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Applying the 3Rs (Reduce, Refine, and Replace) to Vertebrate Pest Control in New Zealand

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ABSTRACT: New Zealand has many invasive vertebrate species that adversely affect native biota, compete with livestock, and spread diseases. Large-scale management of the most critical pests is achieved mainly by lethal control. This includes aerial application of the controversial toxin sodium fluoroacetate (1080), despite vociferous opposition from those concerned about potential non-target deaths, environmental contamination, and animal welfare impacts. We have borrowed a framework from animal welfare science, namely the '3Rs' (reduction, refinement, and replacement), to address some of the concerns about the use of aerial poisoning while sustaining its cost-efficiency. The first aim was to reduce the amount of toxin used so that undesirable non-target impacts are minimised. A range of projects have: 1) developed a method to identify the high-risk habitat within a landscape that needs to be targeted and, equally importantly, the low-risk habitat over which toxic bait does not need to be sown; and 2) optimised the combinations of prefeeding, sowing rate, and bait distribution to achieve the desired percentage kills at the lowest cost and lowest sowing rate of poison bait. To address the second aim, refining toxin use, we have improved target specificity by developing repellents to minimise unintended bykill of non-target species such as deer, and by identifying long-term strategies that minimise the total number of animals killed. The final aim, replacement of 1080, focuses on the search for alternatives, such as fertility control. It also involves development of complementary tools, such as tuberculosis vaccines, that may reduce the frequency or need for repeated use of 1080. This integrated '3Rs' approach has quickly led to changes to operational practice by management agencies, with some operations now using up to 92% less toxic bait than usual, and other operations switching from aerial 1080 poisoning to ground-based non-1080 approaches for ongoing control. Looking forward, the '3Rs' approach offers a framework for continuous improvement in the use of control tools for a wide range of species, whilst also providing a clear pathway to complementary or alternative approaches.

KEY WORDS: 1080, animal welfare, baiting strategies, bovine tuberculosis, framework, invasive species, New Zealand, pest control

INTRODUCTION

New Zealand has a wide range of invasive vertebrates that impact on biodiversity values through predation and herbivory, and impact livestock health through acting as vectors of disease such as bovine tuberculosis (King 2005). Because of the scale of the problems, management of the most critical pests requires the ongoing implementation of lethal control programmes, some of which include the widespread application of vertebrate pesticides and aerial delivery, particularly of sodium fluoracetate (1080) (Morgan and Hickling 2000). The proposed implementation of large-scale aerial application of this toxin has often provoked public opposition from some sectors of society.

Different sectors of society focus on different concerns, with hunters opposing aerial application of 1080 vociferously because of the bykill of deer (Austin et al. 2008), even though these species are also introduced and pose a threat to biodiversity values. Others focus on the welfare impacts of the poison (Sherley 2007) or contamination of waterways (Weaver 2003). To address such concerns is challenging, but one approach is to place the toxin only where it is needed, apply no more toxin than needed to put the target species at risk, and to apply strategies that minimise the number of animals killed. This approach mirrors the '3Rs' framework (Reduction, Refinement, Replacement) that was developed to minimise the number of animals used in research ex-periments (Russell and Burch 1959, Littin and Mellor 2005).

The vertebrate pest in New Zealand on which most control funds are spent is the introduced brushtail possum (*Trichosurus vulpecula*), with about US$35 million dollars spent annually by the Animal Health Board alone to manage this species as a vector of bovine tuberculosis (AHB 2009). About 9 million ha is under control for tuberculosis (Tb) management, with most of this area being treated annually or biennially by ground-based control and the remainder treated using aerial application of 1080 at 5-year intervals. Ground-based control uses traps and poisons such as cyanide, cholecalciferol and anticoagulants (Morgan and Hickling 2000).

The strategic approach taken by the Animal Health Board is based on theoretical modelling (Barlow 1991, 2000) and empirical trials (Caley et al. 1999), and requires possum populations to be reduced to and maintained at low numbers until Tb is extirpated locally.

