



Dual 1080 bait switching for killing cereal-bait-shy possums

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Abstract: To help develop new tactics for the local elimination of possums using a fast-acting toxin (1080; sodium fluoroacetate), we tested whether possums that had survived a cereal 1080 baiting could be poisoned with an alternative peanut butter paste (PB paste) bait that differed greatly in appearance, texture, smell, and taste. A two-stage field trial was undertaken in 2018 in three 50–80 ha study blocks in mature pine forest near Rotorua. All three blocks were baited with hand-laid cereal 1080 baits without first pre-feeding with non-toxic cereal bait, and then baited again 49 days later with hand-laid 1080 PB paste. All three blocks were baited ('pre-fed') with non-toxic PB paste at some time before toxic PB paste was deployed: one block before the cereal 1080 baiting, one block after, and one block both before and after. The non-pre-fed cereal 1080 baiting killed 72.4% of 134 radio-collared possums. Subsequent trail camera monitoring of freshly deployed non-toxic cereal baits recorded 31 visits by possibly half of the 19 radio-collared possums that had survived the 1080 cereal baiting but did not record any bait consumption by them, indicating likely bait aversion. The PB-paste baiting killed 22 of 24 (92%) radio-collared survivors of the cereal 1080 baiting. The two survivors not killed had not been pre-fed before the cereal 1080 baiting. These results indicate that switching to a different bait type can effectively target survivors of current best practice operations, and hints that pre-feeding with the different bait type may be most effective if it is conducted before the possums are exposed to any form of 1080 bait. The finding provides a new tactic that could help achieve complete local elimination of possums through the novel use of tools that are already available.

Keywords: 1080, bait aversion, bait switching, eradication, local elimination, pre-feeding, possum, *Trichosurus vulpecula*

Introduction

The Australian brush-tail possum (*Trichosurus vulpecula*) is an important invasive species pest in New Zealand, and major efforts have been made to reduce the threats it poses to native species conservation (Byrom et al. 2016), and to the beef, dairy, and deer industries that stem from possums being the major wildlife host of bovine tuberculosis (TB) (Nugent et al. 2015). New Zealand's aspirational goals of being completely free of possums by 2050 (PF2050 2016) and of TB by 2055 (OSPRI 2017) are likely to be made much simpler if possums can be eliminated from large forested areas in a single aerial poisoning operation (albeit one possibly involving multiple baitings). Single-operation eradication has already been achieved using an anti-coagulant toxin (brodifacoum; Speedy et al. 2007) but because of long residue persistence times in non-target species that toxin cannot be used on public conservation land (DOC 2000).

Aerial 1080 (sodium fluoroacetate) baiting can deliver extremely high kills, with 100% reductions in low-precision indices of possum abundance (i.e. leg-hold traps) recorded as far back as the early 1990s (Brown & Arulchelvam 1995).

The use of multiple non-toxic pre-feeds, large uniformly sized baits, high baiting rates, GPS guidance, and broadcast baiting systems appears to ensure every possum encounters 1080 bait, and this approach can achieve very high percentage kill rates (% kill). For example, in 2016 we recorded a 99.6% kill of 243 radio-collared possums in an 80 000 ha area of forest after a mostly twice-pre-fed single sowing of 12 g 1080 cereal bait (Nugent et al. 2017). However, there are, as yet, no reports of large-scale local elimination: two years after the operation mentioned above, possums remained detectable at three of four spatially separate intensively monitored areas (each 525 ha; P. Sweetapple, unpubl. data).

Since 2015 we, and others have investigated whether two sowings of toxic 1080 bait in quick succession, variously termed '1080-to-Zero' (ZIP 2018) or 'Dual 1080' (Nugent et al. 2019), might be even more effective. The concept is based on the premise that a few possums will always survive a single 1080 baiting because 1080 is a relatively fast-acting toxin that sometimes acts too quickly for all possums to find and consume a lethal dose. Captive possums typically show clinical signs of feeling unwell less than two hours after ingesting a lethal dose (Littin et al. 2010) and lose their

appetite for a preferred food (apple) even sooner (averaging 41–69 minutes depending on dose; Henderson et al. 1999). If a possum ingests a substantial, but still sub-lethal dose of 1080 within that short ‘pre-toxicosis’ window, it survives but develops a strong and long-lasting learned aversion to the bait used to poison it (Morgan et al. 1996; Moss et al. 1998; O’Connor et al. 1999; Ogilvie et al. 2000; Ross et al. 2000). The survival of some possums cannot be attributed to possums simply not encountering bait or refusing to eat the bait type sown, as possums have been successfully eradicated from a 3400 ha predator-proof fenced area by aerial baiting alone using a cereal bait matrix similar to that used in aerial 1080 baiting, but with a different, slower-acting toxin (the anticoagulant brodifacoum; Speedy et al. 2007). The problem seems to be that a small number of possums survive (and become bait averse), perhaps largely by chance, for a variety of reasons such as lack of appetite through satiation with other foods, or as a result of illness; competitive or other social interactions with other possums; behaviour that reduces the chance of encountering bait (e.g. nesting and foraging predominantly in the canopy), or bait fragmentation during sowing (Nugent et al. 2010).

