Manaaki Whenua
Landcare Research

Operational-scale field testing of Pestex® deer-repellent 1080 cereal bait

OSPRI – R-10827

Prepared for: OSPRI

October 2019

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Contract Report: LC3622

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DOI: https://doi.org/10.7931/2zss-sj24

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Summary

Project and client

Manaaki Whenua – Landcare Research, Lincoln, was commissioned by OSPRI to assess the efficacy of Pestex® deer-repellent 1080 cereal bait in deterring red deer from eating it, compared with non-repellent Pestex® 1080 cereal bait, during aerial baiting operations undertaken to help eradicate bovine tuberculosis (TB) from possums. The possum kill with both bait types was also assessed. The work was undertaken between May and October 2019.

Objective

To assess the effectiveness of Pestex® deer-repellent 1080 cereal bait (relative to Pestex® non-repellent 1080 cereal bait) in reducing by-kill of red deer without reducing possum control efficacy by comparing, in winter 2019, the percentages of radio-collared deer and possums killed between two areas baited with Pestex® cereal 1080 bait, one with and the other without deer repellent.

Methods

- Operational areas in the Clarence and Awatere Valleys were poisoned with either Pestex® non-repellent 1080 cereal bait (Upper Awatere South) or Pestex® deer-repellent 1080 cereal bait (Clarence West and Waiautoa). All the operations were pre-fed with the relevant non-toxic bait, and all used a toxic (1080) bait sowing rate of 2 kg/ha.
- Two to 14 weeks prior to poisoning, 32 deer and 91 possums were radio-collared in the areas treated with deer-repellent bait, and 22 deer and 73 possums were radio-collared in the area treated with non-repellent bait.
- The collared deer and possums were radio-tracked using a fixed-wing aircraft immediately before the application of 1080 bait to determine how many collared animals were still alive and present within the areas to be poisoned.
- Following poisoning, the animals were radio-tracked from the air and on the ground to assess mortality. Collars on dead animals were recovered and jaws and tissue samples were collected from dead deer to determine age and to analyse for the presence of 1080 residue.
- Surviving deer were radio-tracked for at least a month following poisoning to assess if there had been any delayed mortality due to baiting.

Results

- *Deer by-kill.* In the non-repellent area, half of the radio-collared deer had moved out of the treatment area by the time toxic bait was sown, but all of the 11 that remained died within 2 days of the 1080 baiting (100% kill; 95% confidence interval [CI] 74.1–100.0%). In the repellent area, 30 collared deer were still present when 1080 bait was sown, of which 19 died (63.3% kill; 95% CI = 43.9–79.5%). Of the deer killed, 17 (89%) died within a day of bait being sown, one after 2 days and one after 4 days. The latter

two died close to the operational boundary so may not have encountered bait as soon as it was sown.

- *Possum kill.* Of 69 radio-collared possums still present in the non-repellent area when 1080 bait was sown, 68 died, a 98.6% kill (95% CI = 91.1–99.9%). Most (62/65 [95%]) of those that recorded time since death died within 1 day of the baiting, and the other three within 2 days. In the repellent area, all 82 radio-collared possums still present when 1080 bait was sown died, a 100.0% kill (95% CI = 95.1–100.0%). Most (n = 80; 97.5%) died within 1 day of the baiting, and the other two within 2 days.

Conclusions

- Pre-fed Pestex® 1080 bait had very high control efficacy against possums, both with and without the incorporation of the new deer repellent. However, there was also a high deer by-kill when no repellent bait was used at this sowing rate. Where deer-repellent bait was used, we recorded a 36% lower by-kill (95% CI = 13–60%; Fisher exact test P = 0.04), indicating strong evidence of a real reduction.

Recommendations

- Even though a moderately high by-kill of deer still occurred in this trial when Pestex® deer-repellent bait was used, it may warrant further development and testing (depending on the availability of other repellents). This recommendation is based on the inference that the outcome of this trial was similar to the moderately high by-kill also recorded in a recent trial with EDR, a repellent that has proven highly effective in earlier trials.
- If the Pestex® deer repellent (or other deer-repellent baits) are to be field tested further, and given recent confirmation that deer by-kill without repellent is positively related to 1080 sowing rate, we recommend that field tests of both possum control efficacy and deer by-kill be undertaken using high and low sowing rates (e.g. 2.0 vs 1.0, or even 0.5 kg/ha) in preference to comparing repellent efficacy solely at high sowing rates, as in this and other recent trials.
- Provided live capture of deer is feasible and affordable, use of radio-collared deer should be the preferred approach to assessing by-kill. Collaring should ideally be undertaken only a few weeks before 1080 baiting to minimise the risk of deer emigrating from the study area. Some measure(s) of body size should be recorded for all collared deer to help understand (and adjust for) the possible influence of deer size on by-kill risk. Given the mobility of deer in this study (particularly in the non-repellent area), study areas for the different 1080 treatments need to be large (>10,000 ha), separated by at least 5 km, and contain broadly similar habitat.

1 Introduction

Manaaki Whenua – Landcare Research (MWLR), Lincoln, was commissioned by OSPRI to assess the efficacy of Pestex® deer-repellent 1080 cereal bait in deterring red deer from eating it, compared with non-repellent Pestex® 1080 cereal bait, during aerial baiting operations undertaken to help eradicate bovine tuberculosis (TB) from possums. The possum kill with both bait types was also assessed. The work was undertaken between May and October 2019.

2 Background

In forested mountain land, aerial 1080 baiting is the most cost-effective approach to eradicating TB from possums and other wildlife (Warburton & Livingstone 2015). However, this method can sometimes cause high levels of incidental mortality ('by-kill') of deer (Nugent et al. 2001; Morriss et al. submitted). Research starting in 2001 identified a repellent which, when added to carrot and cereal bait as a surface coating that changed the appearance and smell of the bait, successfully repelled deer but was still palatable to possums and rats (Forsyth 2002; Nugent et al. 2004, 2012, 2017; Morriss et al. 2006; Morriss 2007). Epro Ltd have the proprietary rights and have since used this product (Epro Deer Repellent: EDR) widely in pest control operations throughout New Zealand. However, recently, Epro indicated that they may cease producing EDR bait soon.

