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Fallow deer deaths during aerial-1080 poisoning of possums in the Blue Mountains, Otago, New Zealand

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Abstract Incidental kills of deer during aerial-1080 poisoning of brushtail possums (*Trichosurus vulpecula*) using baits containing sodium monofluoroacetate (1080) causes widespread hunter opposition to this control method. We document the deaths of a large number of fallow deer (*Dama dama*) after aerial-1080 poisoning in the Blue Mountains, Otago. Three deer fitted with radio collars all died during the poisoning. Eight randomly located "search cells" (25–57 ha) were each searched twice. One pig (*Sus scrofa*), 53 deer, 58 possum, and 20 bird (three native) carcasses were found. Deer-carcass density varied widely between cells (2.2–38.6/km^2), reflecting differences in deer density but apparently also the amount of ground cover. The total number of deer killed was estimated using Lincoln indices. More fawns were killed than larger adult deer. Comparison with historical harvest data suggested that between two-thirds and three-quarters of the deer present had been killed. This unintended by-kill will have reduced deer impacts on native plants and the risk of Tb spread or persistence in deer. However, such incidental benefits may not offset the increased indirect "social" costs likely to arise from increased hunter opposition to use of aerial-1080 poisoning.

Keywords *Dama dama*; fallow deer; poisoning; sodium monofluoroacetate; 1080; by-kill

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INTRODUCTION

Deer hunters strongly oppose the use of aerially broadcast sodium monofluoroacetate (1080) baits against introduced brushtail possums (*Trichosurus vulpecula*), the most frequently targeted mammalian pest in New Zealand. This attitude persists despite evidence that aerial 1080-poisoning is the most appropriate and cost-effective control method for possum control in remote and rugged areas of forest (Eason et al. 2000; Morgan & Hickling 2000). Hunters oppose the official view of introduced deer as conservation pests (Department of Conservation 2001), and believe that aerial 1080-poisoning frequently kills most of the deer they wish to hunt. Early trials in the 1950s and 1960s with aerially sown carrot baits certainly killed some red deer (C*ervus elaphus*), sika (*Cervus nippon*), and fallow (*Dama dama*) (Daniel 1966). However, more recently, the few possum-control operations in which the effects on deer have been assessed indicate a highly variable by-kill of red deer, ranging from near 0 to over 90%, but mostly 30–60% (see summary in Nugent et al. 2001). This paper documents a high kill of fallow deer during aerial poisoning of possums in the Blue Mountains, Otago, in 2001, and attempts to identify the likely factors determining deer kill rate.

The Blue Mountains herd of fallow deer is a highly regarded hunting resource. The majority of its range has been designated as a Recreational Hunting Area (RHA) since 1980, and is one of only a few areas where deer hunting on conservation land is managed in ways that help maintain harvest levels. The herd was intensively studied in the 1970s and 1980s, and the ecological impacts, age and sex structure, and movement patterns of the deer population have been well documented (e.g., Baker 1973; Nugent 1990a,b, 1994).

Unfortunately, bovine tuberculosis (Tb) has been recorded in both possums and deer within the area (J. Bayley Southern Pest Management pers. comm.), and in August 2001 about 6400 ha of the area was aerially sown with 1080 cereal baits. Previous operations in which incidental deer kill had been monitored all involved red deer (*Cervus elaphus*), and typically used relatively high sowing rates of carrot baits (Nugent et al. 2001). It was therefore not clear in advance what level of fallow deer kill might result from use of the low sowing rate with cereal bait that was proposed for the Blue Mountains. This study was undertaken to assess that.

In all the previous studies, deer kill had been determined using faecal pellet counts, but in this case the method was unsuitable because of the long lag (6–12 months) needed between the operation and the post-control survey to ensure adequate statistical precision. Such a delay is difficult both politically (hunters and managers typically prefer to know the outcome sooner rather than later), and because it creates the opportunity for other factors (such as changes in post-control hunting pressure) to substantially influence the post-control estimate. We therefore initially proposed to assess percent kill directly, by capturing and radio-collaring a sample of animals just before the operation and then estimating what proportion of marked animals were killed. However, it was far more difficult to capture the deer than anticipated, so instead we made systematic ground searches for carcasses 4–6 weeks after the poisoning operation. We counted the numbers of deer killed (rather than the percentage killed) in four of the 10 hunting blocks within the area poisoned. The goal was to determine, in absolute numbers of deer, the extent of the hunting resource lost. Because hunting effort and deer sighting and kill rates in the area have been monitored for almost two decades (unpublished studies by Nugent 1990a; Goonan 1995; Golding 2000), we aimed to assess, qualitatively, whether the estimated number of deer killed was (1) near zero, or (2) close to the estimated annual kill from these blocks, or (3) substantially greater than that.

