean trap-catches resulting from each treatment had relatively large confidence intervals, no attempt was made to test whether any one treatment was more effective than the others. However, to test whether the repeated treatments resulted in an overall lower reduction of density, the post-control trap-catch estimates in Year 1 and Year 2 were compared using a two-way ANOVA with block and year effects. The data were transformed with arcsin^{-1} (square root) function. Approximate 95% confidence intervals for the rates of increase were calculated using the Bias-Corrected Percentile Bootstrap (BC Bootstrap) method (Manly 1997). Estimates of variance in r_m were only determined for the first 12 months to assess the likely magnitude of the variance obtained from using eight trap-catch lines.

5. Results

5.1 POPULATION ESTIMATES AND PERCENTAGE KILLS

5.1.1 Year 1 (1995)

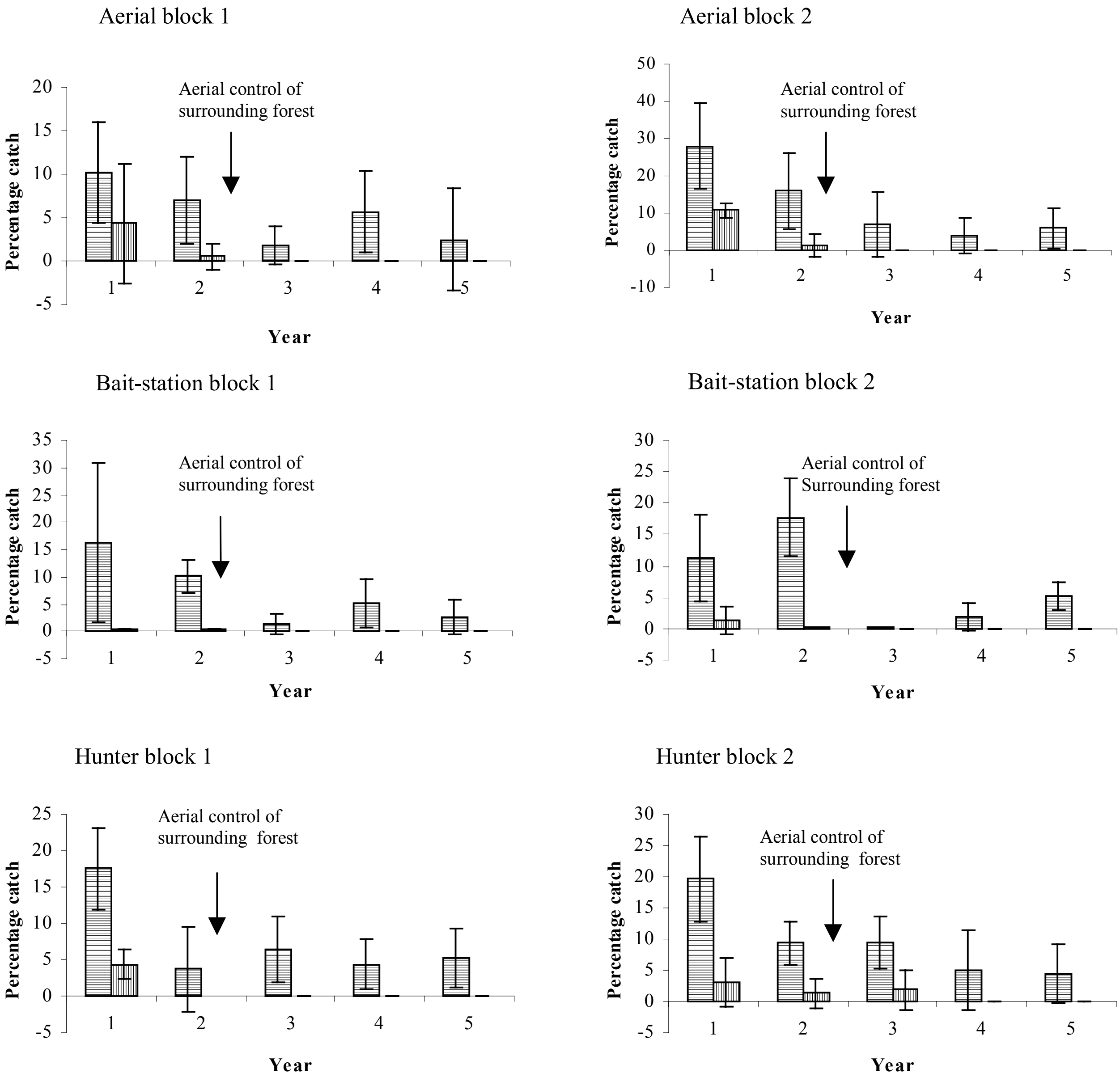
The initial mean trap-catch estimates for the seven blocks ranged from 10.2% to 28%, with four of the blocks having catches between 16 and 19% (Table 1). Except for the aerial treatments, all control operations achieved initial kills in excess of 70% with bait-stations proving to be the most effective (Table 1, Fig. 2).