Two bait manufacturers, Orillion and Pest Control Research LP (PCR), aim to fill this niche. Both companies have developed alternative formulations of deer-repellent cereal bait to be used for broadscale possum and rat control. In both cases the repellent is incorporated into the bait matrix during manufacture (whereas EDR was surface-coated after bait manufacture). MWLR tested the palatability and efficacy of these new repellent formulations on captive possums and ship rats. Both formulations proved to be palatable and effective with both species (Morriss & Arrow 2018), so, in late 2018 OSPRI contracted MWLR to undertake a large-scale operational field trial of the PCR repellent bait to determine its efficacy for killing possums and reducing deer by-kill.

The most direct method of assessing death or survival of possums and deer during a 1080 operation is to radio-collar a sample of animals in the study area. Provided there is no major correlation between how easily animals can be captured and radio-collared and their predisposition to 1080 poisoning, the percentage of radio-collared animals killed provides a simple, direct, and rapid indication of kill that does not require adjustment for other factors affecting indices of animal abundance. Although radio-collaring deer in forested areas is typically difficult and prohibitively expensive, unforested areas in the north-eastern South Island were available for this trial, making the use of radio-collars more affordable than usual.

As there is wide variation in the reported by-kill of deer with standard non-repellent 1080 bait (Morriss et al. submitted), comparison of by-kill in an area where deer-repellent bait is used against a similar area done at a similar time with non-repellent bait is critical in confirming (or not) that the repellent is effective in repelling deer. Without this

experimental design, it is not possible to infer causation (i.e. whether a low by-kill of deer was the result of using a repellent bait, or some other environmental factor such as the availability of alternative food sources). The above design also allows an inference to be made on the effect of deer-repellent bait relative to non-repellent bait for possum control efficacy.

In summary, this report documents the outcomes of a large-scale operational field test of the efficacy of PCR repellent bait in reducing deer kill without adversely affecting possum control efficacy.

3 Objective

To assess the effectiveness of Pestex® deer-repellent 1080 cereal bait (relative to Pestex® non-repellent 1080 cereal bait) in reducing by-kill of red deer without reducing possum control efficacy by:

- comparing, in winter 2019, the percentages of radio-collared deer and possums killed between two areas baited with Pestex® cereal 1080 bait, one with and the other without deer repellent.

4 Methods

4.1 Trial design and study area

4.1.1 Trial design

For both possums and wild deer, the trial used a BACI (before-after-control-intervention) design that compared the numbers of radio-collared animals alive and present in the operational areas immediately before and soon after an aerial 1080 baiting under two treatments: Pestex® bait with deer repellent (the intervention) and Pestex® bait without deer repellent (the experimental control).

For deer, a target sample size of about 20 deer in each treatment was adopted to provide enough statistical power to distinguish between a low deer by-kill (less than the annual reproductive rate of 30–40%) and a high one (>70% by-kill, requiring many years for the population to recover). For possums, the need was to show high (>90% kill) efficacy both with and without repellent, which required larger sample sizes than for deer. Based on the operational thinking above, a target sample size of about 90 possums per treatment was considered appropriate for this trial.

The study required the operational specifications to be identical in the repellent and non-repellent areas (same bait sizes, sowing rates, and pre-feeding regimes) so that any measured difference could be attributed to the presence or absence of the repellent from the bait.

4.1.2 Study areas

The TB possum control operations comprised 15,030 ha in the Clarence Valley and 9,447 ha in the Awatere Valley, divided into the operational areas shown in Figure 1. Pestex® deer-repellent 1080 bait was used in the Clarence West and Waiautoa operational areas, and similar but non-repellent bait in the Upper Awatere South area (Figure 1).

The habitat differed between areas, with semi-arid grassland interspersed with matagouri and sweet briar in the Upper Awatere South area; beech forest and alpine grassland, with mānuka at lower altitude, in the Clarence West area; and mānuka and mixed seral forest with remnant improved pasture in Waiautoa. The altitude in the areas treated ranged from c. 140 to 2,000 m asl.

