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Landcare Research

High effectiveness of deer-repellent Prodeer 1080 possum bait in the northern South Island high country

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High effectiveness of deer-repellent Prodeer 1080 possum bait in the northern South Island high country

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Summary

Project and client

- Manaaki Whenua – Landcare Research, Lincoln, was commissioned by OSPRI to assess whether Prodeer, a newly developed deer-repellent 1080 cereal bait for possum control, is effective in deterring red deer (but not possums) from eating bait.
- Radio-collared deer and possums were monitored during an aerial baiting operation undertaken to help eradicate bovine tuberculosis (TB) from possums. The work was undertaken between February and August 2021.

Objectives

The objective was to determine the possum control efficacy and incidental red deer mortality incurred during aerial 1080 poisoning of possums using Prodeer deer-repellent cereal 1080 bait in the northern South Island high country by determining:

- the mortality of radio-collared deer under OSPRI's standard broadcast aerial 1080-baiting treatment.
- the mortality of radio-collared possums under three different baiting treatments.

Methods

- Three areas in Molesworth and Muller Stations were aerially poisoned with pre-fed Prodeer deer-repellent 1080 cereal bait in June 2021. There were three baiting treatments with differing sowing methods and/or baiting rates:
  - the standard OSPRI specification (broadcast sowing of 1080 bait at 2.0 kg/ha) applied to 59,639 ha in the Bush Gully / Tarndale / Upper Acheron area
  - a low-sow broadcast sowing of 1080 bait at 1.0 kg/ha, applied to 4,868 ha in the Severn catchment
  - a low-sow strip sowing of 1080 bait at 0.8 kg/ha, applied to over 4,356 ha in the Saxton catchment.

  All the operations were pre-fed 3 weeks beforehand with non-toxic Prodeer cereal bait.
- Approximately 2–4 months prior to poisoning, 50 deer and 85 possums were radio-collared in the standard broadcast area, and 57 and 48 possums in the low-sow broadcast and strip-sow areas, respectively. The collared deer and possums were radio-tracked using a fixed-wing aircraft 1–2 days before the 1080 baiting to determine which collared animals were still alive and present within the study areas.
- The animals were then radio-tracked from the air and on the ground to assess mortality. Where possible, collars on dead possums and deer were recovered and tissue samples were collected from dead deer to analyse for the presence of 1080 residue. Surviving deer were radio-tracked three weeks following poisoning to assess if there had been any delayed mortality due to baiting. The numbers of dead and live deer sighted during radio tracking and collar recovery post-poisoning were recorded.

Results

- *Deer*. Only 39 deer were recorded as alive and present in the standard broadcast area just before 1080 baiting. Of these, two died on the day of the 1080 baiting operation, indicating an estimated incidental 1080-by-kill of 5.1% (95% CI 0.9–18.7%). There were 358 incidental sightings of non-radio-collared live and dead deer (351 live, 7 dead) in the baited area after the 1080 baiting which would equate to a by-kill of 2.0%. Most sightings were from the helicopter (98.9%). The relative sighting rate of live and dead deer seen from the helicopter (excluding radio-collared deer) was 10.7 and 0.2 deer per flying hour, respectively.
- *Possums*. Possum control efficacy was high under all three baiting treatments. All the radio-collared possums confirmed as still alive and present in each of the three study areas at the time of 1080 baiting were killed. The lower 95% confidence limits for the 100% kill estimates were 95.7% (n = 70), 93.5% (n = 46), and 93.3% (n = 45) for the standard broadcast, low-sow broadcast, and low-sow strip treatments, respectively. The respective percentages of possums killed within 1 day of baiting were 90.0% (63/70), 93.5% (43/46), and 92.5% (37/40). All the remaining possums in the standard broadcast area died within 5 days, and all within 3 days in the two low-sow areas. Some 1080-killed possums had been scavenged (n = 6), and four dead pigs were observed. The pigs may have been killed by primary or secondary poisoning, but tissue samples were not collected and analysed to confirm this.

Conclusions

- Prodeer 1080 bait was highly effective in deterring red deer from eating 1080 bait, with high survival of radio-collared deer and with few dead deer sighted (relative to numbers of live deer) after the operation. This contrasts sharply with two recent operations in nearby areas with similar habitat, in which non-repellent 1080 bait was used. In these cases, 89% and 100% red deer mortality were recorded in the East Acheron in 2017 and on Muller Station in 2019, respectively.
- Prodeer 1080 bait had high control efficacy against possums for the three baiting treatments assessed. There was no indication that percentage kill was reduced by the addition of a deer repellent, nor by the use of lower-than-usual sowing rates or strip sowing.

Recommendations

- OSPRI should consider using Prodeer 1080 bait where avoidance of a high risk of deer mortality is operationally important. The high possum kill results suggest that the higher cost of using Prodeer bait could be offset by using substantially lower sowing rates, at least in similar habitat to that assessed here.
- The reliability with which Prodeer 1080 bait repels deer should also be assessed by monitoring deer mortality during 1080 operations in other areas (particularly in forested areas, where deer densities are high and/or where there are smaller-bodied deer species such as sika and fallow deer present), as suitable operations arise.
- Provided live capture of deer is feasible and affordable, use of radio-collared deer should be the preferred approach for assessing by-kill.