Current best practice applied to achieve the desired biodiversity or animal health outcomes is often based on experience of what works, which may be quite different from what works while at the same time addresses public concerns (Wilkinson and Fitzgerald 2001). Applying the '3Rs' approach to vertebrate pest control requires a welfare equation to be minimised. Total welfare cost can be accounted for in the following equation:

$$WC_{Total} = (WC_{TL} \times N) + (WC_{TSL} \times N) + (WC_{NTL} \times N) + (WC_{NTSL} \times N)$$

where:
WC_{TL} = welfare cost to target species that are killed
WC_{TSL} = welfare cost to target species that are sub-lethally poisoned or otherwise affected by the control method
WC_{NTL} = welfare cost to non-target species that are killed
WC_{NTSL} = welfare cost to non-targets that are sub-lethally poisoned or otherwise affected by the control method
N = the number of animals in each of these categories.

Clearly, minimising total welfare cost ideally requires each of these components to be minimised. This paper reports how some recent research might be used to do that and, at the same time, to reduce toxic bait application rates (which produces savings in the quantities of toxins being applied to the environment, as well as operational costs).

REDUCTION
Eliminating Low Disease-Risk Areas from Aerial Sowing

Because possums are not distributed uniformly across a landscape, the density of possums in some areas can be too low for the continued cycling of Tb infection. Consequently, such areas could be excluded from control operations without compromising disease control goals and while using significantly less toxin. To test this hypothesis, relative possum density on an 183,000-ha area of South Island high country was surveyed using a trap-catch index (TCI) (NPCA 2008) on 42 river-to-ridgeline transects. Environmental factors such as altitude, slope, aspect, and vegetation cover at each trap site were recorded and EcoSat imagery (Dymond and Shepherd 2004) was used to categorise the total land cover over the area into approximately 25 classes (Byrom et al. 2008).

Combined with four digital datasets, as follows:
- EcoSat (Landcare Research) (Dymond and Shepherd 2004)
- Land Cover Database (Land Cover Database2, Land Information New Zealand)
- Land Environments of New Zealand database (Land Environments NZ, Landcare Research) (Leathwick et al. 2003)
- New Zealand Digital Elevation Model (Digital Elevation Model, Landcare Research),

these data were used to characterise the distribution and relative abundance of vegetation types across the area, and to determine the relationship between the TCI and vegetation type. This relationship was then used to predict possum abundance for the whole area (Byrom et al. 2008).

A predicted TCI map was generated using a program developed jointly by Landcare Research and Massey University, which had raster inputs of EcoSat land cover clusters, height above the valley floor, Land Environment New Zealand 130 classification, mean annual temperature, and a grid size of ~1.8ha. Predicted TCI was categorised into 6 classes (0 - 1% TCI; 1 - 2%; 2 -

5%; 5 - 10%; 10 - 20%; and >20%) that usefully relate to the targets routinely used to assess the effectiveness of possum possum control, and these were projected over the Digital Elevation Map to produce a 3-D map (Figure 1).
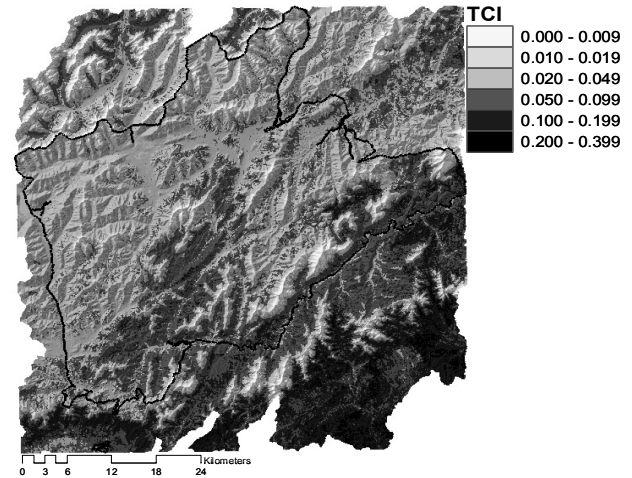

Figure 1. Predicted distribution of possum trap catch index (TCI) within 15 × 15-m pixels at a site in the South Island high country (from Byrom et al. 2008). **The TCI are presented here as proportions but are more usually expressed as percentages.**

