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RESEARCH

Effectiveness of aerial 1080 for control of mammal pests in the Blue Mountains, New Zealand

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Abstract: The endemic fauna of New Zealand evolved in the absence of mammalian predators and their introduction has been devastating. Large-scale aerial applications of cereal baits containing sodium fluoroacetate (1080) are routinely used to control these pests. During one such operation in the Blue Mountains, West Otago, trail cameras were used to monitor the impact of the application on mammalian predators. Both stoats and rats were regularly recorded on cameras throughout the study area before the poison operation, but no stoats or rats were recorded the day after the operation, and none had returned by the time monitoring ended 38 days later. Possum, mouse and hedgehog detections were also significantly reduced. The aerial 1080 operation was therefore effective at controlling pests, and there was no evidence of a decline in bird or deer abundance due to non-target poisoning. Before this study it was not known that hedgehogs could be controlled by aerial 1080; this finding reveals an added benefit from its application. The use of trail cameras was effective at monitoring a range of species and although more labour-intensive than traditional monitoring methods, it provided more detailed information.

Keywords: hedgehog, mouse, pest control, possum, rat, stoat, trail cameras, weasel

Introduction

In New Zealand, many native bird species are impacted by introduced pest mammals and are predicted to decline without pest management (Parkes & Murphy 2003; Innes et al. 2010). Species such as kiwi (*Apteryx* spp.), mohua (*Mohoua ochrocephala*), whio (*Hymenolaimus malacorhynchos*), and bats (*Chalinolobus tuberculatus*; *Mystacina robusta*) are in decline mainly because of stoat (*Mustela erminea*) and/or ship rat (*Rattus rattus*) predation (O'Donnell et al. 1996, Brown et al. 1998; Basse et al. 1999; Dilks et al. 2003; Pryde et al. 2005; Whitehead et al. 2008). Introduced brushtail possums (*Trichosurus vulpecula*) also prey on native birds and carry bovine tuberculosis (Coleman & Caley 2000; Cowan 2005). Mice (*Mus musculus*) and hedgehogs (*Erinaceus europaeus*) are also predators of invertebrates, lizards and ground-nesting birds (Jones & Sanders 2005; Ruscoe & Murphy 2005; Spitzen-van der Sluijs et al. 2009).

Aerial application of cereal baits containing sodium fluoroacetate (1080) is used routinely to control both possum and rat populations over large areas of forest in New Zealand (O'Donnell & Hoare 2012; Elliott & Kemp 2016; Nugent et al. 2019). These operations also control stoats through secondary poisoning (Murphy et al. 1999; Robertson et al. 2019). Conflicting information exists regarding the successful control of mice via 1080 operations (Miller & Miller 1995; Speedy et al. 2007; Fisher & Airey 2009). Hedgehog populations can be reduced by trapping (Reardon et al. 2012), but it is not known what impacts aerial 1080 operations have on them, whether through primary poisoning (by direct consumption of toxic cereal baits), or from secondary poisoning (through scavenging toxic carcasses).

In 2014, there was widespread beech seeding throughout the South Island's beech (*Fuscospora* and *Lophozonia* spp.) forests, and stoat and rodent population irruptions were predicted as a consequence (King 1983; King & Moller 1997). The Department of Conservation (DOC) undertook the "Battle for our Birds" campaign in which aerial 1080 operations were undertaken over selected areas that held vulnerable wildlife populations (Elliott & Kemp 2016).

The aim of our study was to use trail cameras to monitor the fate of a range of pest mammal species, primarily stoats, ship rats and possums, through an aerial 1080 operation in the Blue Mountains, West Otago, one of DOC's "Battle for our Birds" sites.

