
Evaluation of two relative-abundance indices to monitor brushtail possums in New Zealand

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Abstract. Population monitoring of brushtail possums (\textit{Trichosurus vulpecula}) is an essential part of their management in New Zealand, with a trap-catch removal method being used most commonly. An alternative monitoring method (bait-interference), using bite marks on wax blocks, has been promoted as a more cost-effective alternative to using traps. However, neither of these methods has been validated. We assessed the utility of these two methods regarding their accuracy (unbiasedness and precision) in detecting changes in possum abundance by comparing the estimates of relative change in possum density following control obtained from both methods with the kill rate among radio-collared possums in the same study areas. In each of seven control operations, 48–50 possums were collared with mortality-sensing radio-transmitters, and trap-catch and wax-block lines were assessed before and after control. The correlation between trap-catch and radio-transmitter kill estimates ($R^2 = 0.91$) suggests that trap catch, as currently used to monitor relative possum abundance, appears to be sufficiently accurate to manage these pests, with any bias being small. The kill estimates based on the wax-block monitoring were correlated less strongly with the radiotransmitter estimates ($R^2 = 0.66$), although still significant. Until the extent of the potential bias in the wax-block estimates is known, we recommend that traps continue to be used as the main method to monitor possum abundance.

Introduction
Population monitoring of brushtail possums (\textit{Trichosurus vulpecula}) is an essential part of their management in New Zealand. More than NZ$40 million is spent each year to control possums (Cowan 2000), and managers need to know whether control operations have been successful at achieving the required population reductions. Additionally, because possum control is being increasingly carried out under contract, population monitoring has become an important part of the contract process, often determining whether control targets have been met and whether the contractor gets paid. Population monitoring also is an important component of wildlife research, allowing researchers to relate possum densities to impacts on conservation values, and to develop models relating possum density to incidence of diseases such as bovine tuberculosis (Barlow 2000).

Estimates of absolute abundance of wild animals are expensive to obtain and may be unnecessary for many pest-management decisions (Caughley 1977; Skalski and Robson 1992). Almost all monitoring of possum populations carried out in New Zealand has relied on relative abundance indices. Until recently, faecal pellet counts were used commonly to monitor possums (Baddeley 1985), but over the past five years, most population monitoring has been carried out using the number of possums captured in foothold traps set over three nights. Such catch-per-unit-effort models have been used to estimate population abundance of many species (Seber 1982; Pollock and Otto 1984). Batcheler \textit{et al.} (1967) first used the technique in New Zealand to estimate probability of capture for a possum on a specific trap layout. More generally, the number of animals associated with the trap line can be estimated using a removal model (Zippen 1956, 1958; Seber 1982), but the estimate assumes that capture probabilities do not vary nightly. However, the estimator fails for sampling carried out for three nights when the number of animals caught on Night 1 is less than the number caught on Night 3. Field data on possum trap captures show that this requirement is often not satisfied. A simpler approach, just using the percentage catch over three nights (e.g. 20 possums caught in 20 traps set for three nights = 33%) has therefore been used frequently, although little is known about how reliable such an index is for estimating relative possum abundance. This method is used to estimate population reduction (% kill) or
to index the size of the possum population surviving a control operation (residual catch) (NPICA 2000). Although the method is simple to use, it must be sufficiently accurate (i.e. unbiased and precise) to be useful to management.

One drawback of trap-catch monitoring is that it is labour-intensive, requiring field operators to carry packs of foothold traps through rough terrain. Recently, it has been proposed that possum numbers could be indexed by measuring the extent of interference with small cubes of paraffin wax impregnated with an attractive lure. The advantage of using wax is that tooth impressions left in the wax can be used to identify the species of animal biting the wax bait.

To determine whether trap-catch or bait-interference provided the most accurate estimates of kill, we assessed the size of potential biases in estimates of population reduction derived from trap-catch and bait-interference indices by comparing them with population-change estimates derived from possums fitted with mortality-sensing radio-transmitters. We also assessed how well the wax-block estimates of abundance were correlated with those obtained from using traps.

**Methods**

Eight monitoring operations were carried out, seven involving a deliberate reduction in possum numbers and one (Eyre) in the absence of deliberate reduction.