In a 2016–2017 trial using Orillion RS5 cereal bait, we showed that bait-averse ship rats (*Rattus rattus*) could be killed by changing the RS5 bait type slightly for the second 1080 baiting (by surface-coating it with a proprietary deer repellent that changed the appearance and smell of the bait), and by pre-feeding survivors twice before conducting a second 1080 baiting five months after the first (Nugent et al. 2019). In contrast, the effectiveness of the second baiting in killing cereal-bait-shy possums was low: indices of possum activity actually increased after the second baiting. However, somewhat serendipitously, bait-shy possums in that study continued to be attracted to and feed on a peanut butter (PB) lure incorporated in chew-card detection devices (Sweetapple et al. 2011) used to monitor possum and rat abundance before and after the 1080 baitings. It was not clear whether acceptance of that lure reflected the marked difference in appearance, smell, taste and texture of the PB paste from the cereal 1080 baits used on the trial, or because possums had been exposed to, and become familiarised with, the PB paste before they were ever exposed to 1080 (Nugent et al. 2019). Here we address that uncertainty in a follow-up trial, and show that by drastically changing the bait type (from cereal pellet to PB paste) and also pre-feeding with the second bait type, either before or after 1080 baiting with the first bait type, the bait aversion problem in surviving possums can be largely overcome or at least circumvented.

Methods

Study site and treatments

This study was conducted in mid-2018 in a mature c. 20 year old *Pinus radiata* pine plantation 10 km southwest of Rotorua. The mixed, open understorey mostly comprised a low fern cover (mostly *Blechnum* spp.) and occasional native or non-native woody shrubs. The area has not been subject to formal possum control, but had previously been subject to possum trapping for fur. In early May 2018 an exploratory survey along 10 transects spanning the study area, each with 10 chew cards (Sweetapple et al. 2011) spaced 50 m apart and containing 3–5 g of aniseed-lured possum dough (Pest Control Research Ltd.), produced a seven-night chew-card index (CCI₇) of 89%, indicating a moderate-to-high possum density. Rats were also present in moderate numbers (CCI₇ = 59%), and field observations indicated that wallabies (*Macropus eugenii*) were also present.

Three study blocks, each 50–80 ha with buffer zones of at least 300 m and usually 500–800 m wide between them, were established, and each was subject to the same dual 1080 baiting treatment, comprising an initial 1080 baiting with the conventional cereal bait used for aerial poisoning, followed by a second 1080 baiting with a PB paste bait currently registered for ground-based poisoning (‘Pestoff Exterminator paste’; Orillion, Whanganui, New Zealand), but with a different non-toxic PB paste pre-feed regime in each block (Table 1). The PB paste pre-feed was applied only before the cereal baiting in one block, only after it in a second, and both before and after it in a third (Table 1).

The purpose of the initial cereal 1080 baiting was, effectively, to deliberately create a population of survivors with a learned aversion to cereal bait, so we did not attempt to familiarise the possums with that bait type ahead of the first toxic baiting (i.e. we did not use cereal pre-feed), and we used the 6 g baits typically employed when both possums and rats are targeted for conservation purposes (Brown et al. 2015) rather than the 12 g baits typically used in possum control for TB management (Warburton et al. 2015). Animal Ethics Committee approval was obtained for this experimental approach (Manaaki Whenua – Landcare Research [MWLR] AEC 18/04/02). The cereal bait (cinnamon-lured RS5 cereal baits, ‘0.15%’ 1080; Orillion, Whanganui, New Zealand) was distributed along 800–900 m transects spaced about 100 m apart by hand-broadcasting at 1 kg ha⁻¹, with field staff throwing a handful of approximately eight baits sideways on alternate

Table 1. Description of the three baiting regimes.