Methods

The study area was approximately 400 ha of beech forest in the Rankleburn Forest, located in the Blue Mountains, West Otago (Fig. 1). The Rankleburn Forest comprises 6907 ha of native bush dominated by silver beech (*Lophozonia menziesii*) on rolling hill-country, marked by tributaries

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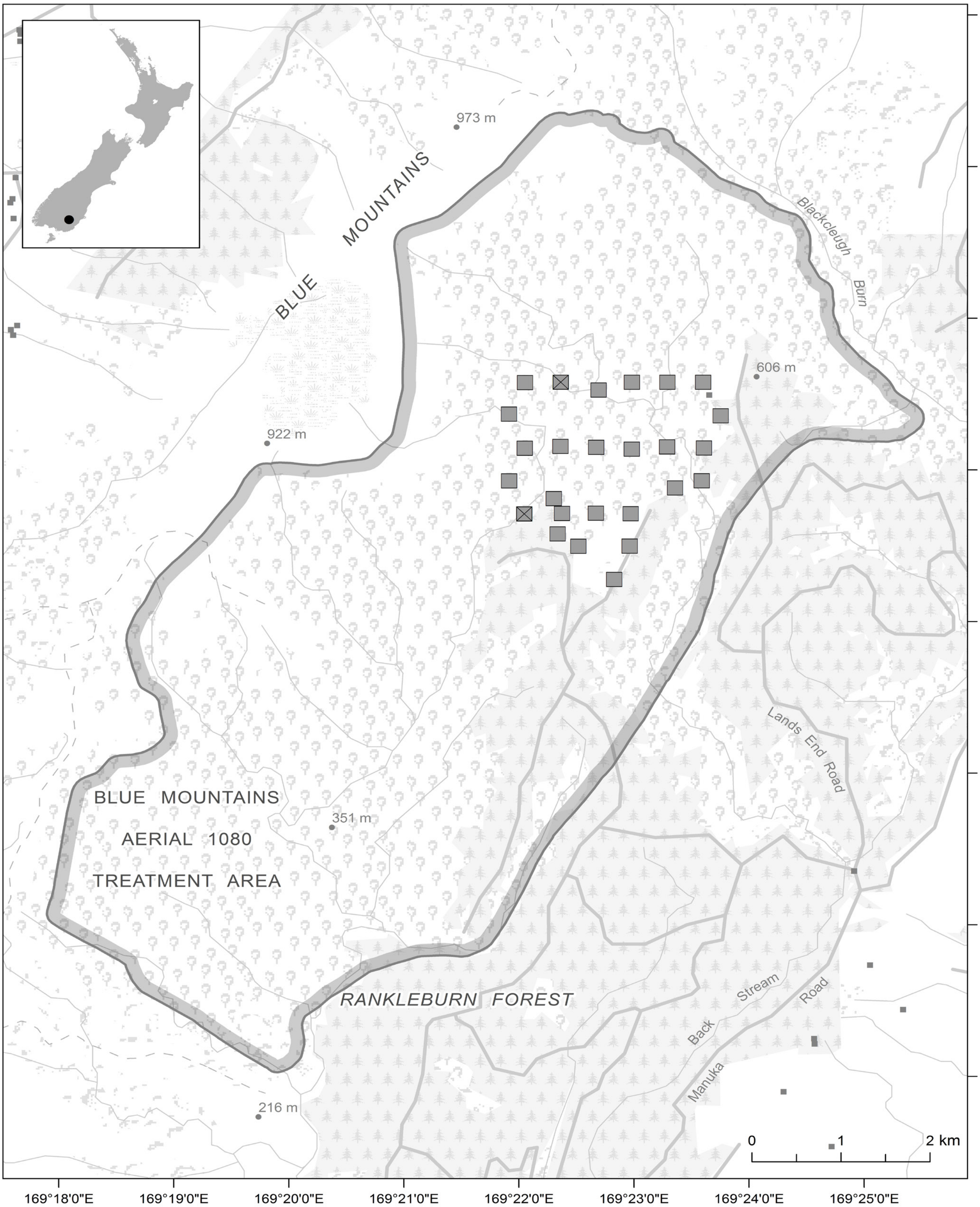