Study area and control operation

The area poisoned covered 10 hunting blocks, about 6400 ha of the north-eastern corner of the Blue Mountains hunting area (c. 27% of the total). About half the area is exotic pine forest managed by Ernslaw One Limited, a forestry company, while the remainder is either patches of highly modified regenerating native forest (the eastern blocks adjacent to the Clutha River) or more-mature native forest dominated by silver beech (*Nothofagus menziesii*) and tussock land (three blocks on the western side of the area). The areas of native forest are administered by the Department of Conservation.

The poison baits were distributed on 22 August 2001, using a helicopter guided by a Global Positioning System (GPS) to sow RS5 cereal pellets containing cinnamon lure and 0.15% w/w of 1080 poison (Animal Control Products, Waimate) at 2 kg/ha. The area had been pre-fed at 1 kg/ha with similar, but non-toxic, bait 12 days previously.

The possum kill was independently assessed using the nationally standardised trap-catch method (NPCA 2001). Immediately after earlier ground-based control work in 2000, a mean trap-catch rate of 3.7% was recorded in the poison area, calculated from 20 trap lines with 20 traps on each, set for 3 nights (Southern Pest Management unpubl. data). After poisoning, in September 2001, a mean trap-catch rate of 0.7% was recorded from 25 trap lines of 10 traps each, set for 3 fine nights (unpublished Southern Pest Management Monitor Report, code: 14097-M-R).

METHODS

Marked-deer estimate of percent kill

We originally planned to radio-collar up to 40 deer, but caught only three. These, captured in May 2001 (by means of a net gun from a helicopter), were each fitted with a radio collar, and then released at the capture site. Their age-class, sex, and location were recorded, as were the number of flying hours spent hunting and the number of other deer seen. The capture and release procedures were approved by the Landcare Research Animal Ethics Committee (AEC Project No. 01/04/02). These three radio-collared deer were relocated 5 days before poisoning and again 13 days afterward, and their locations recorded.

Carcass searches

Four weeks after the poison baits were broadcast, observers searched for carcasses in four hunting blocks. Three blocks (Packers, Armstrong, and Clarks) have no internal road access and are predominantly mature silver beech forest with an open understorey. In these blocks there is thought to be little or no illegal hunting, so estimates of hunter kill are likely to be most complete. The fourth block (Tramways) has long had high deer densities (Nugent 1994), and Tb-infected possums and deer had recently been found there (J. Bayley pers. comm.).

The small, unforested areas in each block were systematically searched 13 days after poisoning, by helicopter in a single pass along more or less parallel flight paths. In two of the four blocks, these open areas were searched a second time at right angles to the previous flight path, but as no further dead deer were found, the remaining two areas were not searched a second time. The number of live deer seen was also recorded.

The forested strata in each block were divided into approximately square "search cells" nominally of about 50 ha each (although those eventually ranged from 25 to 57 ha in size, the discrepancy resulting mainly from difficulties in using hand-held GPSs under a forest canopy). Two randomly selected cells in each block were searched twice by groups of up to 17 observers walking along parallel transects about 20 m apart, with the transects for the second search being at right angles to those for the first. The sex and approximate age-class of each carcass were recorded, plus the distance and bearing to each carcass from where it was first seen. The average visibility of the carcass (i.e., the average distance from any direction from which the carcass could be seen) was subjectively scored. Any sightings of live deer were also recorded. The lower jawbone was removed to determine deer age (Fraser & Sweetapple 1993), and the carcasses were marked with a numbered tag. Marked carcasses found during the second search of each cell were classed as "recaptures". Dead birds (according to species), possums, and feral pigs seen during the searches were also recorded.