1 Introduction

Manaaki Whenua – Landcare Research (MWLR), Lincoln, was commissioned by OSPRI to assess whether Prodeer, a newly developed deer-repellent 1080 cereal bait for possum control, is effective in deterring red deer (but not possums) from eating bait. Radio-collared deer and possums were monitored during an aerial baiting operation undertaken to help eradicate bovine tuberculosis (TB) from possums. The work was undertaken between February and August 2021.

2 Background

OSPRI relies heavily on aerial 1080 baiting for the eradication of TB from possum populations in large areas of forest and mountain land in which possum control is difficult to achieve using ground-based methods (Warburton & Livingstone 2015). However, aerial 1080 baiting can sometimes result in a high level of incidental deer mortality and so is opposed by many hunters (Morriss, Parkes et al. 2020). That opposition can sometimes limit OSPRI's ability to obtain landowner consent to use aerial 1080 baiting. This dilemma has driven research and development aimed at finding methods that deter deer from eating 1080 baits.

Research starting in 2001 identified a repellent which, when added to carrot and cereal bait as a surface coating, changed the appearance and smell of the bait and successfully repelled deer but was still palatable to possums and rats (Forsyth 2002; Nugent et al. 2004, 2012, 2017; Morriss et al. 2006, 2018; Morriss 2007). Epro Ltd have the proprietary rights to this product (Epro Deer Repellent: EDR), and it has been widely used in pest control operations throughout New Zealand. However, the surface coating of baits with repellent is an extra step in bait production and therefore substantially increases the cost of using baits coated with repellent.

Two other companies, Orillion and Pest Control Research LP (PCR), that manufacture bait have recently developed alternative formulations of deer-repellent cereal bait to be used for broad-scale possum and rat control. In both cases, the repellent is incorporated into the bait during manufacture (whereas EDR is surface coated after bait manufacture). MWLR tested the palatability and efficacy of these new repellent formulations on both captive possums and ship rats, and both proved to be palatable and effective with both species (Morriss & Arrow 2018).

With no indication that either formulation affected possum control efficacy, OSPRI began to assess their effectiveness in repelling deer. In a first operational trial, the PCR Pestex® deer-repellent 1080 cereal bait was tested in the Clarence Valley (Morriss et al. 2019). There was a 100% kill of radio-collared possums (n = 82). There was a significant reduction (36%) in deer by-kill (when compared with a no-repellent operation), but still a moderate to high by-kill of radio-collared deer (19/30: 63.3% kill).

This subsequent study was therefore commissioned by OSPRI to assess whether the alternative Orillion deer-repellent cereal bait (Prodeer) might have higher efficacy in reducing deer by-kill. The trial was delayed by the 2020 Covid lockdowns, but in early 2021 OSPRI requested an assessment of deer and possum mortality under their 'standard' 1080 baiting treatment, and of possum mortality under two lower-cost baiting treatments, as follows:

- a 'standard' broadcast baiting treatment (based on OSPRI's Standard Operating Procedures) covering 59,639 ha
- a low-sow (reduced-cost) broadcast-baiting treatment covering 4,868 ha
- a low-sow strip-baiting treatment covering 4,356 ha.

All three treatments used the same 6 g Prodeer 0.15% 1080 bait, both for non-toxic pre-feeding and for the subsequent toxic (1080) baitings. The operation was conducted in the northern South Island high country; specifically, parts of Molesworth and Muller Stations.

For deer, the most direct and robust method for assessing mortality following a 1080 operation is to radio-collar a sample of animals and assess their survival. Provided there is no major correlation between how easily animals can be captured and their susceptibility to 1080 poisoning, the percentage of radio-collared animals killed provides a simple, direct, and rapid indication of lethality that does not require adjustment for other factors such as seasonality, which affect indices of animal abundance. This approach was agreed to by OSPRI and, given the investment in radio-tracking deer, the same approach would also be used for possums.

For operational reasons, OSPRI planned to use Prodeer bait over the whole area being baited. That precluded a direct treatment vs non-treatment comparison of outcomes within the study, based on concurrent use of a non-deer-repellent bait in at least part of the area (see Methods section). The implication of this is that if deer survival is found to be high, it is difficult to unravel whether it is because the deer repellent is highly efficacious, or high survival is due to some other factor, such as, high availability of natural food. In addition, deer densities in the area are generally low (around two deer per square kilometre; Morriss, Yockney et al. 2020), making it unlikely that a statistically robust sample of deer could be collared in the two small areas designated for the experimental low-sow baiting treatments (as OSPRI staff had initially hoped could be done). As a result, deer mortality was assessed only under the standard treatment, but possum mortality was assessed for all three treatments.

This report therefore documents the outcomes of a large-scale operational field test of the efficacy of Prodeer repellent bait in reducing deer by-kill under the standard treatment used by OSPRI. It also documents a comparison of possum control efficacy under that standard treatment, and under two lower-cost alternative treatments.

3 Objectives

The objective was to determine the possum control efficacy and incidental red deer mortality incurred during aerial 1080 poisoning of possums using Prodeer deer-repellent cereal 1080 bait in the northern South Island high country by determining:

- the mortality of radio-collared deer under OSPRI's standard broadcast aerial 1080-baiting treatment
- the mortality of radio-collared possums under three different baiting treatments.