TABLE 1. INITIAL TRAP-CATCH ESTIMATES (±95% CI) AND THE ESTIMATED REDUCTIONS ACHIEVED BY THE THREE CONTROL TREATMENTS IN YEAR 1 (1995).

TREATMENT	TRAP-CATCH ESTIMATES (%)		PERCENTAGE KILL (95% CI)
	BEFORE CONTROL	AFTER CONTROL	
Aerial 1	10.2 ± 5.8	4.4 ± 6.9	56.7% (2.6–100)
Aerial 2	28.0 ± 11.5	10.7 ± 2.0	62.0% (41.4–82.6)
Bait-station 1	16.3 ± 14.6	0.0	100%
Bait-station 2	11.3 ± 6.9	1.3 ± 2.3	88.8% (69.0–100)
Hunter 1	17.6 ± 5.6	4.4 ± 2.0	75.1% (65.7–84.4)
Hunter 2	19.7 ± 6.8	3.1 ± 3.8	84.0% (65.0–100)
Non-treatment	16.4 ± 12.4	-	-

5.1.2 Year 2 (1996)

For those blocks in which the mean population estimate had increased to above the 10% trap-catch threshold (Table 2), the selected treatments were repeated. Because of the Animal Health Board's requirement to carry out possum control over as much area as possible, Aerial block 1 was also re-treated. Although the mean trap-catch in Hunter block 2 was not >10% (9.4%), it was believed to be sufficiently close to 10% that, were it not treated, allowing another 12 months to lapse before control was undertaken, it would have enabled the population in this block to recover to unacceptable levels. Immediately after these repeat treatments were applied, Environment Waikato carried out possum control in



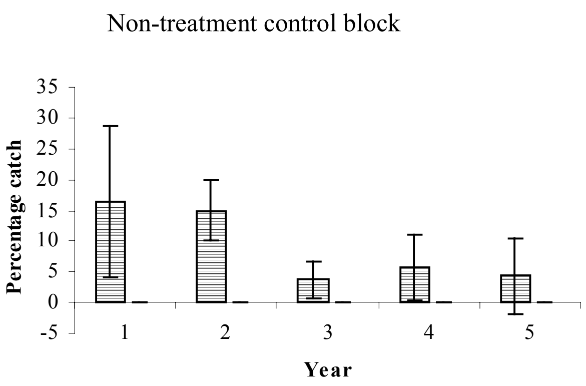


Figure 2. Annual (1995–99) mean percentage trap-catch (± 95% CIs) for each treatment, before (horizontal lined bars) and after (vertical lined bars). Note different scales of vertical axes.

the surrounding forest. This provided an opportunity for this project to determine what effect a reduction in the potential source of immigration would have on subsequent recovery rates (see section 5.2). This peripheral control included the non-treatment control block because local farmers would not accept having uncontrolled areas within this Tb vector area.