The map of predicted TCIs was used to assess what parts of the area could be left out of an aerial 1080 poisoning operation proposed for the easternmost 28,000-ha part of the area in 2008, based on those parts having the lowest risk that the possum population in them could sustain Tb. Based on animal-based stochastic simulation, Ramsey and Efford (2005) recommended that to eliminate Tb from possums, areas with an initial TCI <15% needed to have TCIs reduced to ≤5%. Large parts (30%) of the 28,000-ha area were already below 5% TCI (Figure 1), so in principle these could be excluded from the area poisoned with little risk of failing to eliminate Tb (Nugent et al. 2009). Because the Ramsey and Efford (2005) model also predicts that Tb is rarely able to persist in areas with TCIs <10%, these could also be excluded with only a small increase in the risk of Tb persisting. This would decrease the area needing aerial 1080 treatment by up to 73%. Such reductions in treatment area offer the potential to reduce significantly both the amount of 1080 being applied to the environment and costs, while also reducing the numbers of animals killed and therefore the total welfare cost.

A similar approach is now being applied to ground-based control where possums have been reduced to very low numbers, and survivors persist as isolated individuals or as small groups, and most habitat has no possums. Here, non-toxic detection devices (WaxTags[®] and ChewTrack Cards) are being used to detect where surviving possums are located, so control effort (both traps and poisons) can be restricted just to places with positive detections, rather than across the whole landscape (Sweetapple and Nugent 2008). This strategy is currently being tested to compare the efficacy and costs

of using an informed approach and targeted control with current practice, where control is applied essentially uniformly.

Reducing the Sowing Rate of 1080 Baits

Sowing rates of aerial 1080 baiting has declined from 20kg/ha in the 1970s to current best practice of about 2-3kg/ha (Morgan et al. 1997, Brown and Ulrich 2005). Notwithstanding such a significant decrease in sowing rates, the density of the target pests (perhaps 20 possums/ha at most) suggests that even 2kg/ha of bait (i.e., about 166 12-g baits each delivering a lethal dose) is still excessive, and there is potential to reduce sowing rates even further. A series of trials were therefore established to identify what key factors of an aerial 1080 operation constrained further reductions in sowing rates (Nugent et al. 2009, Warburton et al. 2009). The interaction between bait fragmentation and sowing rate was identified as a critical factor in determining whether possums encountered and ingested a lethal quantity of bait before the onset of toxicosis (about 40-60 mins) (Littin et al. 2009). If bait sowing rates were low and fragmentation occurred, for example, there was a high probability that a possum would encounter a bait fragment, ingest a sublethal dose, not find a second bait or fragment before the onset of toxicosis, survive, and develop bait/poison shyness. Our proposed solution to this problem was to sow bait in high density strips or clusters, rather than the current best practice of broadcast sowing bait uniformly across the operational area. The rationale was that even if bait fragmented, the density of bait in the strips or clusters was sufficiently high that possums would still be able to quickly find more than one bait or fragment. The sowing rate of baits could then be reduced, without reducing the probability that possums could find sufficient baits to ingest a lethal dose. Initial field trials showed that acceptably high kills could be achieved with a prefeed of non-toxic baits followed by sowing toxic baits at only 0.4kg/ha (Table 1). Further trials testing sowing rates as low as 0.25 kg/ha have now been completed with the percentage kills achieved sometimes equivalent to those obtained using the current best practice of 2-3 kg/ha (G. Nugent, pers. commun.).

In welfare terms, this research has the potential to reduce the number of sublethally-poisoned possums, albeit at the cost of initially increasing the total number killed the first time an area is poisoned. As a result of that, however, there are fewer possums present producing offspring that have to be controlled at some future time, so the average annual number killed in a long-term sequence of control operations is lower.

Table 1. The residual abundance (interference index) obtained from applying two sowing rates with and without prefeed.

Treatment	Residual Abundance
Aerial prefeed + aerial broadcast toxic @ 2kg/ha	0.0%
Aerial broadcast (no prefeed)	3.1%
Ground applied prefeed + toxic @ 0.4kg/ha	0.0%
Ground applied toxic @ 0.4kg/ha	17.7%

REFINEMENT
Minimising Kills

If a pest population is reduced to and maintained at or below a target density, that density and the frequency with which control is repeated dictates the numbers of animals being killed. Initial modelling by Barlow (1991) suggested that if Tb-infected possum populations in which Tb was well established and widespread were reduced to 50% of their carrying capacity (K) and maintained at that level, then Tb would be eliminated after 20 years. Modelling by Ramsey and Efford (2005) showed that if Tb-infected possum populations were reduced to a residual density equivalent to a 2% trap-catch and maintained at that level, then Tb would almost always be eliminated in 6-7 years. The Animal Health Board implements this strategy using both aerial and ground-based control operations. Ground-based operations are generally applied annually and aerial operations every 5 years, with an expectation that after 3 such aerial operations over 10 years, the disease will be eliminated.