The density of carcasses within each cell was estimated using the Lincoln index according to the formulae in Pollock et al. (1990):

$$N_c = [(n_1 + 1)(n_2 + 1)/(m_2 + 1)] - 1$$

$$95\%\ \mathrm{CI} = 1.96 \sqrt{[(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)/(m_2 + 1)^2(m_2 + 2)]}$$

where N_c = estimated total number of carcasses present, n_1 = number found in the first search, n_2 = total number found in second search, and m_2 = number of animals "recaptured" during the second search. We investigated potential biases in our calculations by pooling data from all eight cells, and deriving separate estimates for each of three age-classes of deer present in the month of August (fawn c. 9 mo, subadult c. 21 mo, adult ≥c. 33 mo) and, separately, for each of four visibility-of-carcass classes (0–4, 5–8, 9–12, and >12 m). Carcass densities were related to historical data from four faecal-pellet surveys conducted during the 1980s (see Nugent 1988 for a more detailed outline of the design of these surveys).

Historical deer-harvest and hunting data

We collated and summarised historical and recent hunting-related data for the area. Hunting is permitted throughout the week in the three beech blocks, but only at weekends in the remaining seven blocks within the poisoned area. Hunters are asked to report the number of hours hunted (if any), and the numbers of pigs and deer seen and killed. Return rates (of hunter reports) were traditionally high (>90%) but have declined during the 1990s to about 60% in 2000. Historical data on hunting effort and success rates have been summarised by Nugent (1990a) for 1983–90, by Goonan (1995) for 1991–94, and by Golding (2000) for 1998. In addition, we obtained some, but not all, of the original hunting-return data for the 1996–2001 period from the Department of Conservation.

We use trends in the reported sighting and kill rates through time as an index of trends in deer density. The size of the legitimate annual harvest was calculated by dividing the reported kill rate by the return rate.

RESULTS

Marked-deer estimate of percent kill

All 3 radio-collared deer died after the poisoning. The sample comprised 2 males (1 fawn and 1 subadult) and 1 adult female. Based on this sample, at least 37% (lower 95% binomial confidence limit about the sample estimate of 100% kill for a sample size of three) of deer were killed. The radio-collared deer were all relocated 1.0–1.2 km from where they had been released.

Seven helicopter flying hours were spent searching unforested areas. Three carcasses were found during the first search, two on the margin of the native forest in Tramways block and one on the valley flats at the bottom of the three beech blocks. No carcasses were found in the high-altitude tussock areas above timberline in the beech blocks. Seven different live deer, but no new carcasses, were seen during a second search, all on the forest margin of the Tramways block. The sighting rate of one deer per flying hour compares with a sighting rate of more than 2 deer/h seen during the 13 h spent on deer-capture efforts in May 2001.

Carcass searches

Approximately 140 days of search effort were spent in the eight search cells. A total of 54 deer, 1 pig, 58 possum, and 20 bird carcasses were found—16 blackbirds (*Turdus merula*), 1 chaffinch (*Fringilla coelebs*), 1 grey warbler (*Gerygone igata*), 1 tomtit (*Petroica macrocephala*), and 1 "bush robin".

As robins are believed to be absent from the area (Foord 1987) the latter is likely to have been another tomtit. One of the deer was found just outside a search cell, and has not been included in carcass density calculations.

Sixty-four percent of the 36 deer carcasses found within cells in the first searches were "recaptured" in the second searches. Pooling data across cells, the Lincoln-index estimate for the total number of carcasses in these eight cells was 62.2 (Table 1). The pooled total for the separate analyses by age-class was similar (61.7 carcasses). However, none of the four carcasses located during the first search in dense undergrowth (mean visibility of <4 m) were relocated, suggesting a visibility bias, although two deer with visibility of exactly 4.0 m visibility were relocated (Fig. 1). The pooled total for the separate analyses by visibility class (66.8 deer) suggests that about 14 carcasses (7.5%) were not found during either search.

The confidence interval for the total number of deer carcasses within the search area (Table 1) is quite narrow (±15%). However, the wide variation in carcass density between cells means that the across-cell mean density figure is imprecise (19.7 ± 9.1 carcasses/km^2).