Five of the six treatment blocks had recovered sufficiently to be retreated. The treatments were identical to the previous year except for both aerial operations, which were changed to pre-fed carrot bait sown at 8 kg/ha followed by carrot with 0.08% 1080 and sown at 15 kg/ha. All treatments achieved high kills with four treatments achieving kills in excess of 90% (Table 2, Fig. 2).

Trap-catches estimated following control in the second year (1996) were significantly lower than those achieved in 1995 (Block by year effect F = 4.76; d.f. 1,4; $P = 0.0025$). Trap-catch estimates in subsequent years did not recover sufficiently (i.e. trap-catches remained below the threshold level of 10%) to require repeat control before the project ended (Fig. 2).

5.1.3 Year 3 (1997)

Only one of the six treatment blocks had recovered sufficiently to justify repeat control (Table 3, Fig. 2). The hunter used identical methods to previously and achieved a kill of 80%. It should also be noted that the trap-catch in the non-treatment block declined significantly, a result of an aerial 1080 operation. This reduction then enabled us to monitor an additional block for recovery that would get no further treatment.

TABLE 2. TRAP-CATCH ESTIMATES (±95% CI) AND THE ESTIMATED REDUCTIONS ACHIEVED BY THE THREE CONTROL TREATMENTS IN YEAR 2 (1996).

TREATMENT	TRAP-CATCH ESTIMATES (5%)		ESTIMATED PERCENTAGE
	BEFORE CONTROL	AFTER CONTROL	KILL (95% CI)
Aerial 1	7.0 ± 5.0	0.6 ± 1.5	91.1% (63.1–100)
Aerial 2	15.9 ± 10.4	1.2 ± 3.0	92.2% (67.2–100)
Bait-station 1	10.1 ± 3.1	0.0	100%
Bait-station 2	17.6 ± 6.2	0.0	100%
Hunter 1	3.7 ± 5.8	-	-
Hunter 2	9.4 ± 3.5	1.3 ± 2.3	86.6% (66.2–100)
Non-treatment	14.9 ± 4.9	-	-

TABLE 3. TRAP-CATCH ESTIMATES (±95% CI) IN YEAR 3 (1997) BEFORE CONTROL AND ESTIMATED REDUCTION ACHIEVED IN HUNTER BLOCK 1.

TREATMENT	TRAP-CATCH ESTIMATES (%)		ESTIMATED PERCENTAGE
	BEFORE CONTROL	AFTER CONTROL	KILL (95% CI)
Aerial 1	1.9 ± 2.2	-	-
Aerial 2	7.0 ± 8.6	-	-
Bait-station 1	1.3 ± 1.9	-	-
Bait-station 2	0.0	-	-
Hunter 1	6.4 ± 4.5	-	-
Hunter 2	9.4 ± 4.1	1.9 ± 3.2	79.8% (46.2–100)
Non-treatment	3.8 ± 3.0	-	-

5.1.4 Years 4 (1998) and 5 (1999)

None of the treatment blocks had recovered sufficiently to justify repeat control in Year 4 (Table 4, Fig. 2) and so were left for a further 12 months before being monitored again (Table 4). One month before the last trap-catch survey was carried out in 1999, Environment Waikato carried out an aerial operation, which included Hunter block 2, part of Aerial block 2 and a single swath of bait through the non-treatment block. Landcare Research was not notified of this operation.

5.2 RATES OF INCREASE

Over the 12 months following the first control treatments, the rates of population increase in the six treatment blocks varied from −0.17 to 2.64 (Table 5). If we assume the maximum *in situ* rate of increase (r_m) is 0.3, then the contribution of immigration (r_i) to recovery rates was high for some blocks (i.e. up to 2.34).

TABLE 4. TRAP-CATCH ESTIMATES IN YEARS 4 (1998) AND 5 (1999). NOTE THAT AERIAL BLOCK 2, HUNTER BLOCK 2, AND THE NON-TREATMENT BLOCK RECEIVED SOME AERIAL CONTROL BY ENVIRONMENT WAIKATO.