Figure 1. Map of study area in the Blue Mountains, West Otago. Shaded squares represent sites that had trail cameras and DOC 200 boxes. The two shaded squares that are cross hatched had a camera stolen or it malfunctioned.

carved into steep-sided gullies and with tussock land on the alpine areas (up to 1019 m). The native forest is managed by DOC and is surrounded by forestry plantations of Douglas fir (*Pseudotsuga menziesii*) and radiata pine (*Pinus radiata*) with logging roads along eastern ridges for forestry management and harvesting access (Ernslaw One Ltd). The Blue Mountains is a Recreational Hunting Area and has a large herd of fallow deer (*Dama dama dama*), which attracts many hunters from the wider South Island region.

The aerial 1080 operation covered 4618 ha of native forest with toxin applied over the entire study area (Fig. 1). The operation was initiated by DOC as part of the 2014 "Battle for our birds" campaign, although the actual operation was carried out by Operational Solutions for Primary Industries (OSPRI). Pre-feed cereal pellets were aerially sown on 6th November 2014 at a rate of 1 kg ha^{-1}. Toxic cereal pellets (0.15% 1080, 6 g RS5 cereal baits from Animal Control Products Ltd) were aerially applied on the 2nd December 2014 at a rate of 1.5 kg ha^{-1}. Epro Deer repellent (Speedy 2005) was used on the pre-fed and toxic pellets.

To monitor the pest species we used 26 wooden DOC 200 trap boxes with baffles but without traps ('stations'). These trap boxes were placed in a grid, 400 m apart on each line and 800 m between lines. Stations also covered the perimeter of the study area at 400-m intervals (Fig. 1). Twenty-five LTL Acorn 5210A cameras (Model Ltl-5210A, 940 nm infrared, Ltl Acorn Outdoors, Denmark, WI, USA) and one Bushnell Trophy camera (Bushnell Outdoor Products 9200 Cody, Overland Park, Kansas 66214, USA), which were movement and infrared activated, were deployed to record activity around the stations. Upon activation they recorded a 30 second video, with a 30 second delay before a further recording could be made. Cameras operated for 136 days; 98 before and 38 days after the toxin application. Each station was baited with a 4 × 4 cm^2 piece of fresh rabbit and a hen's egg at each servicing.

Aerial 1080 operations are weather dependent and there was a large window of time for when the operation could happen. Cameras were set up and the stations baited on the 27th August 2014, with camera servicing and re-baiting undertaken on the 16th September, 22nd October and 16th December. Cameras were collected on the 7th of January 2015. The SD cards and batteries were changed at each servicing, and all video clips were viewed and the identities of mammal and bird species were tabulated. Except for one faulty camera and one camera that was stolen, all cameras operated effectively throughout the study – all had space remaining on their memory cards and all had maintained battery power between servicing. During heavy fog or early mornings, cameras sometimes experienced high levels of condensation, temporarily affecting the image quality.

For each camera station we recorded whether a visit took place by a particular species during each 24-hr period (i.e. a presence/absence response). A 'visit' is defined as the presence of an animal (one or more video clips recorded within a 24-hr day); animals did not have to enter the tunnel during a 'visit'.

There were 13 days between the aerial 1080 operation and when the bait stations were re-baited, so 13-day periods were used to sample the data-set to compare both the effects of fresh baiting and the aerial 1080 operation. The number of different cameras recording a particular mammal species during each 13-day period were counted. Two-tailed Fisher's exact tests (Sokal & Rohlf 1981) were used to test whether there was a difference in the number of cameras recording a species in the last re-baited 13-day monitoring period before the aerial 1080 operation (starting 23rd October), and the post-operation 13-day monitoring period where the stations had been freshly re-baited (starting 17th December). Two-tailed Fisher's exact tests were also used to test for the effect of baiting on whether a stoat entered a DOC 200 box or not.