We determined which of three possible strategic options generated the minimum number of animals killed over the length of the strategy (and therefore which strategy could be considered the most ethically defensible) (Figure 2) using a computer model (Model-Maker 5, Cherwell Scientific Ltd., Oxford, UK) based on logistic growth and values for maximum rate of increase (r_m), carrying capacity (K), percentage kill for initial and maintenance operations, and control costs as listed in Table 2.

Table 2. The parameter values used in modelling three possible control strategies. Parameter values for K and r_m from Efford (2000). Percent kill and cost values are in the typical range obtained for control operations.

Parameter	Value
Carrying capacity (K)	10
Maximum rate of increase (r_m)	0.3
Percentage kill for initial aerial operations	95%
Percentage kill for maintenance aerial operations	65%
Percentage kill for initial ground operations	90%
Percentage kill for maintenance ground operations	25%
Aerial control costs ($NZ/ha)	$30
Ground control costs ($NZ/ha)	$25

The three strategies were modelled, and each predicted the elimination of Tb from possum populations, but over different periods that determined the expected life-span of each strategy (Ramsey and Efford 2005). Comparison of the cumulative kills over the term of each strategy showed that maintaining the population at about half the carrying capacity resulted in many more animals being killed during the period in which control was applied than either of the other two strategies (Figure 3). This example shows how simulation can be used to identify in advance which strategies will result in the lowest number of animals killed.
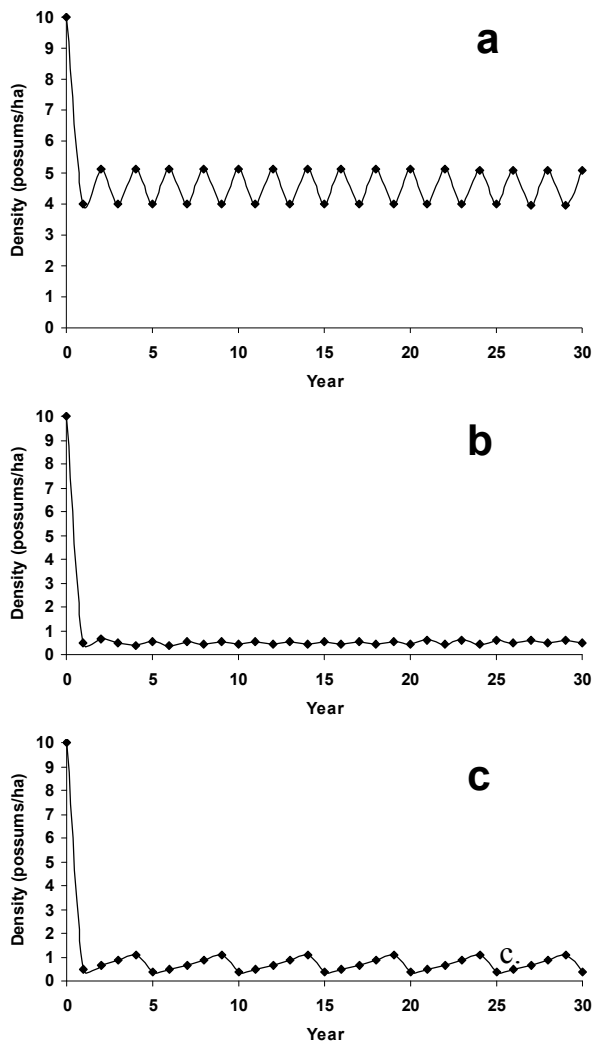
Figure 2. Predicted possum densities resulting from modelling of the application of three strategies, with the initial starting density (K) of 10/ha. a) Maintenance at 50% K; b) Annual maintenance below a 2% TCI; c) Aerial control every 5 years.
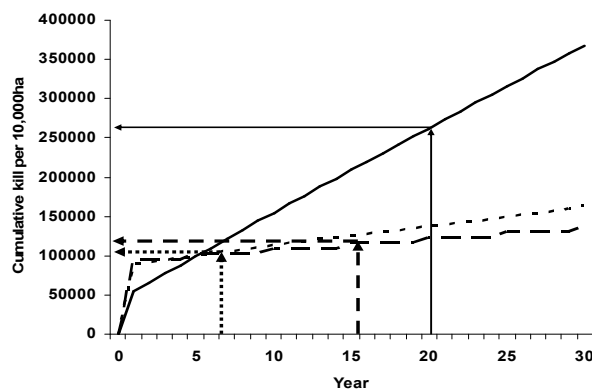