TREATMENT	TRAP-CATCH ESTIMATES (%) YEAR 4	YEAR 5
Aerial 1	5.7 ± 4.7	2.5 ± 5.9
Aerial 2	3.9 ± 4.6	5.9 ± 5.5
Bait-station 1	5.1 ± 4.5	2.5 ± 3.2
Bait-station 2	1.9 ± 2.2	5.2 ± 2.3
Hunter 1	4.4 ± 3.5	5.3 ± 4.1
Hunter 2	5.1 ± 6.4	4.4 ± 4.7
Non-treatment	5.7 ± 5.4	4.4 ± 6.1

TABLE 5. EXPONENTIAL RATES OF INCREASE DUE TO *IN SITU* REPRODUCTION (r_m) AND IMMIGRATION (r_i).

TREATMENT	TRAP-CATCH ESTIMATES (%) YEAR 1 (1995) AFTER CONTROL	YEAR 2 (1996) BEFORE CONTROL	r_m	r_i	TOTAL RATES OF INCREASE
Aerial 1	4.4	7.0	0.3	0.16	0.46 (−0.46 to 1.94)
Aerial 2	10.7	15.9	0.3	0.1	0.4 (0.25 to 0.85)
Bait-station 1	0.0	10.1	–*	–	–
Bait-station 2	1.3	17.6	0.3	2.34	2.64 (1.87 to ∞)
Hunter 1	4.4	3.7	−0.17	–	−0.17 (−2.08 to 0.85)
Hunter 2	3.1	9.4	0.3	0.8	1.1 (0.54 to 2.50)
Non-treatment	16.4	14.9	−0.10	–	−0.10 (−0.50 to 0.56)

* r_m could not be determined because of the zero catch in the first year.

Note: r_m is set at 0.3 unless total r is less than 0.3. The approximate 95% CIs are BC Bootstrap estimates.

In the second year after an Environment Waikato control operation reduced possum numbers in the surrounding forest, the rates of increase declined, although both Aerial block 2 and Hunter block 2 still had rates of increase considerably higher than 0.3 (Table 6). By the fourth year (1998–99) rates were low and sometimes negative for most blocks although bait-station block 2 had an r_m value of 1.0. This high rate was due to the very low starting trap-catch (1.9%) in the previous year.

5.3 OPERATIONAL COSTS

Costs for the three control treatments were similar in Year 1. However, bait-station costs were considerably lower in subsequent years because there were no costs for establishing the bait-stations that had been left in place (Table 7). Costs for routine aerial control carried out by Environment Waikato were between $23 and $25/ha (Kevin Christie pers. comm.). The hunter costs in this project were fixed at $25/ha with control effort adjusted by the hunters to fit this price. Twenty percent of the cost of the bait-stations was included in the total costs on the assumption that the bait-stations would need to be replaced after 5 years.

TABLE 6. TOTAL ANNUAL RATES OF INCREASE FROM 1996 TO 1999.

TREATMENT	TRAP-CATCH ESTIMATES (%)		TOTAL RATES OF INCREASE		
	YEAR 2 (1996) AFTER CONTROL	YEAR 3 (1997) BEFORE CONTROL	YEAR 2–YEAR 3 1996–97	YEAR 3–YEAR 4 1997–98	YEAR 4–YEAR 5 1998–99
Aerial 1	0.6	1.9	1.2	1.24	–0.84
Aerial 2	1.2	7.0	1.7	0.5	0.41
Bait-station 1	0.0	1.3	–*	1.37	–0.71
Bait-station 2	0.0	0.0	–*	–*	1.0
Hunter 1	3.7	6.4	0.55	–0.32	0.19
Hunter 2	1.3	9.4	1.98	0.28	0.56
Non-treatment	14.9	3.8	NA**	0.41	–0.26

* Rate could not be calculated because of the zero catch at T1.
** Rate not applicable because of aerial control.

TABLE 7. COSTS OF THE THREE CONTROL TREATMENTS APPLIED IN NORTHERN PUREORA FOREST.