4 Methods

4.1 Trial design and study area

4.1.1 Trial design

Deer: As noted above, operational and cost constraints resulted in an unreplicated design, with neither a non-repellent treatment nor a no-1080 treatment against which deer mortality could be compared. Low deer mortality after Prodeer 1080 baiting could therefore, in principle, have reflected (i) low mortality with non-repellent bait; (ii) high efficacy of the repellent, or (iii) some unknown mixture of both. However, in both of two recent trials in adjacent areas of similar habitat, 1080 baiting without repellent has resulted in high deer mortality (Morriss et al. 2018, 2019). In the most recent of those trials, 100% (95% CI: 74–100%) of 11 radio-collared deer were killed. We therefore aimed to compare the results of this trial against that outcome, but with any conclusions being subject to the caveat that any difference in outcomes might partly (at least) reflect seasonal or area-related differences in mortality.

Possums: For possums, there was again no formal non-repellent experimental control. Instead, we assumed that OSPRI would want the Prodeer deer-repellent bait to routinely deliver a kill of at least 95% kill of radio-collared possums in future operations. We therefore aimed at a sample size of 90–100 possum for the standard treatment to provide a precise estimate (i.e. with tight confidence limits) of the kill under OSPRI's current standard practice. For the other two treatments, we aimed at a sample size of 40–50 possums based on simulations indicating that this would provide sufficient power to detect a 10–15% reduction in percentage kill (relative to the standard treatment) if the standard treatment delivered a kill of >95%.

4.1.2 Study areas and treatments

The TB possum control operations comprised 68,863 ha of Molesworth and Muller Stations (63,016 ha and 5,847 ha, respectively), divided into the operational areas shown in Figure 1. The habitat was similar in each area: predominantly semi-arid grassland interspersed with matagouri and sweet briar, but also including beech forest remnants and alpine shrubland and grassland. Wilding pines were present in the southernmost part of the main treatment area. The altitude in the areas treated ranged from c. 800 to c. 2,000 m asl.

Prodeer deer-repellent 1080 bait was used in all three operational areas using three different sowing rates and two different sowing methods (Figure 1). The treatment details were as follows.

- Standard broadcast (Bush Gully / Tarndale / Upper Acheron): a single pre-feed of non-toxic Prodeer cereal bait (cinnamon-lured 16 mm [6 g] cereal baits) was broadcast-sown by helicopter along flight paths spaced 180–190 m apart, at the rate of 1.0 kg/ha, followed 18–21 days later by toxic bait (cinnamon-lured 16 mm 0.15% Prodeer 1080 cereal baits) applied at 2.0 kg/ha at the same flight path spacing.
- Low-sow broadcast (Severn): as above, but with the toxic (1080) sowing rate reduced to 1.0 kg/ha.
- Low-sow strip (Saxton): both pre-feed and toxic bait were sown in strips with 140 m between flight paths. The baited strips were nominally 50 m wide with a 90 m un-baited gap in between. The baited swaths received a minimum sowing rate of 1.7 kg/ha, but the overall sowing rate was 0.8 kg/ha for both pre-feed and toxic bait.