An index of bird abundance was calculated by the number of cameras (of 24) that detected a bird species in the 28 days before the poison operation (4th November to 1st December 2014), and the number in the 28 days following the operation (8th December 2015 to 4th January 2015). Bird detections were not included from the 2nd to 7th December, as any bird deaths may have been expected to occur mostly during that time. Two-tailed Fisher's exact tests were used to test for significance. Bird nomenclature follows Gill (2010).

Results

Of the 26 cameras, 24 were present over the entire 136-day study; 98 days before and 38 days after the poison operation. The number of videos recording an animal per camera ranged between 53 and 443. We gathered 4792 videos recording animals; wind could often result in videos of waving vegetation and these were excluded from the totals. The animal species recorded are given in Table 1. Following the major beech masting event in 2014, some cameras recorded videos of mixed-species flocks of several hundred finches feeding on

Table 1. The number of days each species was recorded on one or more of the 26 cameras deployed and total number of visits recorded on all the cameras for each species over the whole study period (27th August 2014–8th January 2015).

Species	No. of days	Total visits
Mouse (*Mus musculus*)	393	831
Stoat (*Mustela erminea*)	332	540
Possum (*Trichosurus vulpecula*)	250	439
Hedgehog (*Erinaceus europaeus*)	225	536
Rat (*Rattus* spp.)	204	478
Hare (*Lepus europaeus occidentalis*)	55	72
Deer (*Dama dama dama*)	25	35
Weasel (*Mustela nivalis*)	23	33
Person (*Homo sapiens*)	10	13
Cat (*Felis catus*)	3	7
Pig (*Sus scrofa*)	2	3
Dog (*Canis familiaris*)	1	4
Ferret (*Mustela furo*)	1	1
Blackbird (*Turdus merula*)	172	230
Song thrush (*Turdus philomelos*)	162	208
Greenfinch (*Carduelis chloris*)	121	476
'Finches'	110	622
Tītitipounamu (*Acanthisitta chloris*)	72	87
Ngirungiru (*Petroica macrocephala*)	51	56
Chaffinch (*Fringilla coelebs*)	50	59
Redpoll (*Carduelis flammea*)	23	32
Goldfinch (*Carduelis carduelis*)	6	9
Pīwakawaka (*Rhipidura fuliginosa*)	4	5
Mohua (*Mohoua ochrocephala*)	4	4
Dunnock (*Prunella modularis*)	4	4
Tauhou (*Zosterops lateralis*)	3	3
Korimako (*Anthornis melanura*)	2	2
Kārearea (*Falco novaeseelandiae*)	1	1
Kererū (*Hemiphaga novaeseelandiae*)	1	1
Riroriro (*Gerygone igata*)	1	1
Ruru (*Ninox novaeseelandiae*)	1	1

the prolific beech seed. The labour input in reviewing and recording camera footage data is summarised in Table 2.

Both stoats and rats were regularly recorded on cameras throughout the study area prior to the poison operation. Rats were almost always solitary, but stoats were twice recorded in family groups of up to six animals in November. The aerial 1080 operation appeared to have an immediate effect on all the mammal pest species (Table 3). The number of cameras recording stoats, rats, mice and hedgehogs were significantly different in the 13-day re-baited period after the operation than the re-baited period before the operation (Two-tailed Fisher's exact tests: stoats $P < 0.0001$, rats $P = 0.0006$, mice $P < 0.0001$, hedgehogs $P < 0.0001$). It was also significant for possums (two-tailed Fisher's exact test $P = 0.003$) but not for weasels (*Mustela nivalis)* (two-tailed Fisher's exact test $P = 0.489$), likely because of the small sample sizes. For deer there was a significant increase in deer recordings (two-tailed Fisher's exact test $P = 0.05$), but again sample sizes were small. The meat and egg baits did not seem to influence the number of stoats recorded at the DOC 200 boxes, but did have an effect on whether stoats entered the boxes or not. Of 140 stoat visits recorded in the three freshly baited 13-day sample periods, 67.9% of stoats entered the DOC 200 boxes; this compared to 52.5% of 141 stoats entering the boxes in the three sampling periods between baiting (two-tailed Fisher's exact test $P = 0.0104$).