Baiting regime	PB paste pre-feed treatment		
	Block 1 Pre- & post-1080 cereal	Block 2 Post-1080 cereal only	Block 3 Pre-1080 cereal only
Pre-feed (PB paste bags, non-toxic, 0.4 kg ha ⁻¹ ; 7 June)	□	×	□
First 1080 baiting (6 g RS5 pellets, 0.20% 1080, 1 kg ha ⁻¹ , 22 June)	□	□	□
Pre-feed (PB paste bags, non-toxic, 0.4 kg ha ⁻¹ ; 18 July)	□	□	×
Second 1080 baiting (PB paste bags, 0.11–0.16% 1080, 0.4 kg ha ⁻¹ ; 10 August)	□	□	□

sides every five paces. Later assay of a single sample of bait indicated a 0.20% concentration of 1080.

The PB paste 1080 bait, nominally containing 0.15% 1080, was loaded into biodegradable bait bags (c. 20 g bag⁻¹) and distributed 7 weeks later along the same transect lines at c. 0.4 kg ha⁻¹ (20 bags ha⁻¹, with two bags stapled either side of a tree at about 10 m intervals). Assay of three bait samples returned concentrations of 0.11%, 0.14%, and 0.16%. Non-toxic PB paste was similarly distributed before and/or between the 1080 baitings (Table 1).

Assessment of possum kill

The effectiveness of both 1080 bait applications was assessed by measuring the survival of possums fitted with mortality-sensing radio collars before the first 1080 baiting. For this, about 100 leg-hold traps were deployed in the 30–40 ha central area of each block at c. 25 m intervals (at sites thought most likely to be used by possums) along trap lines spaced 100 m apart. Traps were lured with flour at deployment, left unset for several nights, then set for the next 2–4 days between 28 and 31 May.

In total, 184 possums were captured across 847 trap nights. Excluding the fourth night of trapping, the three-night trap catch index (TCI) was 23%, suggesting a density of four to five possums per hectare based on trap-modelling predictions (Ramsey et al. 2005). Under MWLR's Animal Ethics Committee approval 16/05/01 "Mark and recapture of possums for Landcare Research projects", injured possums or those too small to radio collar were killed or released, and the remaining adult possums captured were sedated by intramuscular injection of Zoletil at 5 mg kg⁻¹ of possum weight (Morgan et al. 2012), fitted with VHF radio collars with motion-cessation ('mortality mode') signalling and time-since-death functionality (Sirtrack Ltd, Havelock North, New Zealand), and then released.

Of the 150 possums radio collared (91 females, 59 males), nine were not relocated or were only relocated outside the study areas, and seven were dead or had lost their collars before the cereal 1080 baiting on 22 June 2018. Radio-tracking was conducted on 5 and 8 June 2018, and then again in the week before and after each of the two 1080 baitings. The number of survivors and the efficacy of control (possum percentage

kill; % kill) in each block was assessed from the numbers of possums confirmed as still alive in each block at various times after each 1080 baiting compared to the number believed to be alive and present in the poisoned areas at the time of the particular 1080 baiting. A 95% binomial confidence interval around each estimate of % kill was calculated, with a continuity correction as per Newcombe (1998), and the differences in % kill were statistically tested using 2 × 2 contingency tables (Fisher's exact test).

Confirmation of cereal bait aversion

To help assess the possibility of bait aversion, 56 trail cameras (Browning Strike Force HD Pro, set to take a burst of four still images when triggered, with a 10 second delay between bursts) were deployed in mid-July for about three weeks in the two blocks pre-fed only once with non-toxic PB paste. A single undyed non-toxic cereal bait was nailed (through a hole drilled through the centre of the bait) to a tree within the field of view and about 2.0–2.5 m from the camera. This undyed bait differed from the toxic cereal bait in colour (and absence of 1080). From the images collected, the number of separate possum visits to each camera site was determined (a visit being a set of possum images separated in time by more than an arbitrary period of five minutes from any other possum image), and each visit was categorised according to whether or not the possum approached the bait, and whether or not it consumed the bait. Unfortunately, a substantial proportion of images were overexposed and the outcome of some possum visits could not be determined. In addition, some baits were removed by rats, and others were somehow removed without the event being recorded.

Results

Possum mortality following initial cereal 1080 baiting

Overall, 72.4% of the 134 possums confirmed still alive and present in the study area at the time of the first 1080 baiting died within four nights of the 1080 bait being laid (Table 2a). There was no indication that PB paste pre-feeding affected % kill with cereal bait within the first few days after baiting, as there was no significant difference between the % kill in the

Table 2. Mortality of radio-collared possums following cereal 1080 baiting as recorded (a) soon after baiting and (b) a month after baiting. For (a), nine of the original 150 possums were not relocated or were only relocated outside the study areas, and seven were dead or had lost their collars. For (b), a further three possums could not be relocated at or after that time point, and one was alive but well outside the block. Those four possums excluded, the totals in (b) include all the possums in (a).