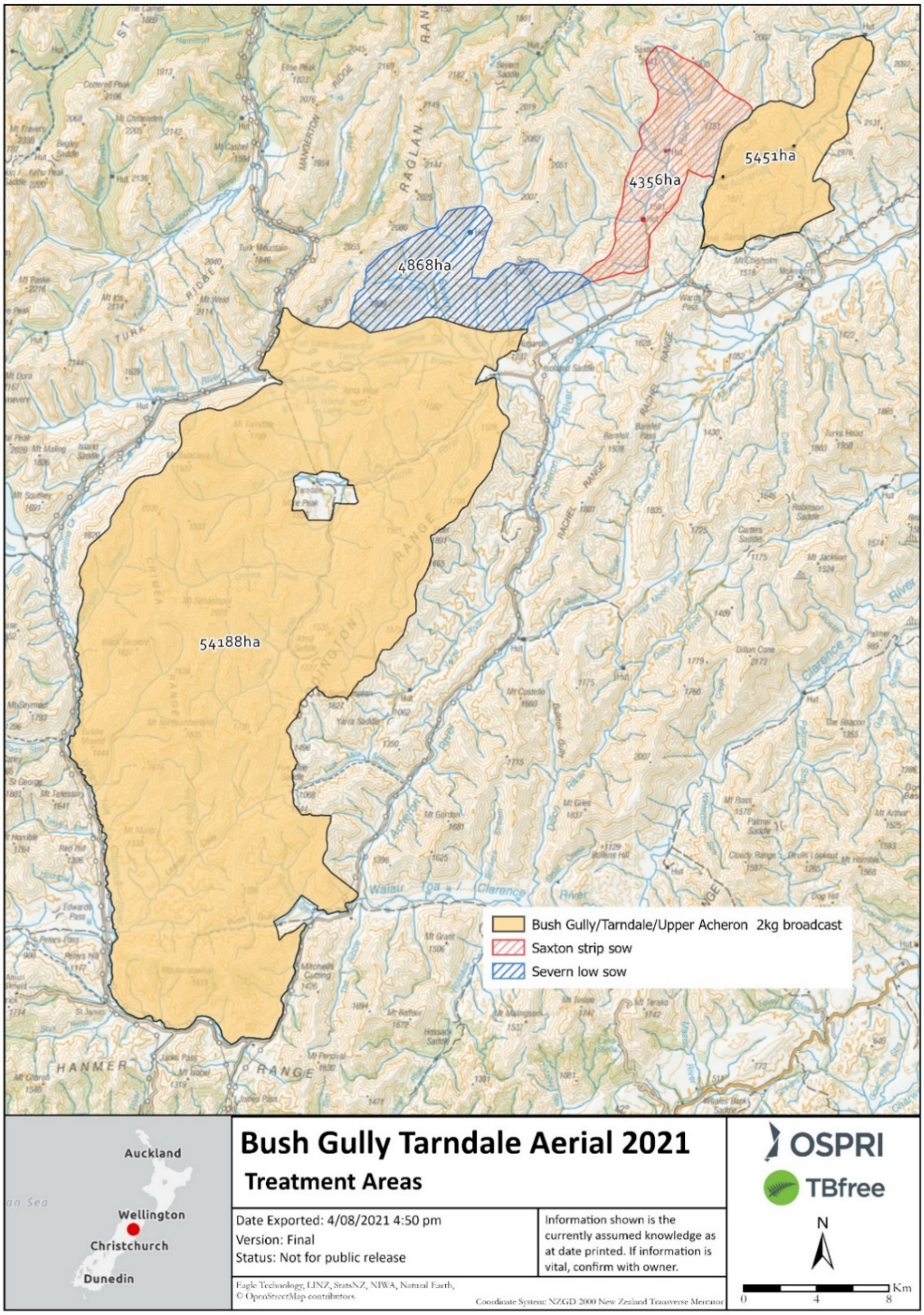

Figure 1. TB possum control operational areas on Molesworth and Muller Stations, poisoned in June 2021. The area of each block is shown. There was no monitoring of possums or deer in the separate northeast part of the standard broadcast 2 kg/ha area.

4.1.3 Baiting operations

The baiting operations were conducted by Vector Free Marlborough and are summarised in Table 1. The operational areas were pre-fed once, with toxic bait sown 19–21 days later. Most of the toxic baiting was completed on 10/11 June 2021, with a small amount of mostly boundary sowing completed on 12 June 2021.

Precipitation of 4.0 mm was recorded at Maling Pass on the western edge of the operational area the day after toxic baiting was completed, but only 1.0 mm was recorded at Molesworth homestead that same day. Most toxic bait, once sown, was likely to have had two or three fine nights before rain was recorded. A total of 449.0 mm of precipitation was recorded at Maling Pass over the following month and a half, whereas 153.6 mm was recorded at the Molesworth homestead for the same period.

Table 1. The name and size of TB possum control operational areas on Molesworth and Muller Stations, poisoned with Prodeer 1080 cereal bait, June 2021

Treatment	Area (ha)	Pre-feed sowing rate	Pre-feed sowing dates	Toxic sowing rate	Toxic sowing dates
Standard broadcast	59,639	1 kg/ha	22/23 May 2021	2 kg/ha	10–12 Jun 2021
Low-sow broadcast	4,868	1 kg/ha	22 May 2021	1 kg/ha	10 Jun 2021
Low-sow strip	4,356	0.8 kg/ha	22 May 2021	0.8 kg/ha	10 Jun 2021

4.2 Assessment of outcomes

4.2.1 Radio-collaring deer for by-kill assessment

Deer were located using an MD520 Notar helicopter and tranquilised by the observer using a dart-gun or captured using a netgun (see Latham et al. 2020). Once the deer was incapacitated, it was fitted with a drop-off VHF mortality-sensing radio collar (Lotek, Havelock North). The tranquilised deer were then injected with a reversal drug before release at the site of capture.

Deer in the central core of the operational area were targeted in an effort to minimise the risk of them moving out of the operational area before toxic bait was sown. Radio-collaring of deer was carried out when deer were most likely to be active and visible. Fifty deer of mixed age and sex were collared during 14–22 April 2021 (34 adults [18 F, 16 M], 3 yearlings [1 F, 2 M], and 13 fawns [6 F, 8 M]; see Appendix 1).

The collared deer were radio-tracked using a fixed-wing aircraft on two occasions before poisoning to determine which deer were still alive and present in the study areas. They were radio-tracked again using a fixed-wing aircraft 10–11 days after 1080 baiting. A helicopter was used to radio-track and accurately locate live and dead deer 20–22 days after baiting. Radio-collared deer emitting 'live' signals were tracked until they were sighted and confirmed as alive. Sightings of other uncollared deer (live and dead) from the

helicopter during post-1080 monitoring were also recorded. The collars on surviving deer are scheduled to drop off in September or October 2021.

The location of deer was recorded, and dead deer had their radio-collars removed and a sample of muscle (50 g) from a rear leg collected for 1080 analysis. Deer tissue samples were analysed to determine 1080 concentration, using Toxicology Laboratory Method TLM 005 (with a method detection limit of 0.001 mg/kg), at the MWLR Toxicology Laboratory.

The date and time of movement cessation to the nearest hour of dead deer was determined from the radio-collar time-since death (TSD) function. Any other non-target species found dead were noted. The location of any uncollared possums found dead was also recorded, but no samples were collected.