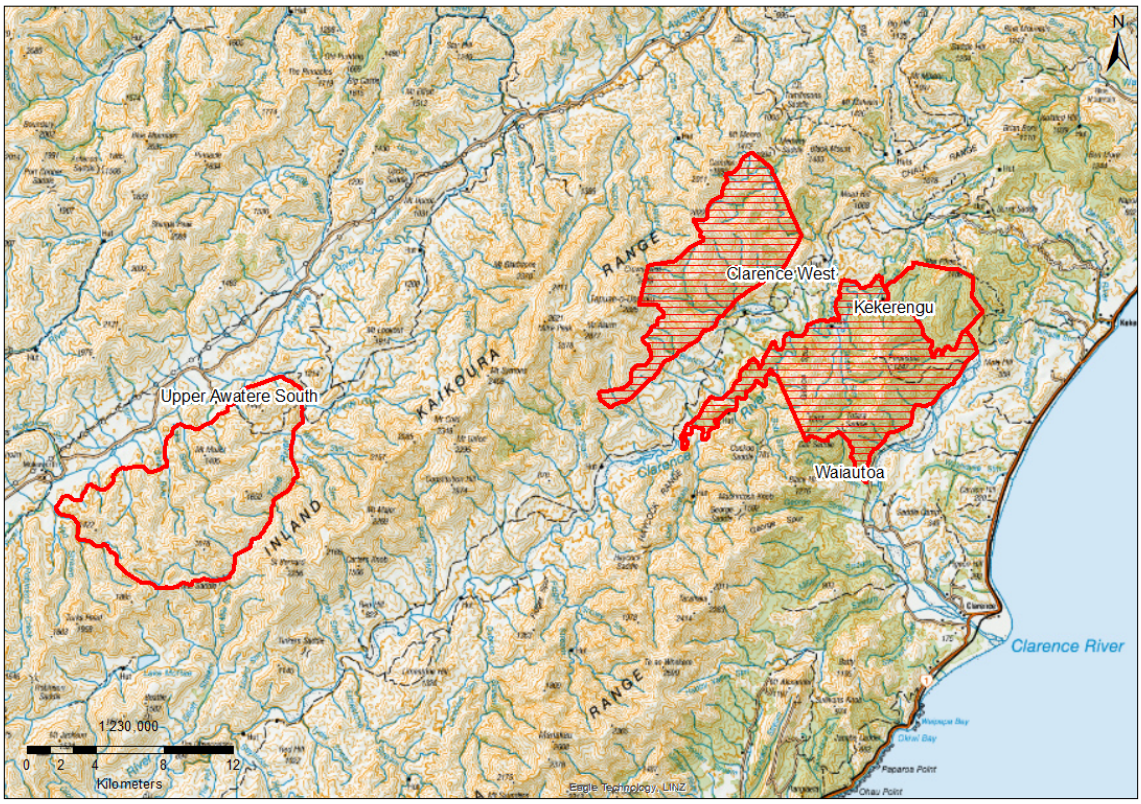

Figure 1. TB possum control operational areas in the Clarence and Awatere Valleys, poisoned June–July 2019. The areas cross-hatched were poisoned with Pestex® deer-repellent 1080 cereal bait and the remaining areas were poisoned with Pestex® non-repellent 1080 cereal bait. There was no formal monitoring of possums or deer in the Kekerengu operational 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 16 mm (6–8 g) cereal Prefeed Plus, with either repellent or non-repellent baits according to the experimental treatment, followed by the repellent or non-repellent Pestex® 1080 bait (16 mm 6–8 g cereal baits), respectively, broadcast at 2 kg/ha 19–20 days later.

In the Awatere area there were three fine nights before 2.2 mm of rain (snow) was recorded, with a total of 136.6 mm of precipitation over the following 2 months. The Clarence operations were pre-fed on 8/9 July 2019, followed 17–18 days later with toxic bait (Table 1). In the Clarence there were five fine nights before 15 mm of rain was recorded, with a total of 109.0 mm of precipitation recorded in the 2 months following toxic baiting.

Table 1. The name and size of TB possum control operational areas in the Awatere and Clarence Valleys, in Marlborough & North Canterbury, respectively, poisoned June–July 2019. DR = deer repellent

Operational area	Area (ha)	Bait type	Pre-feed sowing rate	Pre-feed sowing dates	Toxic sowing rate	Toxic sowing dates
Upper Awatere South	9,447	Pestex® 16 mm	1 kg/ha	20 May 2019	2 kg/ha	8–9 Jun 2019
Clarence West / Waiautoa	13,280	Pestex® DR 16 mm	1 kg/ha	8–9 Jul 2019	2 kg/ha	25–26 Jul 2019

4.2 Assessment of outcomes

4.2.1 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 the poison bait. In the central core (at least 300 m in from the block boundary) of the Waiautoa and Upper Awatere South blocks, we set traps on best sign, with a minimum of 30 m between traps, in April/May 2019. Leg-hold traps (Victor #1) were set on the ground at different sites for one to four nights.

The trap catch rate was low in the Upper Awatere South area (17 possums per 100 trap nights, resulting in capture of 73 possums) and moderate to high in the Waiautoa area (58 possums per 100 trap nights; 91 possums). The difference in trap catch rates probably reflects aerial 1080 baiting by OSPRI in Upper Awatere South in 2013 but no previous aerial 1080 baiting in Waiautoa.

Captured possums were sedated by intramuscular injection of Zoletil at 5 mg/kg of possum weight, then externally examined and palpated for TB lesions, weighed, ear-tagged, sexed, and fitted with a VHF radio collar (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 three times in each area: initially on 3 June 2019 (to ensure collars were operable), then immediately prior to baiting, and finally 3–4 days after the toxic baiting dates in Table 1. 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 4 days after the 1080 baiting, experienced staff used radio telemetry to locate and recover dead radio-collared possums. Two collared possums in Waiautoa were not found during post-poison ground searches so were later searched for using aerial tracking from a helicopter, with one of the two located. Staff also recorded any other species or unmarked possums found dead. Of the 164 possums radio-collared, two were never relocated during subsequent radio-tracking, most likely because of collar failure. A further nine died of unknown causes prior to baiting, one died because it moved to the block boundary and ate a Feratox cyanide pellet, and the collar on one possum broke off before the 1080 baiting.

The single radio-collared possum still alive after the 1080 baitings was subsequently tracked to its nest and shot, to recover its radio-collar.

4.2.2 Radio-collaring deer for by-kill assessment

Deer were located using a McDonnell Douglas 520 Notar helicopter (MD520N) and tranquilised by the observer using a dart gun or caught using a net gun. Once incapacitated, a programmable drop-off VHF mortality-sensing radio-collar was fitted, and then those that were tranquilised were administered with a reversal drug. A veterinarian was part of the capture crew to administer the drugs and monitor the welfare of captured deer. Deer in the central core of the operational areas were targeted to minimise the risk of them moving out of the operational area before toxic bait was sown.

A representative mix of ages and sexes were collared (see Appendix 2). Initially, 22 deer were collared in each area, and then a further 10 deer were collared in the repellent area (by redeploying collars recovered from the non-repellent area, where 1080 baiting was completed 7 weeks earlier than in the repellent area (Table 1). One of the collared deer died before the 1080 baiting (reducing sample size in the repellent area to 31 deer).

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 three, 30 and 90 (Upper Awatere South only) days after the 1080 baiting dates. A helicopter was used to radio-track and accurately locate live and dead deer either 4 days (Upper Awatere South) or 19 days (Waiautoa and Clarence West) after baiting. Radio-collared deer emitting 'live' signals were tracked until they were sighted and confirmed as alive. The collars on those surviving deer are scheduled to drop off in November 2019.

The location of deer was recorded and dead deer were transported to a sampling site, where the radio-collars were removed, the deer were weighed using the digital on-board cargo hook scales of the helicopter, a lower jawbone was collected for determining age, and samples of muscle (50 g) from a rear leg were collected for 1080 analysis. The weight recorded was for the entire carcass ('liveweight'). The date and time of movement cessation to the nearest hour of dead deer was determined from the radio-collar TSD function.