**Trap-catch monitoring**

Trap-catch monitoring involved placing 10 Victor No.1 foothold traps at 20-m spacing on 10 lines located throughout 800–1000 ha of forest. Traps were lured by placing a mixture of flour and icing sugar on the tree trunk behind each trap, set for three fine (no rain) nights, and checked daily. When checking the traps, we recorded whether a possum or non-target animal had been captured, whether the trap was still set, sprung, or had let a possum escape. After we completed a baseline survey (i.e. pre-control), the possum population was reduced either by an aerial application of baits containing 1080 poison (at Kaingaroa, Maramarua and Mangakahia) or by ground application of baits containing cyanide paste (at Coalgate, Geraldine, Mokaihaha, and Ngamu). Two to three weeks after the control operation, trap-catch monitoring was again carried out using the same protocol as for the baseline survey but with the post-control trap lines being 200 m from, and parallel to, the pre-control trampines.

For the analysis, traps that had clearly been sprung by an escaped possum (e.g. fur found on trap jaws) were treated as having caught a possum. If the trap was sprung with no clear evidence of cause, or if the trap had caught a non-target animal, a half trap-night was removed from the total number of trap-nights (Nelson and Clark 1973; Beauvais and Buskirk 1999).

**Wax-block monitoring**

The wax blocks were ice-cube-sized blocks of moulded wax, containing orange oil as a lure, and coated with wax containing a bright red dye to facilitate finding them on the forest floor. Each block was mounted on an ice-block stick, which enabled it to be set upright in the ground. Twenty blocks were set at 10-m spacing along lines that were established 200 m from, but parallel to, the pre-control trap lines (on the opposite side to the planned position of the post-control trap lines), and treated as an ‘experimental pair’. The wax blocks were left out over three fine nights and checked daily for possum interference. Any block that was interfered with was replaced, and the species that had bitten the block was recorded. An index of interference was calculated using the proportion of blocks interfered with on each line after one, two and three nights.

**Radio-collared possums**

In each trial block except Trial 8 (Eyre, Table 1), 48–50 possums were captured in Soft Catch foothold traps. These traps were distributed throughout the control block and were baited with peanut butter. This was done to avoid any potential aversion problems that might have arisen from using bait material or lures used in the control operations or in the trap and wax-block monitoring. Captured possums were collared with a mortality-sensing radio-transmitter. The transmitters emitted one pulse per second when the transmitter was moved, but after being stationary for 12 h the pulse rate changed to two pulses per second. When all radio-collared possums had been released, each was checked to ensure that the transmitter was operating. One week after the control operation had finished the radio-transmitters were rechecked and the proportion of functioning radio-transmitters with signals from apparently dead animals provided an estimate of the proportional reduction in the possum population. That is, failure of transmitters before the post-control follow-up was treated as uninformative censoring (Cox and Oates 1984). Because Trial 8 involved no deliberate reduction in the possum population, no possums there were fitted with radio-transmitters.

**Data analysis**

The estimate of kill ($\hat{k}$) from the two index methods was computed as:

$$\hat{k} = 1 - \frac{\bar{x}_2}{\bar{x}_1},$$

where $\bar{x}_1$ is the average value of the index computed from the sample of 10 lines from baseline monitoring and $\bar{x}_2$ is the average value of the index computed from the 10 lines monitored after control.

Comparisons between estimates obtained by the three kill-estimating methods were carried out using single-degree-of-freedom contrasts (Sauer and Williams 1989), each having a null Chi-square distribution (assuming that the parameters estimated, i.e. proportional reduction, have the same value). A composite test statistic was formed by summing the seven independent Chi-square statistics to form a seven-degree-of-freedom test also having a null Chi-square distribution. An estimate of the average discrepancy between the two index-based estimates of proportional population change and the radio-telemetry estimate was obtained by computing a weighted average of the difference between the pair of estimates at each site (treating Site 8 as a known reduction of zero), weighting by the inverse of the estimated sampling variance. For the wax-block estimate, the Trial 2 estimate (Kaingaroa) was omitted as both the radio-collars and the wax-block estimates had an estimated sampling variance of zero, because every collared possum was killed.

The asymptotic sampling variance of the estimate of ($\hat{k}$) is given by

$$\text{Var}(\hat{k}) = (1 - \hat{k})^2 \left( \frac{\hat{\sigma}^2}{s_1} + \frac{\hat{\sigma}^2}{s_2} + \hat{\sigma}_1^2 \hat{\sigma}_2^2 \rho \right),$$

where $\hat{\sigma}_1$ is the true sampling coefficient of variation of $\bar{x}_1$, $\hat{\sigma}_2$ is the true sampling coefficient of variation of $\bar{x}_2$ and $\rho$ is the true sampling correlation between the paired pre- and post-control monitoring lines. Estimates of the sampling variance were obtained by substituting estimated values for unknown parameters.
The estimated sampling variance of the proportional change in the possum population obtained by the radio-transmitters was obtained by assuming that the number of dead animals \(y\) out of the \(n\) fitted with transmitters was a binomial random variable with index \(n\) and probability \(\kappa\).