TREATMENT	TOTAL COST/HA
Aerial RS5 cereal pellets	$23.00
Aerial carrot (pre-fed)	$23.00
Hunter	$25.00
Bait-station Year 1*	$25.14
Bait-station repeats**	$12.66

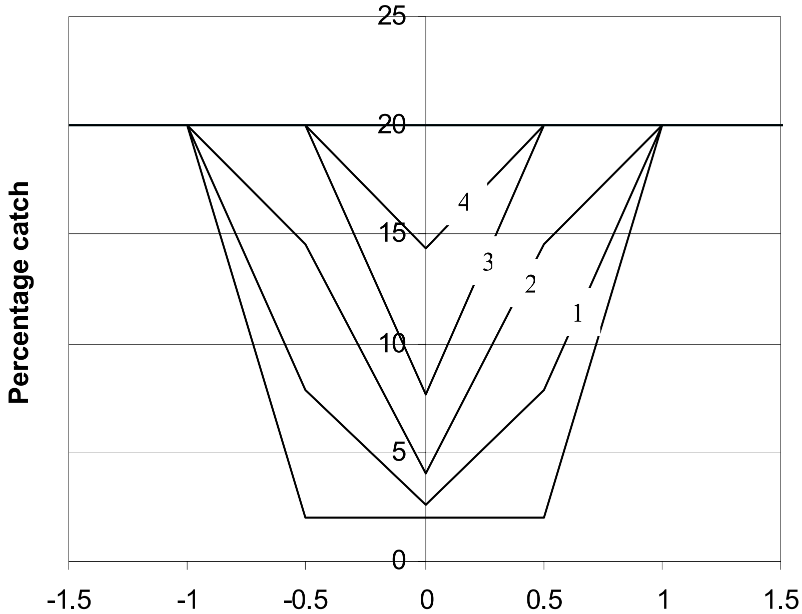
* Costs are based on a $20.00 hourly rate and bait-station costs have been depreciated over 5 years.
** Includes time, bait, and 20% of the bait-station costs.

5.4 MODELLING POPULATION RECOVERY

The estimated rates of recovery generated by the MS Excel diffusion model were of the same order as the empirical rates obtained from the trial blocks, and therefore managed to predict what the likely contribution of immigration was to population recovery. Starting with an initial trap-catch density set at 20%, a 90% kill reduced this to a 2% trap-catch. The model predicted that after 12 months the mean density across the block would be 6.1%, requiring a rate of increase of 1.12 (i.e. an *in situ* breeding contribution of 0.3 and 0.82 from immigration: Fig. 3A). After 24 months the population would have increased to a mean of 11% trap-catch, justifying repeat control if the trigger index was set at 10%. In contrast, when the block's radius was increased from 500 m to 1 km, the mean density after 12 months recovery was only 2.5% trap-catch (r_m = 0.23), and 5 years was required for the population to increase to 10% trap-catch (Fig. 3B).

Figure 3. Simulated possum population recovery. Each V-shaped line represents the profile of percentage catch across the control block each year (numbered from 1 to 4 in graph A, and 1 to 6 in graph B following control until the average density reaches the carrying capacity of the surrounding habitat (this was set at a 20% trap-catch). Graph A represents a block with a 500-m control radius, and graph B represents a block with a 1-km control radius.

A.



B.