A proportion of uncollared dead deer found during post-poison fieldwork were similarly sampled (Upper Awatere South, n = 10; Waiautoa and Clarence West, n = 7). Any other non-target species found dead were noted and muscle samples collected for 1080 analysis from species not normally seen in post-1080 baiting carcass searches. The location of any uncollared possums found dead was also recorded but no samples were collected.

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.

4.3 Data analyses

The deer from the non-repellent area were substantially larger than in the repellent area (see results), which will have resulted in differences in 1080 concentration for a given amount of bait consumption. To account for this and to obtain a coarse measure of total 1080 consumption, 1080 concentration was multiplied by liveweight to provide a 'Total 1080 Index'. To test the hypothesis that lethality was inversely related to body size (i.e. large animals were more likely to survive), we compared inferred weights of survivors and deer that were killed by eating 1080 bait. Because actual weights could only be recorded for killed deer, we inferred weight for survivors based on the age/sex averages for those actually weighed.

Carcass weights and 1080 concentrations were compared using t-tests. The proportions of deer and possum killed by the two bait types were compared using contingency tables.

5 Results

5.1 Efficacy of possum control

Radio-tracking 3–4 days after the 1080 baitings indicated that 68 of 69 possums still present in the non-repellent area were dead, as were all of 82 still present in the repellent block (Table 2). A one-tailed Fisher's exact test indicated no support for the hypothesis that the repellent bait was less effective in killing possums than non-repellent bait (P = 0.45).

TSD estimates were obtained for 65 possums in the non-repellent area, with 62 (95%) of those dying within 1 day of bait being sown, and the other three (5%) within 2 days. In the repellent area, TSD estimates indicated 80 (97.5%) were killed within 1 day and the other two within 2 days. There was therefore no evidence that the repellent resulted in possums taking longer to be killed.

Table 2. The fate of radio-collared possums and deer following aerial baiting with Pestex® 1080 cereal bait with or without deer repellent. 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 %kill and (and associated 95% confidence limits).

	Location 1 day before baiting		Post-baiting status			
Species / bait type	**Inside**	**Outside**	**Alive**	**Dead**	**% kill**	**(95% CI)**
Possums						
Non-repellent	69	0	1	68	98.6%	(91.1–99.9)
Repellent	82	0	0	82	100.0%	(95.1–100.0)
Deer						
Non-repellent	11	11	0	11	100.0%	(74.1–100.0)
Repellent	30	1	11	19	63.3%	(43.9–79.5)

5.2 Deer by-kill

All 11 (100%) of the radio-collared deer still alive within the non-repellent area when 1080 bait was sown died (Table 2). The TSD data indicated that the deer that were killed by 1080 all died within 1 or 2 days of toxic bait being sown. In addition, 19 uncollared dead deer were seen within the baited area. However, some deer survived, as three live deer (and two live chamois) were also seen during post-1080 monitoring.

In contrast, a third (36.7%) of the collared deer in the repellent area survived (Table 2). Thus, where deer-repellent bait was used in this study, we recorded a 36.7% lower by-kill (95% CI = 13–60%; Fisher's exact test $P = 0.04$).

Of the 19 deer killed in the repellent area, 17 (89%) died within a day of bait being sown, one after 2 days and one after 4 days. The last two deer that died were close to the operational boundary so may not have encountered bait as soon as it was sown. Three of the 11 surviving deer were aerially radio-tracked in the repellent block at the time bait was sown, and also on 29 July 2019, 3 days after baiting. However, they were located 0.4–1.6 km outside the operational area during carcass recovery (3 weeks later) (Appendix 2). An additional 12 uncollared dead deer, seven live deer and three live chamois were also seen during post-1080 monitoring.

The concentrations of 1080 in leg muscle tissue (Appendix 1) were, on average, higher in the repellent area than in the non-repellent area (0.352 mg/kg; 95% CI = 0.272–0.432), [n = 20; one deer not sampled] vs 0.784 mg/kg; 95% CI = 0.588–0.980 [n = 26], t = 3.7, df = 44, P = 0.0006). However, there was a negative linear relationship between live weight and 1080 concentration in the repellent area (R^2 = 0.22, df = 25, P = 0.017) but not in the non-repellent area (R^2 = 0.003, df = 19, P = 0.80) (Figure 2). As a result, the average 'Total 1080 Index' (1080 concentration × liveweight) in killed deer did not differ greatly between the repellent and non-repellent areas (36.9 ± 10.1 mg vs 45.1 ± 10.1 mg; t = 1.1, P = 0.28).

The lack of any major difference in this index despite the difference in 1080 concentration reflected the 68% greater average weight of the deer carcasses from the non-repellent area compared to the repellent area (means of 106.0 ± 14.7 kg, n = 21 vs 63.1 ± 7.5 kg, n = 26, respectively, t = 5.4, df = 44, P < 0.001). The mean weight of killed deer (collared and uncollared) in the repellent block was only 10% lower than the mean weights of the 11 survivors (inferred from the age/sex averages of the killed deer; 69.1± 11.5 kg), providing little direct support for the hypothesis that by-kill risk was lower for larger deer (t = 0.86, df = 35, P = 0.39).