The density estimate (not corrected for visibility bias) for each cell ranged from a low of 2–3 carcasses/km^2 for the two cells in Packers to about 40 carcasses/km^2 in one of the Clarks' cells. The uncorrected density of carcasses in cells was positively correlated with the relative abundance of deer during the 1980s (as indexed by faecal-pellet-group densities recorded on transects passing through or near the search cell; Fig. 2).

Fresh deer sign was seen in all eight cells, and eight live deer were seen during searches. The ratio of live deer seen to carcasses found (4:2) was much higher for the Packers block than for any of the other three blocks (4:51 overall; Table 1).

Table 1 The number of deer carcasses found, and live deer seen, by search cell, with estimates of cell area, the total number of carcasses and associated 95% confidence interval, and carcass density. One of the total of 54 deer found was just outside the boundary of a search cell, and not included here. The numbers of deer in each of six age and sex classes is also shown, with Lincoln index estimates of the number in each class for the total area searched.

Cell	Area (km^2)	Live deer seen	No. of deer carcasses found: Search 1	Search 2: Relocated	Search 2: New	Total carcasses found	Estimated total carcasses present	95% CI	Carcass density (n/km^2)
Packers 1	0.38	2	1	0	0	1	1.0	0.0	2.7
Packers 2	0.46	2	1	1	0	1	1.0	0.0	2.2
Armstrong 1	0.52	0	3	2	4	7	8.3	3.5	15.9
Armstrong 2	0.49	0	7	5	2	9	9.7	2.0	19.7
Clarks 1	0.57	0	2	0	3	5	11.0	11.8	19.3
Clarks 2	0.25	2	5	4	4	9	9.8	2.4	38.6
All beech total	2.67	6	19	12	13	32	39.0	8.8	14.6
Tramways 1	0.51	2	12	7	2	14	15.3	2.9	29.7
Tramways 2	0.40	0	5	4	2	7	7.4	1.5	18.6
Tramways total	0.91	2	17	11	4	21	23.0	3.8	25.3
Four-block total	**3.58**	**8**	**36**	**23**	**17**	**53**	**62.2**	**9.5**	**17.4**
Fawns	Female		8	5	4	12	14.0	4.1	
(c. 9 mo)	Male		7	4	4	11	13.4	4.7	
	All		15	9	8	23	27.8	6.9	
Subadults	Female		4	4	3	7	7.0	0.0	
(c. 21 mo)	Male		3	2	1	4	4.3	1.3	
	All		7	6	4	11	11.6	1.9	
Adults	Female		11	6	5	16	19.6	5.9	
(≥33 mo)	Male		3	2	0	3	3.0	0.0	
	All		14	8	5	19	22.3	5.5	
Total			**36**	**23**	**17**	**53**	**61.7**	**16.0**	

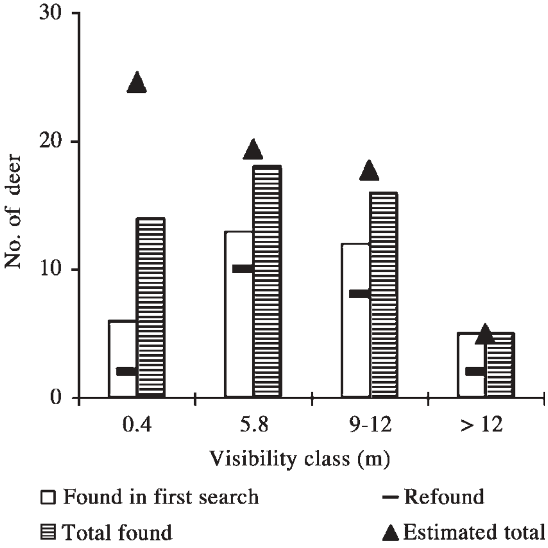

Fig. 1 Numbers of deer found during the first search, relocated, and overall for the entire area searched, subdivided into four classes based on a subjective assessment of the visibility of the carcasses from four directions (averaged across the four main compass axes). The triangles are the estimated total number of deer in each visibility class.