Figure 3. The cumulative kills from three strategies modelled. The duration of each strategy (i.e.; the time required to be confident of Tb eradication) is denoted by the arrows.
Maintenance at 50% K = solid line;
Annual maintenance control below 2% CI = dotted line;
Aerial control at 5 yearly intervals - dashed line

REPLACEMENT

Research to improve the way conventional controls are used does not address the view that reliance on lethal controls should be reduced and use of non-lethal controls increased (McLeod et al. 2007). A programme of research has been focusing on the development of fertility control vaccines for possums based on zona pellucida antigens (Duckworth et al. 2007). This programme of work has progressed to the stage of testing experimental vaccines containing possum zona pellucida proteins that reduce the fertility of captive female possum by 30-40% when the vaccine is orally delivered (as in a bait) or nasally delivered (as an aerosol spray), using a non-living bacterial ghost vaccine delivery system (Walcher et al. 2008). The same antigens had no effect on fertility when injected into mice or chickens, so they appear to be specific for possums (Duckworth et al. 2008). Further research is underway to develop single-dose oral vaccines that are effective in at least 60% of female possums for at least two breeding seasons.

For disease management, lethal control could be replaced by vaccination, and this approach has been investigated for possums and Tb using the live Bacillus Calmette-Guérin (BCG) vaccine developed long ago for humans. Large-scale application of vaccines to wild animals requires oral delivery, but the BCG bacillus is killed by stomach acids. To overcome that, New Zealand researchers have developed an edible lipid matrix to protect the BCG bacilli as that matrix passes through the stomach, and a recent field trial showed that oral vaccination of free-ranging possums with lipid-borne BCG significantly reduced Tb infection rates in possums, with vaccine efficacy estimated to be about 95% (Tompkins et al. 2009). As a consequence of this success, two possible options for using vaccines have been identified. The first is to integrate vaccine delivery with poison baits, so most possums will be killed but survivors will encounter vaccine bait and become vaccinated against the disease (G. Nugent, pers. commun.). The second option is to use vaccinated possums in a buffer, rather than killing them. For this, the density of possums remains at carrying capacity and potentially acts as a "social fence" to potentially dispersing infected animals (Pech et al. 2010). Clearly, use of a vaccine incurs far lower welfare costs than does lethal control.

DISCUSSION

The framework provided by the principles of the '3Rs' has enabled an integrated programme of research to be developed that has led to changes to operational best practice, and has delivered not only improved cost-effectiveness but also reduced welfare costs. Some recent aerial control operations against possums and rodents have used up to 80% less toxic bait, and ground control operations are using fewer traps or toxic baits because control is only applied where surviving pests are first located by detection surveys. Future work plans to test the application of aerial thermal infrared sensing such as FLIR (Drake et al. 2005) to detect the presence of pests, so control can be targeted to those areas of greatest priority.

Using "reduction" as a driver for improvement, we have developed a new approach to control that integrates both spatially-targeted control and a low-sow bait application strategy, both of which have resulted in control being more ethically, environmentally, and economically defensible. We are now using a similar approach to refine aerial application of toxic baits for rabbit (*Oryctolagus cuniculus*) control.

The process developed to identify strategies that kill the least animals will be extended to determine the optimal strategies for managing irruptive species such as rodents, and for production pests such as wallabies. Further out, when fertility control agents and vaccination tools become available, they too will be integrated into the tool-box as potential alternatives for some of the current suite of broad-spectrum toxins. Together, these approaches will help address current concerns about aspects of pest management held by some sectors of society, by reducing the overall welfare and environmental costs of animal pest management in New Zealand.

Although the '3Rs' approach has become embedded in the animal ethics approval process for research projects, we believe the same philosophy can drive improvements in pest management by continually challenging management and its underpinning science to reduce, refine, and replace what is current best practice, but what can always be improved on.

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