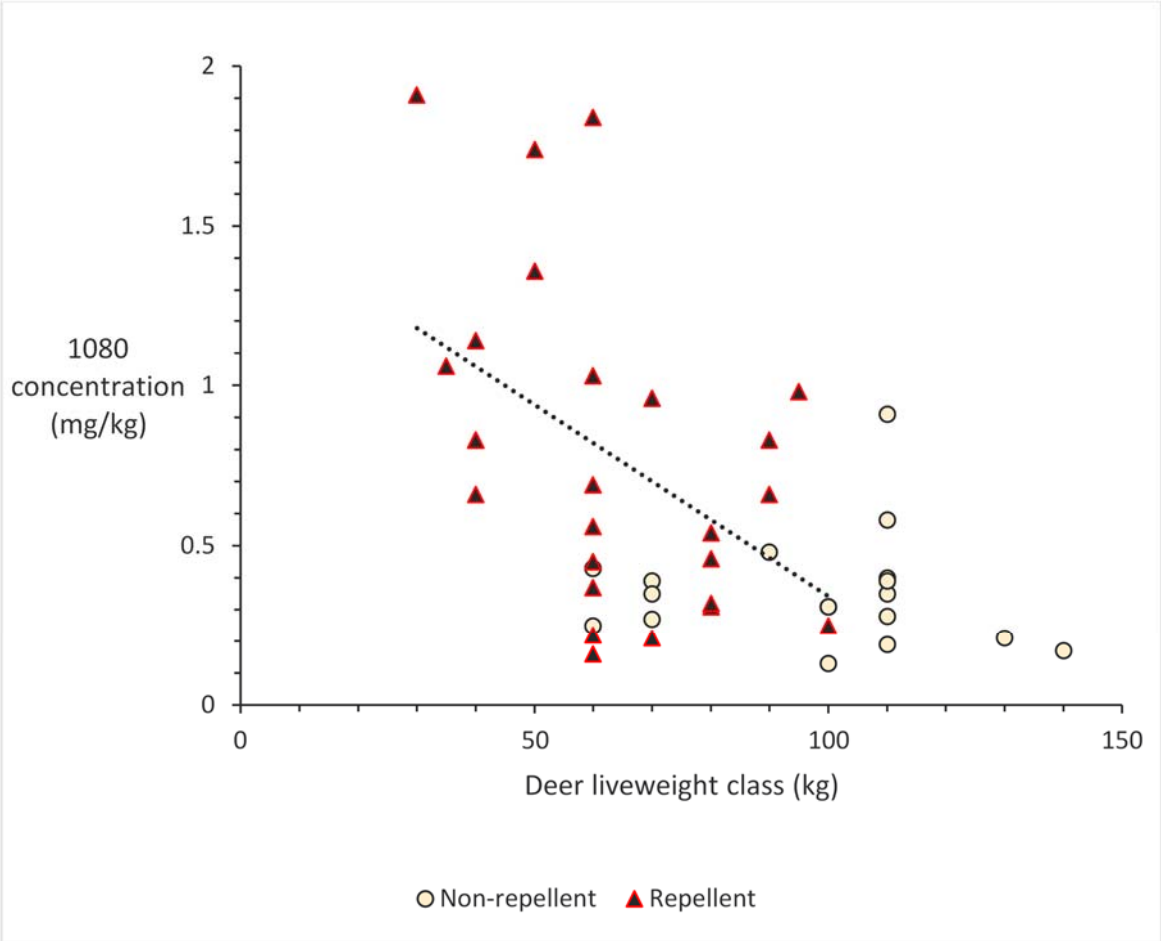

Figure 2. Area-specific relationships between 1080 concentration in leg muscle tissue and the liveweight of deer killed during aerial baiting with Pestex® 1080 cereal bait. The dotted line represents a negative relationship between weight and 1080 concentration in the repellent area (see text). There was no such relationship evident in the non-repellent area.

5.3 Other observations

5.3.1 Possum movements and weights

Including some possums that died before the 1080 baitings, the mean distance between the locations of individual possums at capture and death was 360.3 ± 55.7 m (n = 73) in the non-repellent area and 222.1 ± 59.0 m (n = 91) in the repellent area. The difference is likely to be a real effect (t = 3.32, df = 162, P = 0.001). However, the mean weight of adult possums in the non-repellent area (3.13 ± 0.13 kg, n = 68) was similar to that in the repellent area (3.02 ± 0.10 kg, n = 90) (t = 1.29, df = 156, P = 0.19).

The sole surviving possum was an adult male of slightly above-average weight (3.2 kg). It was shot towards the end of the study 577 m from where it was captured.

5.3.2 Deer movements

Deer movements after collaring are summarised visually in Appendices 2. The average distance between the locations at which deer were captured and where they died or were last recorded was 7.1 km (range: 0.3–23.0 km) in the non-repellent area and 1.7 km (range: 0.2–16.0 km) in the repellent area. The largest shift was by a yearling, which moved 23 km before being shot a month after collaring.

5.3.3 Incidental observations

During ground-based searches for radio-collared possums, we also found the carcasses of four uncollared possums, one stoat, one blackbird, one chamois, and three goats in the non-repellent area, and 13 uncollared possums, two rabbits, and three chaffinches in the repellent areas. Muscle tissue was analysed from one goat and one chamois, and both contained 1080 (0.36 and 0.23 mg/kg, respectively) indicating that they had been poisoned.

6 Discussion

6.1 Repellent impact on possum control efficacy

Pre-fed Pestex® 1080 bait had high control efficacy against possums, both with and without the incorporation of the new PCR deer repellent. There was therefore no evidence suggesting that the repellent had any adverse effect on the percentage of possums killed or the rate at which they were killed. The TSD data confirmed that at a sowing rate of 2 kg/ha almost all possums encountered and ate a lethal quantity of bait on the first night it was available. The possums did not differ greatly in size between the areas, suggesting there was no great difference in per capita food availability that could have affected bait uptake.

6.2 Repellent efficacy in reducing deer by-kill

The 100% kill of deer when non-repellent bait was used is the highest by-kill ever recorded. The actual kill is likely to have been lower, as the small sample size (n = 11) resulted in a wide confidence interval. Certainly, some deer survived and were seen in the area after the 1080 baiting, although these may have been immigrants. The outcome is similar to the high deer kill recorded in two recent operations; specifically, ≥90% by-kills of red deer on Molesworth Station in 2017 (Pinney 2019; Morriss et al. 2018, 2019) and in Timaru Creek in 2018 (Morriss & Nugent. 2018). Those two operations used a different type of bait (Orillion RS5) but the same sowing rate of 2 kg/ha.