Block number & treatment	n	n killed (%)	95% CI
(a) 4 nights after baiting			
1. PB paste pre-fed after first 1080	41	26 (63.4%)	46.9–77.4%
2. PB paste pre-fed before first 1080	46	32 (69.6%)	54.1–81.8%
3. PB paste pre-fed before and after first 1080	47	39 (83.0%)	68.7–91.9%
All	134	97 (72.4%)	63.9–79.6%
(b) 33 nights after cereal 1080 baiting			
1. PB paste pre-fed after first 1080	40	30 (75.0%)	58.5–86.8%
2. PB paste pre-fed before first 1080	45	36 (80.0%)	65.0–89.9%
3. PB paste pre-fed before and after first 1080	45	39 (86.7%)	72.5–94.5%
All	130	105 (80.8%)	72.7–86.9%

block that had not been pre-fed with PB paste (63.4%) and in the two blocks combined that had been pre-fed (76.3%) (Fisher's exact test, $P = 0.14$).

One month (33 nights) later a further eight (21%) of the surviving 37 possums had died. Given the longer time between the cereal 1080 baiting and this mortality assessment, there is greater potential for some unknown small proportion of these deaths to have resulted from factors other than 1080 (i.e. died naturally during the one-month period). However, if they were all killed by 1080, the overall % kill increased to 80.8% (Table 2b). Again, the difference between the not-PB-paste-pre-fed and the PB-paste-pre-fed blocks combined was not significant (Fisher's exact test, $P = 0.33$).

Cereal bait aversion

Possums were recorded on 50 of the 56 trail cameras deployed 3 weeks after the first (cereal) 1080 baiting to monitor possum interactions with a non-toxic cereal bait nailed to a tree within the field of view of each camera. Possums approached the bait to within about 0.5 m at each site during 80 (38%) of the 208 possum visits recorded, but consumed bait during only five (2.4%) of those visits. Among the 208 recorded visits, there were 31 visits by radio-collared possums recorded across eight camera different sites (with at least two collared different possums at three of those sites), possibly representing up to about half the 19 radio-collared possums known to still be alive at that time in the two blocks monitored. No bait was seen to be consumed by the radio-collared possums.

Possum survival after the second (pre-fed PB paste) 1080 baiting

Of the 25 possums still alive 33 days after the cereal 1080 baiting (Table 2b), one could not be subsequently relocated. Following the second (PB paste) 1080 baiting, 22 (92%) of the remaining 24 possums were killed, all within 72 hours. For the 20 with functioning movement sensors, movement ceased on average 17 hours after sunset on the day bait was laid (10 August; range 1–28 h, 17 in less than 24 h). All of the 14 possums in the blocks pre-fed with PB paste either before (nine) or both before and after (five) the first (cereal) 1080 baiting were killed. Although two of 10 possums did survive in the block that was pre-fed only after the first 1080 baiting, the % kill (80%) for the second (PB paste) baiting in that block did not differ significantly from the 100% kill in the other two blocks combined (Fisher's exact test, $P = 0.16$).

The overall combined kill for the 129 possums successfully located in the blocks before and after both 1080 baitings was 98.4% ($n = 129$; 93.9–99.7%, 95% CI). The combined kill was 95% ($n = 40$; 85.5–98.6%) in the post-cereal-1080-pre-fed-only block compared to 100% ($n = 89$; 96.0–100.0%) for the other two blocks, but the difference may not be real (Fisher's exact test, $P = 0.09$).

Discussion

All but two of the 24 possums successfully tracked through the second (PB paste) baiting were killed within three days on the same set of transects that were used for the cereal 1080 baiting. This outcome suggests it is unlikely that many of the possums that survived the first cereal 1080 baiting did so simply because they did not encounter bait because they lived exclusively in the 70–80 m wide unbaited areas between

transects, or for some other reason.