**Results**

Radio-transmitter-based estimates of the reduction in possum abundance at the seven sites where possum control was carried out ranged from 25% to 100% (Table 1). There was a reasonably strong linear correlation between the trap-catch and radio-transmitter estimates \(R^2 = 0.91, P < 0.001\) (Fig. 1) and a weaker linear correlation between the wax-block and radio-transmitter estimates \(R^2 = 0.66, P = 0.014\) (Fig. 2).

There was weak evidence of disagreement between the trap-catch and radio-transmitter estimates \(\chi^2_8 = 14.90, P = 0.06\). Stronger evidence of a disagreement between the two methods was provided by the estimate of the average discrepancy between the two estimates of \(-0.035\) (s.e. = 0.015), which indicates that trap catch gave a slightly smaller estimate of proportional population change than did the radio-transmitters. This effect was consistent across the trials, with six of seven trap-catch estimates of population reduction being smaller than the radio-transmitter estimates (Table 2).

In comparison, the composite test based on contrasts (excluding Trial 2, Kaiangaroa) of the wax-block estimates with the radio-transmitter estimates of proportional population reduction was not significant \(\chi^2_7 = 2.94, P = 0.89\). However, a 95% confidence interval for the average discrepancy between the wax-block estimates based on the estimated average of 0.041 (s.e. = 0.055) ranged between \(-0.067\) and 0.149. Thus, our data have insufficient power for us to rule out the possibility that wax-blocks lead to moderately smaller estimates of population change (i.e. discrepancies in the range \(-0.067\) to 0) or potentially larger estimates of population change (i.e. discrepancies in the range 0 to 0.149).

**Discussion**

The trap-catch and wax-block percentage-kill estimates were correlated with the estimates obtained from the mortality-sensing radio-transmitters. However, there was some evidence that the trap-catch index estimates underestimated percentage reduction (% kill) compared with the estimates based on radio-transmitters. Results for the

![Fig. 1](image1.png)

![Fig. 2](image2.png)

**Table 1. Possum-monitoring indices and proportional kill estimates (\(\kappa\)) obtained before and after control from three monitoring methods**

For radio-transmitters, \(n\) is the number of functioning transmitters at the time of post-control follow-up and \(y\) is the number of these that indicated a dead possum.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Type</th>
<th>Trap catch (\kappa) s.e.</th>
<th>Wax blocks (\kappa) s.e.</th>
<th>(n) ((y))</th>
<th>Radio-transmitters (\kappa) s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mangakahia</td>
<td>Aerial</td>
<td>0.394 0.113</td>
<td>0.743 0.257</td>
<td>48 (23)</td>
<td>0.479 0.072</td>
</tr>
<tr>
<td>2. Kaiangaroa</td>
<td>Aerial</td>
<td>0.971 0.017</td>
<td>1.000 0.000</td>
<td>41 (41)</td>
<td>1.000 0.000</td>
</tr>
<tr>
<td>3. Ngamu</td>
<td>Ground</td>
<td>0.748 0.116</td>
<td>0.908 0.092</td>
<td>52 (41)</td>
<td>0.788 0.057</td>
</tr>
<tr>
<td>4. Geraldine</td>
<td>Ground</td>
<td>0.820 0.037</td>
<td>0.659 0.341</td>
<td>49 (45)</td>
<td>0.918 0.039</td>
</tr>
<tr>
<td>5. Coalgate</td>
<td>Ground</td>
<td>0.699 0.057</td>
<td>0.659 0.341</td>
<td>48 (27)</td>
<td>0.563 0.072</td>
</tr>
<tr>
<td>6. Maramarua</td>
<td>Aerial</td>
<td>0.894 0.035</td>
<td>0.940 0.060</td>
<td>48 (45)</td>
<td>0.938 0.035</td>
</tr>
<tr>
<td>7. Mokaihaha</td>
<td>Ground</td>
<td>-0.113 0.146</td>
<td>0.389 0.073</td>
<td>44 (11)</td>
<td>0.250 0.065</td>
</tr>
<tr>
<td>8. Eyre</td>
<td>No control</td>
<td>0.064 0.264</td>
<td>-0.147 0.59</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
radio-transmitter trapping and by the trap-catch monitoring. The possum population that was trap shy, this component of the population before and after control would be more tenuous. Providing the trap-shy proportion was the same in the population before and after control (i.e. the control did not selectively remove one component of the population) then there are likely to be no biases from using foothold traps in the kill estimate obtained. However, if trapping was used as the control method, the assumption of constant trap-shy proportions before and after control would be more tenuous. A second possible bias could have resulted from using foothold traps to capture possums to radio-collar and to obtain trap-catch indices. If there was a proportion of the possum population that was trap shy, this component of the population would have been missed both by the radio-transmitter trapping and by the trap-catch monitoring. Such a bias would affect all three monitoring methods equally and therefore would not invalidate their comparison. A fourth possible bias is that the collared possums were unrepresentative of the population with respect to age and gender. No effort was made to balance the sex ratio of the collared possums, and there was no method available to age live possums. However, evidence from other research suggests that aerial 1080 operations do not differentially target specific age classes or one particular sex (Henderson et al. 1999). Consequently, we believe that the radio-collars provided unbiased estimates of the percentage kills.