A recent meta-analysis covering 26 cereal-bait-1080 operations (or parts of operations) conducted since 1999 has shown that deer by-kill was more likely to be low or moderate when sowing rates of ≤ 1.5 kg/ha were used (Morriss et al. submitted). Malham et al. (2019) report no discernible impact of aerial 1080 baiting by the Department of Conservation on the sighting rate of deer, with the operations they monitored mostly using a sowing rate of 1 kg/ha.

The 37% lower by-kill in the repellent area provides strong evidence of a real reduction in deer by-kill risk if repellent bait is used. Nonetheless, the actual by-kill was still moderately high at 63% (Table 2). As the rate of increase of un-hunted deer populations with high food availability is of the order of 35% p.a. (Forsyth et al. 2010), it could take as little as 3–4 years for the population to recover to the pre-1080 level in the repellent area if there were no hunting offtake. However, the small body size of the deer in the repellent area suggests the population may be nutritionally limited, and it is also likely some hunting will occur, so recovery could take longer than that. However, given the mobility of deer seen in this study, we would expect deer immigration into the poisoned areas from surrounding unpoisoned areas, which should speed up population recovery.

Despite the lack of strong evidence from this study, it is intuitively likely that the much smaller size of the deer in the repellent area will have increased deer by-kill there. That inference is based on the absence of any major difference in the 'Total1080' index between the two areas, which implies that the deer that died had eaten a similar amount of bait under each treatment. If so, and if the deer in the repellent area had been larger in size, we would therefore have expected more of them to have survived (i.e. a lower by-kill). That possibility is supported by under-representation of large-bodied deer (adult stags) among 1080-killed fallow deer in the Blue Mountains in 2001 (Nugent & Yockney 2004), and by their over-representation among survivors after a Molesworth 2017 operation in which most red deer were killed (Morriss et al. 2018, 2019).

The finding that the deer that were killed in the repellent area had apparently eaten as much bait (on a per-individual basis) as those in the non-repellent area weight is counter-intuitive. It suggests that the deer in the repellent area were either strongly repelled by the bait or not at all – there was no indication that the repellent caused deer to feed more cautiously (which we expect would have resulted in a lower 1080 concentration).

The partial but far from complete protection provided to deer from using repellent observed in this study is strikingly similar to the outcome we recorded in Timaru Creek in 2018 (Morriss & Nugent 2018). There, the number of deer recorded on trail cameras

before and after aerial 1080 baiting was compared between areas baited with 12 g RS5 cereal 1080 bait with and without the surface-coated EDR deer repellent. Because deer sighting rates vary seasonally, the estimates of by-kill were calculated after accounting for the natural changes in sighting rate recorded in a nearby unpoisoned area. The adjusted estimated kills based on the number of deer photographs recorded in the month before and the month after 1080 baiting were 52.7% for the EDR repellent area and 90.4% for the non-repellent area. The 40.4% reduction in by-kill risk (calculated from the no-1080-adjusted counts of visitors to camera sites) has a 95% CI of 21.0–59.0%, which spans much the same range as that for the 36% lower by-kill (95% CI = 13–60%) recorded in this study.

We therefore conclude that the new PCR repellent is moderately effective, and suggest it is likely to be as effective in reducing by-kill to low levels if used under the conditions in which EDR has previously been successful. The effectiveness of the repellent is likely to be enhanced by reducing the 1080 sowing rate to 1 kg/ha, and possibly also by reducing the interval between operations.

6.3 Other findings

If the distance between capture and final locations of possums is of much the same order as home-range radius (Yockney et al. 2013), this suggests mean home range sizes of about 40 ha in the non-repellent area and 15 ha in the repellent area. The difference possibly reflects differences in density and/or habitat type between the areas. Given the sowing rate of about 300 6-g baits/ha, individual possums would have had access, on average, to roughly 4500–12,000 baits. As there are few bait competitors compared to forested areas in which rodents are abundant, this appears to be far more bait than is necessary.

The finding of 1080 in a chamois is, to our knowledge, the first confirmed record of chamois by-kill during 1080 baiting. Numbers of chamois seen (one dead and two alive in the non-repellent area) were too small to infer the level of by-kill, but in comparison we saw 30 dead deer but only three live deer in the same area at the same time.

Apart from a failed attempt to catch and radio-collar fallow deer in order to assess 1080 by-kill in the Blue Mountains, Otago, in 2001 in which only three deer were caught (Nugent & Yockney 2004), this is the first time by-kill has been assessed directly from the mortality of radio-collaring deer. We consider it was successful, despite the sample size in the non-repellent area being reduced by half by deer emigration. The reason(s) so many deer emigrated from the non-repellent area but only one from the repellent area are not known, but it suggests that where possible such radio-collaring should be done only a few weeks before the 1080 baiting.

With hindsight, it would have been useful to record some biometric data when deer were captured (perhaps body length, girth, and shoulder height, or, even better, actual liveweight if at all feasible). This would have enabled a direct assessment of the effect of body size on by-kill risk.

7 Recommendations

- Even though a moderately high by-kill of deer still occurred in this trial when Pestex® deer-repellent bait was used, it warrants further development and testing (depending on the availability of other repellents). This recommendation is based on the inference that the outcome of this trial was similar to the moderately high by-kill also recorded in a recent trial with EDR, a repellent that has proven highly effective in earlier trials.
- If the Pestex® deer repellent (or other deer-repellent baits) are to be field tested further, we recommend that field tests of both possum control efficacy and deer by-kill be undertaken using high and low sowing rates (e.g. 2.0 and 0.5 kg/ha) in preference to comparing high sowing rates with and without repellent.
- Provided live capture of deer is feasible and affordable, use of radio-collared deer should be the preferred approach to assessing by-kill. Collaring should ideally be undertaken only a few weeks before 1080 baiting to minimise the risk of deer emigrating from the study area. Some measure(s) of body size should be recorded for all collared deer to help understand (and adjust for) the possible influence of deer size on by-kill risk. Given the mobility of deer in this study (particularly in the non-repellent area), study areas for the different 1080 treatments need to be large (>10,000 ha), separated by at least 5 km, and contain broadly similar deer habitat.