Although we did not monitor bait acceptance in a similar nearby area not subject to cereal 1080 baiting, the cereal RS5 used is obviously designed to be highly palatable to possums, and in previous studies we have recorded high acceptance. For example, in the precursor study that prompted this study (Nugent et al. 2019), possums consumed some bait on 40% of visits to bait stations at which four different non-toxic cereal bait types (and carrot) were present, with almost all of the cereal bait completely removed in just two nights at sites visited by possums. Morgan (2004) recorded 97–100% acceptance by possums of non-toxic cereal bait in winter in a nearby area (Kaingaroa) of pine forest habitat (i.e. habitat similar to that in our study area). In contrast, no radio-collared possums were photographed consuming non-toxic cereal baits a month after the first (cereal) 1080 baiting. Consumption by un-collared possums (which is likely to include some possums that moved into the study area after the first 1080 baiting) was also low (2.8% of visits). Given that RS5 cereal is highly palatable, the non-consumption by radio-collared survivors clearly and strongly suggests most cereal-1080 survivors had developed a learned bait aversion, which in turn implies that most of them had not only encountered toxic cereal bait but had eaten some of it.

This trial therefore shows that switching to a bait type that differed greatly in smell, taste, texture, and appearance was effective in circumventing learned aversion to the cereal pellet baits now almost universally used in aerial 1080 baiting of possums. It provides field-trial validation of previous findings with captive possums in which 64% of cereal RS5 bait-shy possums were killed with a toxic 1080 gel bait (Ross et al. 2000). We know from the 99.6% kill of 243 radio-collared possums achieved by a 'high intensity' cereal 1080 operation mentioned in the introduction (Nugent et al. 2017) that first applications of 1080 can nowadays achieve high kills. Combining that level of kill with the 92% kill achieved by the second application of 1080 in this study (of 24 presumed mostly cereal-bait-averse possums) suggests that post-cereal-1080 baiting with PB paste is potentially capable of achieving 99.96% kills. Thus, if the pre-poison possum density was one possum per hectare, the resulting residual density could be of the order of one possum per 2500 hectares. Equally simplistically, if the 100% kill of the 14 possums PB-paste-pre-fed before they first encountered 1080 bait can be achieved at operational scales, this would deliver complete elimination.

Having demonstrated that a high proportion of survivors of a cereal-bait 1080 operation that are likely to be cereal-bait averse can be killed with a second sowing of 1080 using a markedly different bait, the next questions revolve around how best to operationalise this finding. Pre-feeding the first (cereal) 1080 baiting with non-toxic cereal bait would have improved initial kill (Nugent et al. 2011), and there are also indications that such pre-feeding reduces the level of bait aversion (Ross et al. 2000), possibly also making the second baiting more effective as well.

Although not statistically significant, our results hint that the best approach may be to familiarise possums with the bait type that will be used for the second 1080 baiting before they encounter any form of 1080 bait. Whether that might apply in dual 1080 baiting where the two forms of cereal bait already registered for aerial 1080 baiting were used is not known, but it might. If so, that would make adoption of dual 1080 far easier than if use of a very different not-yet-registered bait was necessary). There is no indication from this trial that

pre-feeding between the two 1080 baitings was needed, as all nine survivors pre-fed only before the first 1080 baiting were killed; in effect, 100% of 45 such possums were killed from three baitings (PB paste pre-feed, cereal 1080, and PB paste 1080). Nonetheless, we consider pre-feeding with both bait types desirable, which would have required four baitings (PB paste pre-feed, cereal pre-feed, cereal 1080, PB paste 1080), unless the two pre-feeds could be sown in a single baiting. That would be feasible with hand-laying of bait, as in this trial, but PB paste is currently not aerially deliverable, and is registered for ground-based use only. At present, therefore, a cereal-then-PB-paste dual-1080 regime would be best suited for relatively small-scale use in areas suited to ground-based baiting, with the cereal bait delivered aerially, and hand-laid PB paste then used to ‘mop up’ survivors. For large-scale use, the suggested form of aerial dual-1080 therefore requires development (and registration) of an aerially sowable PB paste (perhaps in biodegradable sachets, as have been used to sow a live TB vaccine for possums in New Zealand; Nugent et al. 2016), or some other form of bait that differs greatly from RS5 cereal bait. For the latter, the key question is what factors need to differ (appearance, smell, taste, texture), and by how much? The non-target risks of any new (and currently unregistered) form of bait would also need to be extensively evaluated, whereas we presume the non-target impacts of a registered PB paste bait have already been assessed.

We conclude that dual 1080 baiting with different bait types does have the potential to locally eliminate possums. This approach would more or less instantly eliminate possums as a local TB reservoir, and (provided that possum elimination can be confirmed with high confidence) therefore substantially reduce or even eliminate the need for repeat TB-related 1080 operations in future and the economic and social costs associated with them. For conservation, it opens the door to some form of progressive or roll-back elimination of possums from ever-larger areas through sequential application of the approach (and other tools) at and beyond the boundaries of the possum-free area.

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