When estimating percentage kill as part of a population manipulation, the experimental design should ideally include a non-treatment experimental control (Skalski and Robson 1992). This was not essential for this experiment because we were comparing the performance of the three indices rather than attempting to assess how each estimated the actual impact of the control operations. Nevertheless, changes in capture or wax-block interference probabilities between monitoring periods could have affected kill estimates, and Trial 8 was used to obtain an indication of how stable these probabilities might be. The results indicate that over a period of four weeks the trap-catch and wax-block interference rates did not change significantly, and, given that all monitoring was carried out within 4–6 weeks, it is unlikely that estimates were affected significantly by changes in capture and interference probabilities.

We conclude that the trap-catch monitoring method, as it is currently used to monitor relative possum abundance, appears to be sufficiently accurate to aid in managing these pests, with any bias being small. Thus, the quality of management decision-making will largely be determined by the precision of the estimates, which in turn is a simple function of the effort (sample size) that managers put into monitoring. The kill estimates based on the wax-block monitoring were less strongly correlated with the radio-transmitter estimates than the trap-catch estimates, although

<table>
<thead>
<tr>
<th>Trial</th>
<th>Trap catch</th>
<th>Wax blocks</th>
<th>P</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mangakahia</td>
<td>−0.085</td>
<td>0.134</td>
<td>0.53</td>
<td>0.264</td>
</tr>
<tr>
<td>2. Kaiangaroa</td>
<td>−0.029</td>
<td>0.017</td>
<td>0.09</td>
<td>0.000</td>
</tr>
<tr>
<td>3. Ngamu</td>
<td>−0.041</td>
<td>0.129</td>
<td>0.75</td>
<td>0.120</td>
</tr>
<tr>
<td>4. Geraldine</td>
<td>−0.098</td>
<td>0.054</td>
<td>0.07</td>
<td>−0.259</td>
</tr>
<tr>
<td>5. Coalgate</td>
<td>0.136</td>
<td>0.091</td>
<td>0.14</td>
<td>0.097</td>
</tr>
<tr>
<td>6. Maramarua</td>
<td>−0.043</td>
<td>0.049</td>
<td>0.38</td>
<td>0.003</td>
</tr>
<tr>
<td>7. Mokaihaha</td>
<td>−0.363</td>
<td>0.160</td>
<td>0.02</td>
<td>0.139</td>
</tr>
<tr>
<td>8. Eyre</td>
<td>0.064</td>
<td>0.264</td>
<td>0.81</td>
<td>−0.147</td>
</tr>
<tr>
<td>Weighted mean</td>
<td>−0.035</td>
<td>0.015</td>
<td>0.041</td>
<td>0.055</td>
</tr>
</tbody>
</table>

For the wax blocks, the reported P-value is the significance level of the one-degree-of-freedom contrast between the index-based estimate and the radio-transmitter estimate.
these were still significant. Additionally, the average bias in the wax-block estimates, although not large (4.1%), had a large error and could therefore be potentially biased significantly high or low.

For all monitoring except for one post-control survey, the wax-block percentage interference was consistently less than the percentage catch from the traps. This would suggest that, at a lesser density, wax blocks are more likely to become insensitive to the presence of possums, although there were insufficient data to confirm that wax-block estimates would become zero when traps were still detecting at least some possums. Even though the wax blocks had lesser percentage takes than the catches in traps, the coefficients of variation were similar for both monitoring methods, which suggests that there was no loss of precision when using wax blocks. Because wax blocks are light and easy to put out, more wax-block lines could be established per day than trap lines and therefore the resulting estimates of possum abundance could be more precise than those obtained from trap lines. However, until the extent of the potential bias in the wax-block estimates is known, we recommend that traps continue to be used as the main method to monitor possum abundance.

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