6. Conclusions

Each of the three treatments used resulted in high kills, although bait-stations consistently achieved higher kills than aerial control and ground-based hunters. This result supports previous research results on using bait-stations for possum control (Thomas 1995). Bait-stations achieved these high kills at lower costs than the other treatments, with the cost in all years, apart from the first, being about 50% of the costs of the other treatments. However, the costs for the bait-station blocks in this trial are conservative because both blocks had one edge that was accessible by vehicle. Consequently, there was no time required for ferrying bait. One person could manage two grid lines of stations (i.e. a total of 18 stations) with one load of bait, returning to the access point where the vehicle and more bait was available. As larger areas are controlled using this method, the ferrying time for each additional 144-ha block would increase. For example, for the next adjacent 144 ha, sufficient bait for 18 stations would need to be ferried through the nearest 1.2 km with a return trip to the access point. Therefore, for every adjacent 144 ha, each person would have to walk an additional 2.4 km, which could take about 1.5 hours. Consequently, for every additional 18 stations (32 ha) an additional 1.5 hours of ferrying time would be required (i.e. an extra $1.10/ha, based on $20/hour). This ferrying cost would then double for each hectare in every additional block of 144 ha further away from the access point to the area. Steep terrain and dense understorey, which would impede travel, would significantly increase the time required to service each bait-station, and as the blocks in this trial were on relatively flat terrain, again the costs/ha should be regarded as conservative. A comparison between an aerial 1080 and bait-station operation carried out at a management-level scale (i.e. 5000 ha each) resulted in costs of $50.33/ha for the bait-station operation (Corson 1999).

Repeating the poison treatments at 12-month intervals (aerial and bait stations) did not reduce the efficacy of these methods. This is in contrast to other repeat control operations that have been ineffective because of toxin and/or bait aversion (O'Connor & Matthews 1999). In these trials both the second aerial and bait-station repeat control applications included pre-feeding, and the second aerial operation also included a change in bait from cereal RS5 to carrot. Moss et al. (1998) demonstrated that pre-feeding significantly reduces the risk of possums developing aversion to 1080 bait, and Morgan et al. (1995) and O'Connor & Matthews (1999) showed that changing the bait base (e.g. from cereal to carrot) overcame any aversion that developed. These results indicate that frequent use of even an acute toxin such as 1080 can remain effective if prefeeding and bait-switching is employed.

The main determinant of the frequency of maintenance control was the rate of population increase following control. In the relatively small trial blocks, population recovery rates were rapid with immigration often contributing more to recovery than reproduction. However, because of the relatively low number of monitoring lines that could be established in each block, the annual estimates of RTC were imprecise and therefore the apparent rates of increase in any one block could have been influenced by the imprecision of any one RTC estimate.

To achieve a precision that would detect the observed changes in percentage catch over any given time period, as significant, would require a 10-fold increase in the number of monitoring lines. The limited size of our treatment blocks could not accommodate this number of lines.

Although five of the six treatment blocks required a second treatment in Year 2, in subsequent years only one block was treated and then none required further treatment for the following 2 years. Thus, although the rates of increase did not decline between the first and second, and second and third treatments, the absolute densities did. Therefore, because the initial densities at the start of the second period were significantly lower than in Year 1, the same rate of recovery could be achieved with a reduced number of immigrants. As the density increased into the third and fourth year, the rates of increase declined, presumably because of the lower number of potential immigrants available from outside the control blocks.

Monitoring with traps could have had an impact on population numbers and hence rates of recovery. However, this impact was likely to be minimal given the high rates of increase recorded during each 12-month period, and the relatively small proportion of possums captured during monitoring (e.g. a 10% catch during monitoring resulted in 16 possums being caught compared with about 100–150 caught in each of the hunter blocks during control). The non-treatment block also showed no significant change in the mean percentage-catch from year to year (except when aerial control was applied) indicating that the trap monitoring was not having a significant impact on the possum population and that catch rates were relatively stable over a 12-month period when control had not been applied.

Because immigration was such a major factor in determining population recovery time, our results should not be extrapolated to large management areas where the perimeter-to-area ratio would be considerable smaller than in this project. These results have particular relevance to managing possum populations that are having localised effects on conservation species such as native snails (*Paraphanta* spp.) or wood rose (*Dactylanthus* spp.), where the management area is tens to hundreds of hectares rather than thousands of hectares.