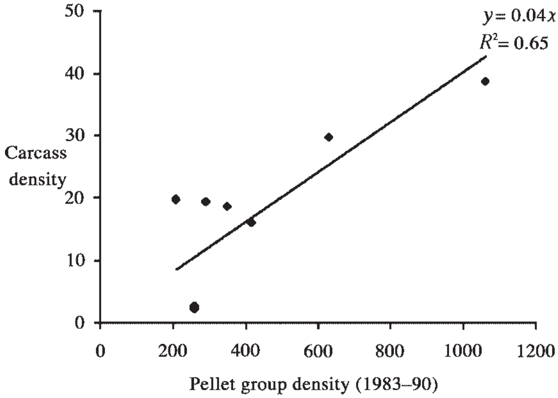

Fig. 2 Relationship between carcass density (per km^2) in each cell and the faecal-pellet-group density recorded on 2-km-long transects passing through or near the cell, averaged across surveys conducted in 1983, 1985, 1987, and 1990 (G. Nugent unpubl. data). The same set of transects was surveyed in each survey, and estimates for each transect were consistent between surveys. The same transect is used for both cells in Packers, and the trend line is forced through the origin (no deer, no kills).

The deer found dead were predominantly young, and included similar numbers of male and female fawns, but the sex ratio increasingly favoured females with increasing age (Table 1). The total number of fawns found was almost 50% higher than the number of adult females. There was little evidence that adult females tended to be found in denser undergrowth, as neither mean visibility (6.0 ± 1.9 m for adults; 8.8 ± 1.9 m for fawns) nor mean distance-at-first-sighting (10.0 ± 3.7 and 5.9 ± 1.3 m, respectively) differed significantly or in a consistent direction.

The four carcasses found outside search cells (1) or by helicopter (3) comprised 1 male fawn, 2 male subadults, and 1 adult female, so the overall ratio of fawns to adult females was 24:17.

Hunting effort, harvest levels, and total kill

Closures to hunting (to allow for possum control) disrupted hunting patterns after 1998 (Appendix 1), so the data for 1999–2000 do not represent the normal pattern of harvest between blocks. We used instead the data for 1991–98. Excluding 1993 (when hunting was also disrupted by closures for forestry operations) and 1995 (for which we have no data), the four blocks searched for carcasses typically produced about 80% of the reported harvest from the poison area (Table 2). Again excluding 1993, estimated annual kills for the three beech blocks were reasonably consistent, ranging between 35 and 58 deer, and mostly between 40 and 50 deer.

The low carcass densities recorded in the two Packers cells cannot be attributed to low deer densities in that block, as the estimated annual kill in 1991–98 was similar to that for the other two beech blocks (Table 2), and the deer sighting rate in 2000–01 in Packers (0.24/h) was intermediate between those in Clarks (0.30/h) and Armstrong (0.19/h).

For the Blue Mountains as a whole, hunting effort appeared to be more or less constant between 1991 and 1998, with an upward trend in reported sighting and kill rates suggesting an increase in deer density (Table 2).

Qualitatively, our best-guess extrapolation from Table 1 is that almost 500 deer were killed. This was calculated by summing separate estimates for the three beech blocks (19.5 km^2 × 14.6 carcasses/km^2 = 285), and Tramways (3.4 km^2 × 25.3 carcasses/km^2 = 86 deer) and assuming (from Table 2) that these blocks contained about 80% of the deer population (and therefore the deer kill) in the poisoned area.

Table 2 Estimates of the total number of deer killed annually by permitted hunters in the four blocks in which carcass searches were undertaken, relative to the numbers for the other six hunting blocks in the poison area. The numbers represent the reported kill divided by the return rate. The bottom section of the table shows overall trends in the numbers of permits issued, return rate, and reported sighting and kill rates for the entire Blue Mountains area for these years (no data are available for 1995).

	1991	1992	1993	1994	1996	1997	1998
Packers	51	42	39	35	46	41	58
Armstrong	45	49	19	41	36	36	41
Clarks	42	47	26	43	43	42	42
Tramways	22	30	16	17	21	19	20
Four-block total	**160**	**168**	**100**	**136**	**146**	**138**	**161**
% of overall total	79	81	59	78	80	84	75
Total for other six blocks	**43**	**39**	**69**	**39**	**34**	**30**	**55**
% of overall total	21	19	41	22	20	16	25
All Blue Mountains: Permits issued	2292	2564	2360	2382	2480	2645	2649
Return rate (% of permits)	87	88	88	76	77	72	68
Sighting rate (deer seen/h)	0.142	0.131	0.134	0.143	0.163	0.163	0.187
Kill rate (deer killed/h)	0.019	0.019	0.018	0.022	0.026	0.025	0.032

CONCLUSIONS

The poison operation reduced possum densities to very low levels (post-poison mean trap-catch rate of 0.7%). It is also clear that some hundreds of deer were killed.