4.2.2 Radio-collaring possums for kill assessment

To directly assess percentage kill, possums were captured before 1080 baiting, fitted with radio-collars, released, and then monitored to determine whether or not they were killed by eating toxic bait. Possums were captured using leg-hold traps set on best sign to optimise capture rates. Trapping focused on the cores of the operational areas in suitable habitat. Traps were deployed for up to 3 nights at each trap site. There were two trapping periods: 15–21 February and 19–22 April 2021.

The percentage trap catch (TC) provides an approximate index of pre-control possum abundance for comparison between treatment areas, as follows:

- standard broadcast: 95 possums collared, TC = 19.5% (10 of these possums were captured in an area that was subsequently excluded from the operational area by OSPRI, and so were also excluded from this study)
- low-sow broadcast: 57 possums collared, TC = 25.3%
- low-sow strip: 48 possums collared, TC = 30.0%.

All captured possums were sedated/immobilised with an intramuscular injection of Zoletil (5 mg/kg). Once sedated, possums were weighed, and sexed. They were then visually inspected and palpated for TB, but none with visible or palpable lesions were detected.

The possums were then fitted with a VHF radio-collar (approximate weight 30–40 g; Lotek, Havelock North). The radio-collars had time-since-death (TSD; more accurately, the time since movement of the collar ceased) capability, which was used to determine when possums died, particularly in relation to the date on which 1080 bait was sown. After processing, possums were placed in a secure position near the capture site and left to recover from anaesthesia.

Aerial tracking of radio-collared possums by fixed-wing aircraft was undertaken twice in each area: initially on 9 June 2021, 1–3 days before the toxic baiting, and then 10 days after toxic baiting (22 June 2021). The pulse rate of all signals located was recorded as either slow (40 pulses/minute, indicating a live possum) or fast (80 pulses/minute; indicating possum death, or the loss of a collar by a possum).

Starting 20 days after the 1080 baiting, experienced staff used radio telemetry to locate and recover dead radio-collared possums. Of the 190 possums radio-collared (excluding the 10 individuals collared outside the operational area), 18 either died of unknown causes before the 1080 bait was sown (n = 10), or had collars break (n = 2) or slip off (n = 6). An additional 11 could not be relocated during radio tracking, most likely because of collar failure. Staff also recorded any other species or unmarked possums found dead.

5 Results

5.1 Deer by-kill with standard broadcast Prodeer bait

Of the 50 deer collared, only 39 were confirmed as alive and present in the baited area 1–2 days before the bait was sown (Table 1). Four were not relocated at that time, and seven had moved out of the standard broadcast area. Of the 39 deer confirmed present and alive during baiting, two died (an adult male and an adult female), indicating a 5.1% kill (95% confidence interval [CI] 0.9–18.7%, calculated as per Newcombe 1998). The TSD data on their collars indicated both deer had died on the day bait was sown. Analysis of muscle samples confirmed the presence of 1080 in both (0.98 mg/kg and 0.42 mg/kg, respectively).

Excluding all radio-collared deer, we recorded 358 incidental sightings of live and dead deer (351 live, 7 dead) in the baited area while carrying out radio tracking and radio collar recovery after the 1080 baiting. Note that these were incidental sightings as staff were transported to sites for on-ground radio collar recovery, or during close approach to radio-collared deer to confirm survival. One collared deer was observed in a mob of 37. Most sightings were from the helicopter (98.9%). Of the total sightings, just seven (2.0%) were of dead deer. Of the 354 helicopter-based sightings, six (1.7%) were of dead deer. Excluding radio-collared deer, the relative sighting rate of live and dead deer seen from the helicopter was 10.7 and 0.2 deer per flying hour, respectively.

Fifteen live chamois were also seen from the helicopter. No dead chamois were seen. Of 12 pigs sighted (10 from the helicopter), four were dead (two sightings from the helicopter and two on the ground).

5.2 Efficacy of possum control with three baiting treatments

All the 161 possums with functioning radio collars that were confirmed as alive and present within the baited areas died, an average overall kill of 100% (95% CI 97.1–100.0%) (Table 2).

The lower 95% confidence limits around the 100% kill estimates for the individual treatments were 95.7% (n = 70), 93.5% (n = 46), and 93.3% (n = 45) for the standard broadcast, low-sow broadcast, and low-sow strip treatments, respectively. The respective percentages of possums killed within 1 day of baiting were 90.0% (63/70), 93.5% (43/46), and 92.5% (37/40). Although the percentages for possums killed 1 day after baiting were higher for the two low-sow treatments than for the standard broadcast treatment, it is

important to note that they do not differ statistically (Fishers Exact Test, $p = 0.81$; to compare the percentage of possums killed between the low-sow treatments and the standard treatment, where p is the probability of observing the data as extreme if the null hypothesis were true). Of the possums that survived more than 1 day after baiting, all died within 5 days of baiting in the standard broadcast area, and within 3 days in both low-sow areas. There was therefore no indication that possums took longer to find bait and be killed under the low-sow treatments than under the standard broadcast treatment.

Table 2. The fate of radio-collared possums and deer following aerial baiting with Prodeer 1080 cereal bait. The location columns show which of the animals still alive when 1080 bait was sown were inside or outside the respective study areas. Only animals inside the study areas were used to calculate the percentage kill and associated 95% confidence limits (calculated as per Newcombe 1998).