Two dunnocks (*Prunella modularis*) and one song thrush (*Turdus philomelos*) were found dead after the 1080 operation and one blackbird (*Turdus merula*) appeared to be affected by 1080 on a trail camera video clip. However, there were no significant differences in the number of cameras recording birds over a 28-day period before and after the aerial 1080 operation (Table 4).

Table 2. Equipment costings and labour inputs for using cameras as a monitoring method.

Equipment	Cost (2015 NZD)	Labour input (at one camera station)	Time (minutes)
LTL Acorn 5210A	220	Preparation of camera before deployment (camera & SD card testing, charging batteries)	30
Acorn security housing	60	Field placement and servicing	20
Python bike lock	50	Time to review and record fifty 30 second video clips	100
Rechargeable batteries (8 IMEDOIN)	58		
16Gb SD card (SanDisk)	45		

Table 3. The percentage of cameras (of 24) that recorded a species over eight 13-day sampling periods throughout the study (the data from the two cameras that were not present for the entire study are excluded). The stations were baited with rabbit meat and a hen's egg four-times during the study (sample periods 1*, 2*, 4* & 8*). Between baiting, eggs were still mostly present but the rabbit had been taken. The aerial 1080 operation was undertaken on the 2nd December 2014.

Sample	Monitoring period	Stoat	Rat	Mouse	Possum	Hedgehog	Weasel	Deer
1*	28 Aug–9 Sep	95.8	25	33.3	70.8	25	0	4.2
2*	17 Sep–29 Sep	66.7	37.5	62.5	70.8	41.7	8.3	0
3	9 Oct–21 Oct	75	41.7	62.5	66.7	54.2	8.3	4.2
4*	23 Oct–4 Nov	83.3	41.7	75	50	70.8	8.3	0
5	6 Nov–18 Nov	66.7	45.8	58.3	87.5	66.7	4.2	8.3
6	19 Nov–1 Dec	91.7	25	54.2	75	50	12.5	4.2
7	3 Dec–15 Dec	0	0	0	0	4.2	4.2	12.5
8*	17 Dec–29 Dec	0	0	8.3	8.3	0	0	20.8

Table 4. The number of cameras out of a total of 24 that recorded a bird species in the 28 days (4th November–1st December 2014) before the aerial 1080 operation and 28 days after the aerial operation (8th December 2014–4th January 2015), leaving a 5-day window after the operation when birds could be still vulnerable. Probabilities calculated using two-tailed Fisher's exact tests.

Bird	Before 1080	After 1080	Probability
Blackbird	14	12	0.77
Song thrush	11	11	1.0
Chaffinch	7	8	1.0
Tītitipounamu	4	10	0.11
Ngirungiru	4	8	0.32
Redpoll	1	3	0.30
Korimako	1	1	1.0
Tauhou	1	0	1.0
Riroriro	0	1	1.0
Greenfinch	0	1	1.0
Unidentified	10	9	1.0

Discussion

Our study was not designed as a controlled experiment and had no non-treatment sites. The use of trail cameras however, allowed a detailed monitoring of the effectiveness of the management operation. Aerially applied 1080 appeared to be extremely effective at killing the targeted pest species. Although 1080 can be effective for possum and rat control through primary poisoning (Innes et al. 1995; Nugent et al. 2019) and stoat control through secondary poisoning (Murphy et al. 1999; Robertson et al. 2019), the speed at which this happened in our study was unexpected. No stoats or rats were recorded the day immediately after the operation, and none returned by the time we finished our monitoring (38 days after the operation). Few studies have recorded how quickly pests die after control operations. Murphy et al. (1999) found that stoats started dying within two days of an aerial 1080 poison operation and after seven days, 12 of 13 radio-collared stoats had died. The 13th stoat died after 18 days. Dowding and Murphy (1994) monitored five radio-collared rats through an aerial 1080 operation. The three males died within four hours on the night following the operation, but the two females were alive three days later. Eight out of 10 rats monitored through a 1080 bait station operation died within the first 2 days of the poison operation (Smith et al. 2009).