8 Acknowledgements

We thank Ben Davidson from the Rangiora Vet Centre and Wyndon Aviation for assistance with deer capture and radio-collaring. Thanks to Oscar Pollard, Grant MacPherson, Andrew Withers (Valley Pest Control), Dayna Hamilton and Jake Knowles (Excell) for possum trapping and collaring and/or carcass recovery. Thanks to the landowners in and around the operational areas who allowed access for animal monitoring. Also, thanks to OSPRI for funding and Ivana Giacon for appendices cartography, Dave Latham and Simon Howard for reviewing the report, Ray Prebble for editing, and Kate Boardman for final formatting of this report.

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Appendix 1. Concentrations of 1080 in deer carcasses

Table 3. Concentrations (mg/kg) of 1080 in muscle tissue samples collected from red deer carcasses from two study area baited with Pestex® 1080 cereal bait, with and without deer repellent, June–July 2019. The sex, liveweight, and age-class (adult >2 years, yearling c. 1.5 years, juvenile c. 0.5 years) of each deer are also shown

1080 bait type	ID	Sex	Liveweight (kg)	Age class	Muscle 1080 concentration (mg/kg)
Non-repellent	CH15	Female	60	Juvenile	0.25
Non-repellent	CH17	Female	100	Adult	0.13
Non-repellent	CH23	Female	60	Juvenile	0.43
Non-repellent	CH27	Female	110	Adult	0.19
Non-repellent	CH33	Male	140	Adult	0.17
Non-repellent	CH37	Female	110	Adult	0.58
Non-repellent	CH51	Male	130	Adult	0.21
Non-repellent	CH63	Female	100	Adult	0.31
Non-repellent	CH73	Female	70	Juvenile	0.27
Non-repellent	CH79	Female	110	Adult	0.28
Non-repellent	WPT 75	Male	170	Adult	0.16
Non-repellent	WPT 77	Female	110	Adult	0.35
Non-repellent	WPT 85	Male	190	Adult	0.47
Non-repellent	WPT 84 B	Male	70	Juvenile	0.39
Non-repellent	WPT 84 A	Female	90	Adult	0.48
Non-repellent	WPT 88	Male	110	Adult	0.40
Non-repellent	WPT 89 A	Female	110	Adult	0.91
Non-repellent	WPT 89 B	Female	70	Juvenile	0.35
Non-repellent	WPT 91	Male	110	Yearling	0.39
Non-repellent	WPT 92	Female	100	Adult	0.31
Repellent	CH19	Female	70	Adult	0.96
Repellent	CH21	Female	40	Juvenile	1.14
Repellent	CH25	Female	70	Yearling	0.21
Repellent	CH29	Female	60	Yearling	1.03
Repellent	CH31	Male	100	Adult	0.25
Repellent	CH39	Male	90	Adult	0.66
Repellent	CH41	Male	40	Yearling	0.66
Repellent	CH55	Male	60	Juvenile	0.56
Repellent	CH65	Female	80	Yearling	0.31
Repellent	CH71	Female	50	Juvenile	1.36
Repellent	CH85	Female	60	Adult	0.69
Repellent	CH91	Female	90	Adult	0.83

1080 bait type	ID	Sex	Liveweight (kg)	Age class	Muscle 1080 concentration (mg/kg)
Repellent	CH95	Male	95	Adult	0.98
Repellent	CH97	Female	80	Adult	0.46
Repellent	CH15	Female	40	Juvenile	0.83
Repellent	CH35	Female	60	Adult	0.37
Repellent	CH45	Female	60	Adult	1.84
Repellent	CH61	Female	30	Juvenile	1.91
Repellent	CH75	Male	60	Juvenile	0.16
Repellent	W2	Female	60	Yearling	0.22
Repellent	W1	Male	35	Juvenile	1.06
Repellent	B2	Female	80	Adult	0.54
Repellent	B3	Female	50	Adult	1.74
Repellent	B1	Female	40	Juvenile	0.83
Repellent	W3	Male	60	Yearling	0.45
Repellent	B4	Female	80	Adult	0.32