The computer model developed to predict recovery times with *in situ* reproduction and immigration rates produced estimates of rates of increase of the same order that were found empirically. The model was deterministic and therefore took no account of possible stochastic effects on r_m that might result from random events such as variations in food availability and weather (Renshaw 1991). Consequently, the model would not generate the possible range of r_m values that were likely to be found empirically. Nevertheless, the model was still useful in predicting the potential effect of immigration on rates of increase given a fixed mean value for r_m. It is the contribution of immigration to rates of increase that will vary most with size of control area; therefore, the model provided a method of contrasting the required frequency of control given control blocks of varying diameters. The model did not attempt to estimate immigration due to localised 'creep' of possums that had home ranges immediately adjacent to the control block (Efford et al. 2000). Such creep would have a relatively large impact on rates of recovery of small areas that have a large perimeter-to-area ratio—therefore the model would have potentially underestimated rates of increase. The model indicated that with an increase in control radius from 500 m to 1 km, rates of increase can be significantly reduced. Consequently, managers who need to protect localised areas of high conservation value could use such a model to determine an optimum control strategy, balancing the frequency of repeat control with the area treated, and the risks of inducing behavioural resistence or causing undesirable environmental impacts if repeat control is done too frequently.

7. Recommendations

The authors recommend that:

- Bait-stations be considered as the most cost-effective control option providing access on foot (i.e. to deliver pelleted bait) is possible.
- Using acute poisons (e.g. 1080) for repeat treatments be considered providing the bait matrix is changed and if pre-feeding is also carried out.
- For managing possums in small areas, managers consider the significant contribution to population recovery that immigration has and optimise their control with respect to frequency and 'buffer' area treated.
- Professional hunters using traps and cyanide can provide control as cost-effective as aerial 1080 but, as with bait-stations, their cost-effectiveness will be influenced by terrain and density of vegetation cover.

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9. References

Clout, M.N.; Barlow, N.D. 1982: Exploitation of brushtail possum populations in theory and practice. *New Zealand Journal of Ecology 5*: 29–35.

Corson, P. 1999: Pirongia possum control operation 1996–1998. Unpublished Department of Conservation Report, Hamilton. 44 p.

DOC 1994: Department of Conservation National Possum Control Plan 1993–2002. Department of Conservation, Wellington. 82 p.

Efford, M.; Warburton, B.; Spencer, N. 2000: Home-range changes by brushtail possums in response to control. *Wildlife Research 27*: 117–127.

Manly, B.F. J. 1997: Randomization, bootstrap and Monte carlo methods in biology. Chapman & Hall, London.

Morgan, D.R.; Meikle, L.; Hickling, G.J. 1995: Induction, persistence and avoidance of 1080 bait shyness in captive brushtail possums. *Proceedings of the 10th Australian Vertebrate Pest Conference, Hobart, Australia*: 328–332.

Morgan, D.R.; Thomas, M.D.; Meenken, D.; Nelson, P.C. 1997: Less 1080 bait usage in aerial operations to control possums. *Proceedings of the fiftieth New Zealand Plant Protection Conference 50*: 391–396.

Moss, Z.N.; O'Connor, C.E.; Hickling, G.J. 1998: Implications of prefeeding for the development of bait aversions in brushtail possums (*Trichosurus vulpecula*). *Wildlife Research 25*: 133–138.

O'Connor, C.E.; Matthews, L.R. 1999: 1080-induced bait aversions in wild possums: influence of bait characteristics and prevalence. *Wildlife Research*: *26*: 375–381.

Parkes, J.P.; Choquenot, D. 1999: Proceedings of workshops on Project 2398: Optimising possum control through adaptive management. Landcare Research Contract Report LC9900/008 (unpublished), 17 p.

Renshaw, E. 1991: Modelling biological populations in space and time. Cambridge University Press, Cambridge. 403 p.

Saunders A. 2000: A review of Department of Conservation mainland restoration projects and recommendations for further action. Department of Conservation, Wellington. 219 p.

Thomas, M.D. 1995: Possum control in native forest using sodium monofluoroacetate (1080) in bait stations. *Proceedings of the forty seventh New Zealand Plant Protection Conference*: 107–111.