Possums, hedgehogs and mice, which also have an impact on native species, were likewise controlled by the operation. The use of trail cameras allowed for continuous monitoring of the pest populations and indicated how quickly they were reduced in abundance. An unexpected result of the camera monitoring was that hedgehogs were found to be common throughout the beech forest, as they have been considered less abundant in higher country (Jones & Sanders 2005). In the past, hedgehog control has been largely undertaken by trapping (Keedwell & Brown 2001; Reardon et al. 2012) and it was not known previously that aerial 1080 could be such an effective control method. Hedgehogs are omnivorous (Jones & Sanders 2005) so could have died from primary and/or secondary poisoning. Aerial operations using brodifacoum cereal baits result in high hedgehog mortality (Speedy et al. 2007, Griffiths et al. 2015) but no monitored hedgehogs died during an intensive four-month brodifacoum bait station operation (Berry 1999), indicating primary poisoning may be the main route as hedgehogs are unlikely to be able to access bait stations. If aerial 1080 operations routinely control hedgehogs along with possums, rodents and stoats this would be of real conservation benefit. However, hedgehogs hibernate in colder areas in winter (Jones & Sanders 2005), so in such areas, winter 1080 operations might not be expected to control them.

Although trail cameras proved an effective method for monitoring the effectiveness of the aerial toxin operation, the initial setup cost of camera plus security case and locks is substantial. It is difficult to compare the effectiveness of trail cameras with tracking tunnels for detecting and monitoring predators in the study area due to the huge difference in effort between methods; our cameras recorded continuously compared with one-night monitoring for rodents and three nights for mustelids in each tracking session (Gillies & Williams 2013). There were four rodent tracking lines in our study area and in the November before the operation, the one-day tracking rate was 10% for rats and 38% for mice (DOC unpubl. data). About two weeks after the 1080 operation, tracking rates dropped to 0% for both rats and mice. There were three mustelid tracking lines within the study area and the three-day mean mustelid tracking rate per line was 37% in November pre-operation, with 100% of lines tracked, and this also dropped to 0% after the operation (DOC unpubl. data).

Birds have been found dead after aerial 1080 operations, but non-target kills are becoming rarer due to reduced sowing rates and improved bait quality (Greene et al. 2013; Morriss et al. 2016). In our study, there was no evidence of a decrease in bird abundance in the four weeks after the aerial 1080 operation using cameras as a monitoring method. Mohua have been monitored in our study area since 2007. The October 2014 mohua counts (before the aerial 1080 operation) suggested a decline in mohua numbers from the year before, but the count in 2015 (after the aerial 1080 operation) was the highest since counts began in 2007 (R. Collen unpubl. report).

The aerial 1080 operation was effective at controlling mammalian pests and there was no evidence of a decline in bird or deer abundance from non-target poisoning. The rapidity with which pests were no longer detected was surprising. Before this study it was not known that hedgehogs would also be controlled by aerially delivered 1080, which is an added benefit from the operation.

Trail cameras are being used increasingly to monitor small mammals in New Zealand (Nichols et al. 2017; Anton et al. 2018; Murphy et al. 2018; Nugent et al. 2019). Cameras monitor a broad range of species and can provide information on species identity (e.g. weasels compared to stoats) that is not gained from more ‘traditional’ monitoring methods, such as tracking tunnels and chew cards. Furthermore, they provide information on behavioural interactions, and frequency and timing of visits. Another advantage of cameras is that the animal does not have to enter or interact with anything to be detected. While considerable time is currently required to process footage, this is likely to be reduced in the near future with advances in machine learning (Norouzzadeh et al. 2018).

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