Appendix 2. Movements of radio-collared deer

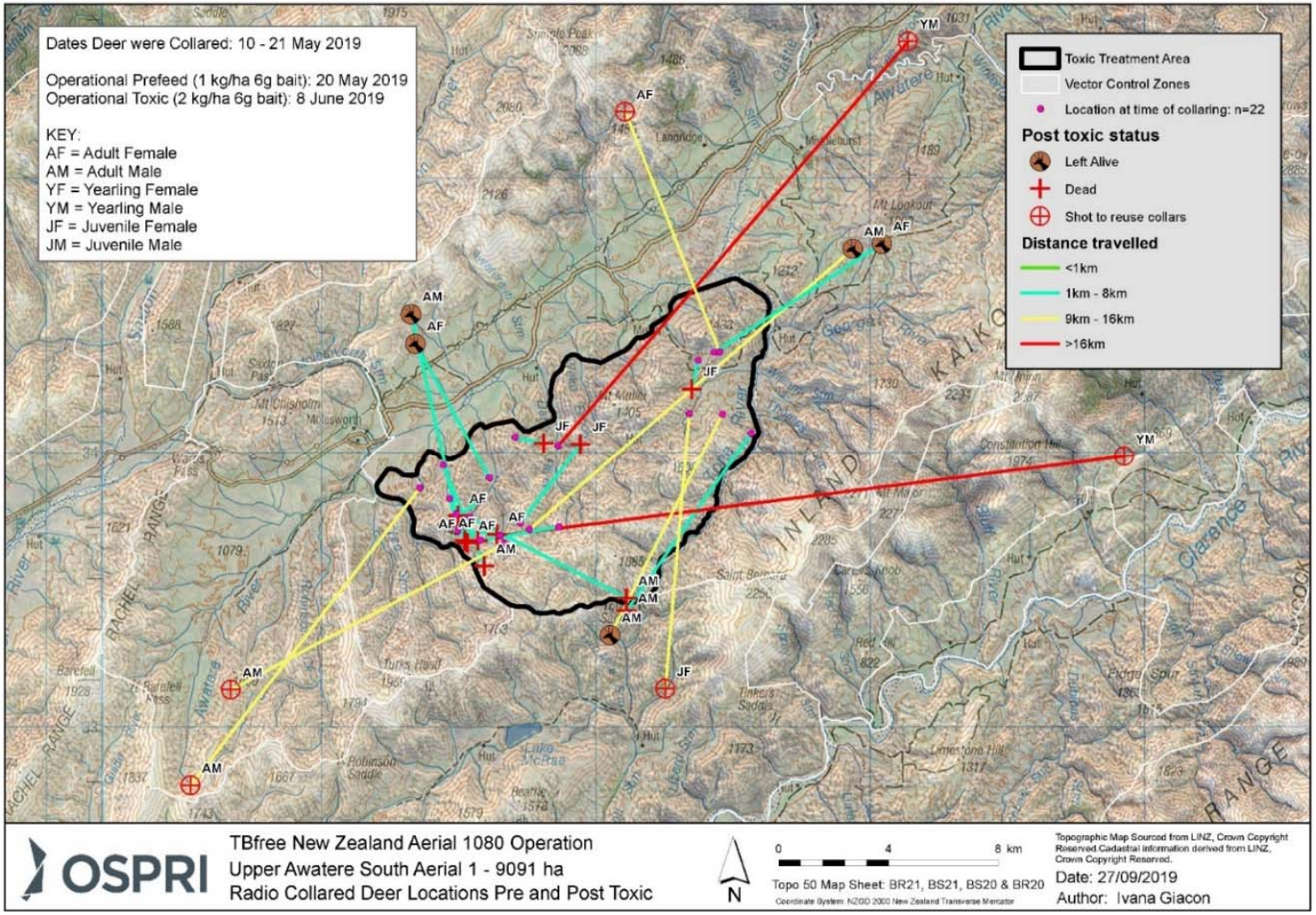

Figure 3. Capture and final known locations of radio-collared deer in the Upper Awatere South operational area baited with Pestex® 1080 cereal bait without deer repellent.

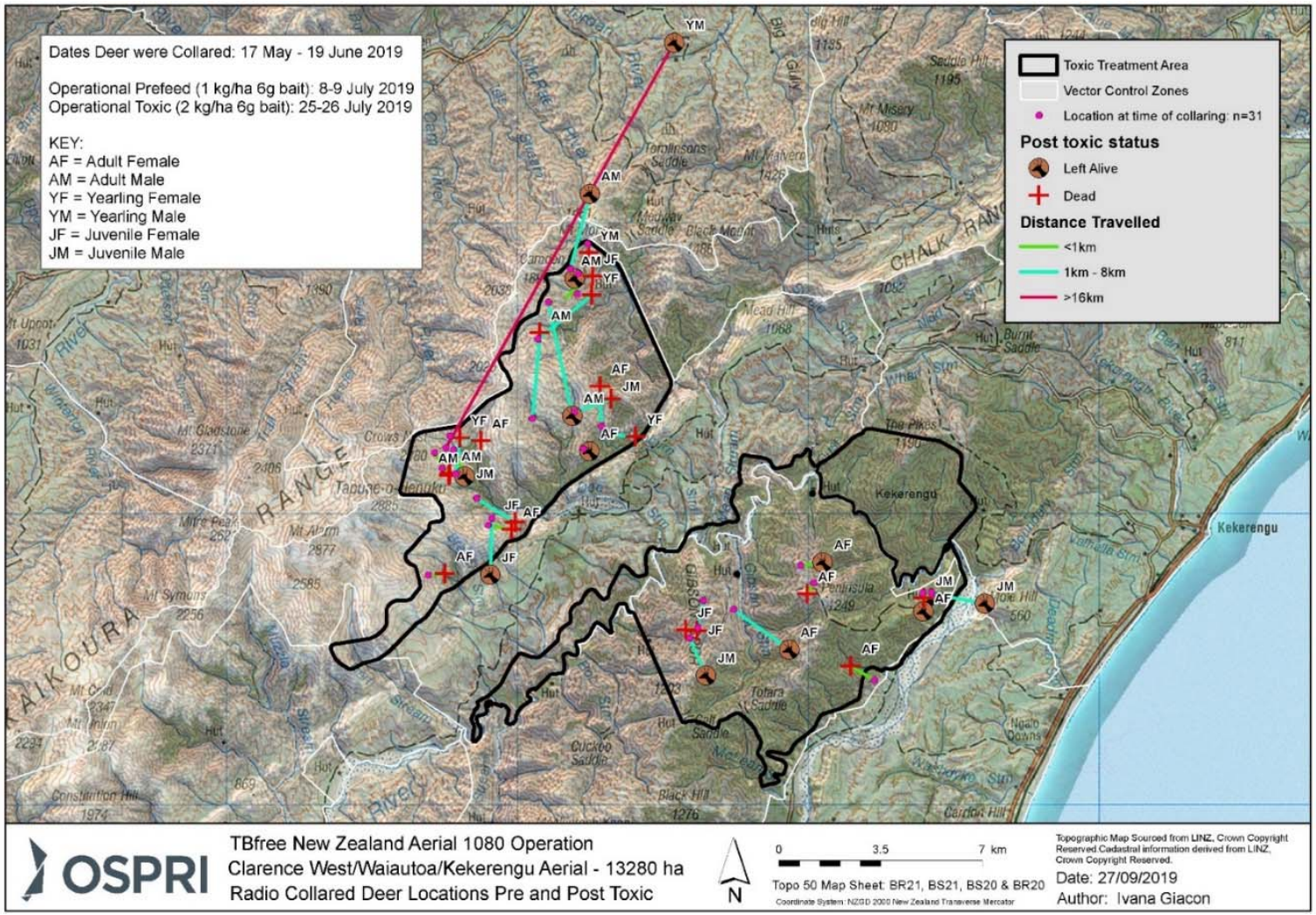

Figure 4. Capture and final known locations of radio-collared deer in the Clarence West and Waiautoa operational areas baited with Pestex® 1080 cereal bait with deer repellent.