	Location 1–3 days before baiting		Post-baiting status			
Species / baiting treatment	**Inside**	**Outside**	**Alive**	**Dead**	**% kill**	**(95% CI)**
Deer						
Standard broadcast	39	7[1]	37[2]	2[2]	5.1%	(0.9–18.7%)
Possums						
Standard broadcast	70	0	0	70	100.0%	(95.7–100.0)
Low-sow broadcast	46	0	0	46	100.0%	(93.5–100.0)
Low-sow strip	45	0	0	45	100.0%	(93.3–100.0)

[1]An additional four deer were not located 1 day before baiting, but one of these was in the operational area following baiting.

[2]Only includes the deer that were confirmed alive in the operational area 1 day before baiting. Another two were outside the area but within 150 m of the operational boundary when radio tracked so may have been exposed to toxic bait in the days prior.

5.3 Incidental observations

5.3.1 Deer movements

Deer movements after collaring are summarised visually in Appendix 2. The average distance between the locations at which deer were captured and where they died or were last recorded was 3.7 km (range: 0.3–17.8 km; Appendix 1). The largest movements were by two deer, an adult male that moved 16.8 km and a yearling female that moved 17.8 km. Both moves resulted in the deer being outside the operational area at the time it was baited.

5.3.2 Possum movements and weights

Including some possums that died before the 1080 baiting, we recorded a substantially larger mean distance between the locations of individual possums at capture and death in

the two areas subject to broadcast baiting than in the low-sow strip area (Table 3). The difference is likely to be a real effect (ANOVA, $F_{2,120} = 5.04$, $p = 0.008$).

The mean weight of adults was likewise also higher in the broadcast areas than in the strip-sown area (Table 3; ANOVA, $F_{2,164} = 14.16$, $p < 0.001$). These differences possibly indicate a difference in density between areas (see Discussion). The mean weight of adult possums differed among areas, being smaller in the Saxton area where the mean weight of adult possums was 3.04 ± 0.15 kg ($n = 38$), which was one-fifth smaller than in the two other areas (Table 3).

Table 3. Capture-to-death location distance (m) and weights of adult possums (>2.25 kg) from each of the areas subject to different baiting treatments. The means and resulting 95% CIs were calculated using a one-way ANOVA.

		Adult weight			Capture-to-death location distance (m)	
Baiting treatment	**N[1]**	**Mean**	**95% CI**	**n[2]**	**Mean**	**95% CI**
Possums						
Standard broadcast	82	3.49	±0.14	66	289	±60
Low-sow broadcast	47	3.73	±0.17	32	217	±128
Low-sow strip	38	3.04	±0.15	25	92	±24

[1]Includes all adult possums initially radio-collared in each area.

[2]Includes adult possums where death locations were recorded during post-poison radio collar recovery.

6 Discussion

6.1 Efficacy of Prodeer bait in minimising deer by-kill

Despite the lack of an experimental control, our results strongly suggest that Prodeer 1080 bait is highly effective in deterring red deer from eating 1080 cereal baits. Few of the radio-collared deer within the baited area died, and many live deer were seen in the area in the following weeks compared to a small number of sightings of dead deer. The latter is in stark contrast to the sighting of 92 dead deer and just two live deer soon after an aerial 1080 operation without deer repellent in October 2017 during a helicopter-based survey conducted by the Marlborough branch of the New Zealand Deer Stalkers Association (Morriss et al. 2018; Pinney 2019). That operation covered c. 60,000 ha immediately east of the operation monitored in this study.

The results also differ markedly from those recorded in the monitoring of 11 radio-collared red deer in a standard broadcast aerial 1080 operation with non-repellent bait on Muller Station to the northeast of Molesworth in 2019 (Morriss et al. 2019). All 11 of those deer were killed. The difference in mortality is highly likely to be real (Fishers Exact Test, $p < 0.0001$: testing the difference in mortality rates of deer in this study and the deer monitored on Muller Station in 2019). We therefore consider that despite the lack of

replication and of a concurrent experimental control, the extreme difference in mortality is most likely attributable to the use of the Prodeer repellent.

Our recent meta-analysis (Morriss, Parkes et al. 2020) covering 26 cereal-bait-1080 operations (or parts of operations) conducted since 1999 indicated that there was a high likelihood of high deer mortality when sowing rates of >1.5 kg/ha were used, but only moderate or low mortality with sowing rates below that. It therefore appears likely that deer mortality will have also been minimal in the two low-sow areas in this study. The helicopter spent less time in these smaller areas as there were no radio-collared deer present, but five live deer were recorded as seen from the helicopter. Ground-based staff also saw abundant fresh deer sign and recorded three live deer while radio-tracking dead possums.

Deer mortality in this study was lower than in our 2019 assessment of the effectiveness of Pestex® deer-repellent bait (Morriss et al. 2019). In that study, 63% of radio-collared deer (n = 30) died in the area that Pestex® deer-repellent bait was used, significantly higher than the 5.1% recorded here (Fishers Exact Test, $p < 0.001$: testing the difference in mortality of deer in the current study and in the 2019 trial of Pestex deer repellent). That suggests Prodeer was a more effective repellent (subject to the caveat that some of the difference might reflect non-treatment effects (e.g. effects of year, season, deer density, or deer size) on vulnerability to poisoning.

6.2 Efficacy of possum control with Prodeer 1080 bait

Pre-fed Prodeer 1080 bait had high control efficacy against possums regardless of baiting treatment: for all areas combined, at least 97% (lower 95% CI) of radio-collared possum were killed. As all monitored possums in each area died, there is no evidence that the repellent had any adverse effect on percentage kill.

Although the lower 95% CIs were lower in the two low-sow areas, that is an artefact of the smaller sample sizes in those areas. The percentages of possums killed within 1 day of baiting were similar for all three treatments, i.e., there was no evidence that the lower overall density of bait nor the 90 m gaps between baited areas in the low-sow strip area resulted in possums taking longer to find and consume a lethal dose of 1080 bait. The 100% kill in the low-sow strip area was achieved despite indications that possums were less mobile in that area (Table 3). In addition to lower mobility, the operational trap catch rate recorded was highest in this area and the adult mean weight lowest, all of which are possibly indicators that possum density may have been highest in that area. If so, it suggests that even lower sowing rates could have been used. That possibility is supported by previous strip-sowing research in the northern South Island high country – most notably achievement of 100% possum kill using pre-fed strip sowing at both 0.4 kg/ha and 0.29 kg/ha with flight path spacings of 125 m and 175 m (Morriss et al. 2015). The obvious implication is that OSPRI could substantially reduce sowing rates (and therefore baiting costs, which is especially important if deer-repellent baits are used) without markedly affecting control efficacy.

6.3 Incidental findings

We did not find any dead non-target bird or small mammal species, nor any dead chamois. However, some pigs were killed. Because the relative detectability of live and dead pigs is not known, the impact on the pig population cannot be directly assessed. It is also not clear whether the pigs were killed because of eating bait or by secondary poisoning when scavenging carcasses.

7 Recommendations

- OSPRI should consider using Prodeer 1080 bait where avoidance of a high risk of deer mortality is operationally important. The high possum kill results suggest that the higher cost of using Prodeer bait could be offset by using substantially lower sowing rates, at least in similar habitat to that assessed here.
- The reliability with which Prodeer 1080 bait repels deer should also be assessed by monitoring deer mortality during 1080 operations in other areas (particularly in forested areas where deer densities are high and/or where smaller-bodied deer species such as sika and fallow deer are present) as suitable operations arise.
- Provided live capture of deer is feasible and affordable, use of radio-collared deer should be the preferred approach for assessing by-kill.

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Appendix 1. Sex, age-class and fate of red deer radio collared in the Bush Gully / Tarndale area of Molesworth Station

Table A1. Red deer radio-collared 14–22 April 2021 in an area baited with Prodeer 1080 cereal bait, June 2021. The sex, age-class (adult >2 years, yearling c. 1.5 years, juvenile c. 0.5 years), fate, and distance between radio-collaring and last recorded location of each deer are shown.

ID	Sex	Age class	Exposed to bait	Fate	Distance between capture and last location (km)
CH01	Female	Adult	Y	Alive	2.3
CH03	Male	Adult	Y	Alive	2.3
CH05	Female	Adult	Y	Alive	2.2
CH07	Female	Adult	Y	Alive	0.5
CH09	Male	Adult	Y	Alive	5.7
CH11	Female	Adult	Y	Alive	1.2
CH13	Male	Adult	Y	Alive	6.8
CH15	Male	Juvenile	Y	Alive	2.7
CH17	Male	Adult	Y	Alive	5.4
CH19	Female	Juvenile	Y	Alive	0.9
CH21	Female	Juvenile	N	Alive	5.3
CH23	Female	Juvenile	Y	Alive	1.8
CH25	Male	Juvenile	Y	Alive	2.3
CH27	Male	Adult	Y	Alive	2.3
CH29	Female	Adult	Y	Alive	3.2
CH31	Female	Adult	Y	Alive	3.3
CH33	Male	Adult	N	Alive	16.8
CH35	Female	Adult	N/Y[1]	Alive	0.9
CH37	Male	Juvenile	Y	Alive	0.9
CH39	Male	Adult	Y	Dead	0.7
CH41	Male	Juvenile	Y	Alive	0.8
CH43	Female	Adult	Y	Alive	3.7
CH45	Female	Yearling	N	Alive	17.8
CH47	Male	Adult	Y	Alive	2.7
CH49[2]	Male	Adult	?	?	?
CH51	Female	Adult	Y	Dead	1.3
CH53	Male	Adult	Y	Alive	5.0
CH55	Male	Juvenile	Y	Alive	0.3
CH57	Male	Adult	N	Alive	5.5
CH59	Male	Yearling	Y	Alive	0.6
CH61	Male	Juvenile	Y	Alive	4.3

ID	Sex	Age class	Exposed to bait	Fate	Distance between capture and last location (km)
CH63[3]	Male	Adult	Y	Alive	1.9
CH65	Female	Adult	Y	Alive	0.9
CH67[2]	Female	Adult	?	?	?
CH69	Male	Adult	Y	Alive	6.7
CH71	Female	Juvenile	Y	Alive	1.4
CH73	Female	Adult	Y	Alive	0.5
CH75	Female	Adult	N/Y[1]	Alive	3.4
CH77	Male	Juvenile	N	Alive	6.0
CH79	Female	Adult	Y	Alive	0.5
CH81	Male	Adult	N	Alive	8.3
CH83	Male	Adult	N	Alive	6.8
CH85	Female	Adult	Y	Alive	0.8
CH87[2]	Male	Adult	?	?	?
CH89	Female	Juvenile	Y	Alive	3.2
CH91	Female	Adult	Y	Alive	0.6
CH93	NR	Yearling	Y	Alive	7.2
CH95	Female	Adult	Y	Alive	7.9
CH97[4]	Female	Adult	Y/N	Alive	9.6
CH99	Female	Juvenile	Y	Alive	0.5

[1] Not in the operational area 1 day before baiting but was when tracked 21 days post-poison.

[2] These three radio-collared deer were not found until 2 months after the baiting operation. All three were east of the operational area (5–20 km) and almost certainly had moved there well before the baiting operation and therefore were unlikely to have been exposed to bait.

[3] Signal not heard the day before baiting but was tracked and sighted in the operational area post-poison.

[4] This deer was in the operational area 1 day before baiting but had moved out when tracked and sighted 21 days post-poison.

Appendix 2. Movements of radio-collared deer

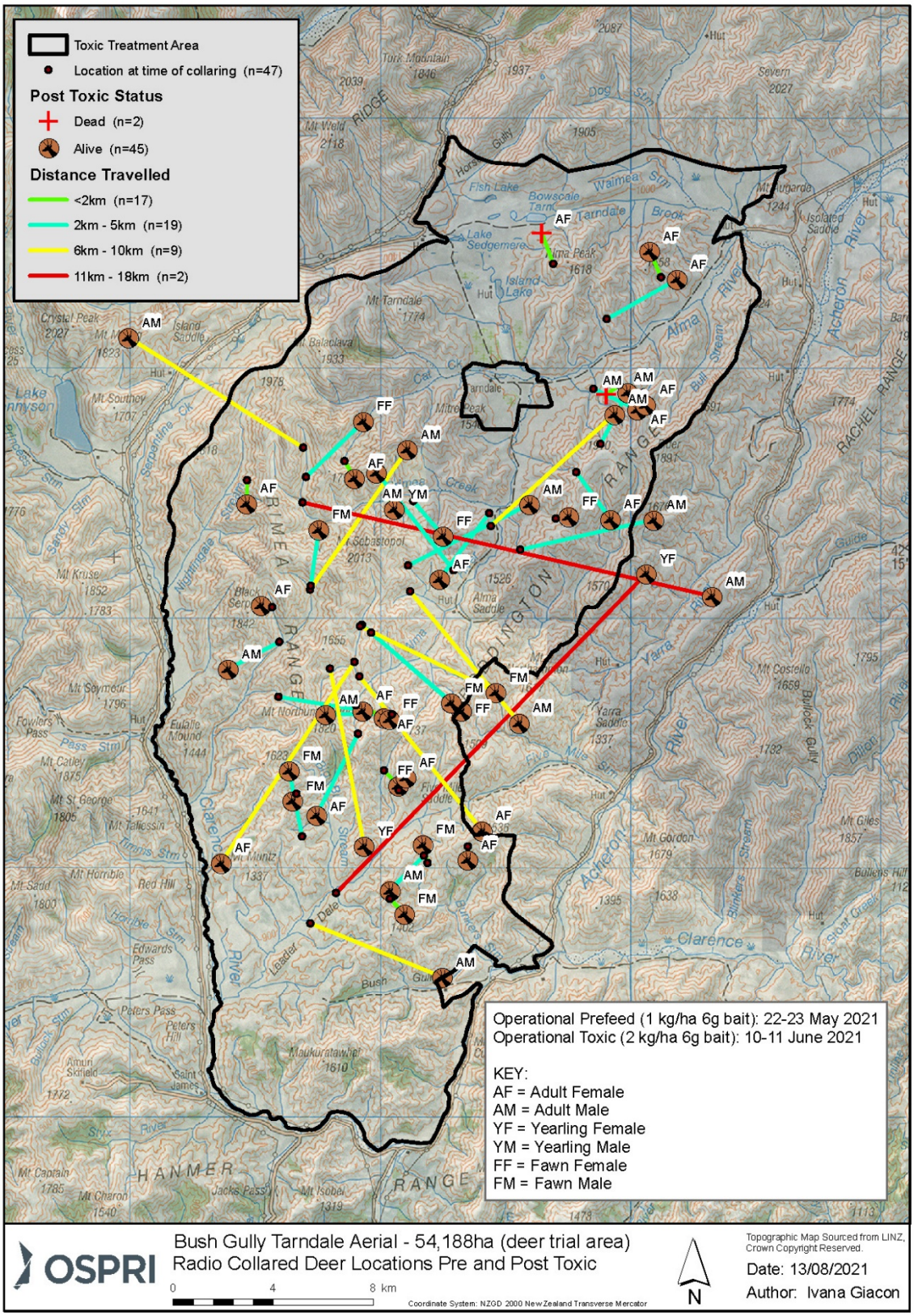

Figure A1. Capture and final known locations of radio-collared deer in the Bush Gully / Tarndale operational area baited with Prodeer 1080 cereal bait.