The deer killed must have comprised a high proportion of the population. Nugent et al. (2001) estimate that the nationwide average for densities of wild deer in forest is only 3–4 deer/km^2, so it is simply difficult to imagine that the densities of close to or above 20 carcasses/km^2 recorded in over half the cells could comprise any less than half the deer present. Likewise, the deaths of the three deer fitted with radio collars also indicates a two-in-three chance that over two-thirds of the population was killed. Countering that, some deer survived in all blocks, with (effectively) 2 live deer/km^2 seen during one of the helicopter flights around Tramways. In the Packers block the much larger ratio of live deer seen to carcasses found (Table 1) suggests a lower percentage kill than for the other two beech blocks, especially since the sighting rate recorded by hunters during 2000–01 was similar for the three blocks. The low density of carcasses is unlikely to reflect low deer density in the part of the block searched, as twice as many pellet groups were found in the 1990 faecal pellet survey in this (high-altitude) part of the block than on the lower-altitude part (unpubl. data).

The higher number of dead fawns found compared with the number of dead adult females indicates greater mortality amongst fawns than adults, especially as the number of adult females must exceed the number of fawns by about 10% (Baker 1973). An alternative explanation, that the adult females were harder to find, is unlikely, as separate Lincoln indices for each age and sex class show the same predominance of fawns (Table 1). Fraser (1989) reports a similar pattern among red deer found dead after a 1080 poison operation in Pureora Forest Park, in which only 1 adult (a female) but 3 fawns and 3 subadults were found.

It appears that at least one-third of adult females survived even in the three blocks with high densities of carcasses. As adult females are likely to comprise about 40–50% of the breeding population (because hunting selectively removes males; Nugent 1990a; Goonan 1995), it is unlikely that more than 85% of deer were killed in these three blocks even if all fawns died. Coupled with evidence of much greater survival in the Packers block, our best guess is that somewhere between two-thirds and three-quarters of the deer in the poison area were killed.

For the Blue Mountains as a whole, more deer were seen and killed by hunters in 1998 than annually between 1991 and 1994, despite similar numbers of permits being issued each year (Table 2), suggesting increasing deer densities. The reduction in permitted effort since 1998 is likely to have allowed deer numbers to increase even further. Projecting forward from the estimated 216 deer killed in 1998 in the poisoned area (Table 2), we estimate the 2001 harvest would normally have been close to 250 deer. Our guess at the number of carcasses is twice that, another indication that the kill is likely to have substantially reduced the population.

The by-kill of fallow deer in the Blue Mountains appears higher than is usual for red deer (Nugent et al. 2001). Semi-feral fallow deer near Tai Tapu, Canterbury, were also apparently severely affected by aerial-1080 poisoning in 1998—over 30 fallow deer were seen from a helicopter during about 5 h flying time before poisoning, but only 1 fallow and 1 red deer (both adult males) were seen after poisoning (D. Hunter pers. comm.). Some of the variation in carcass density in this study reflects variation in deer density between blocks (Fig. 2), but mortality rate was also related to deer size. Habitat, particularly the density of ground cover, also appeared to be important, with observers noting the coincidence between dense ground cover, low carcass density, and more abundant fresh deer sign in both the search cells in Packers. The implication is that larger deer and those in areas with dense ground cover take longer to find enough bait to consume a lethal dose.

If so, lowering the toxicity and sowing rate might be expected to reduce deer mortality. However, Fraser & Sweetapple (2000) recorded equally high kills of red deer with both 0.08 and 0.15% 1080 on carrot baits sown at 15 kg/ha. Meenken & Sweetapple (2000) report only a small (5%) reduction in deer faecal-pellet-group density after an aerial operation in which cereal bait (0.15% 1080) was sown at 3 kg/ha overall but with the baits concentrated in strips at 25 kg/ha, yet found a 54% reduction where the bait was uniformly sown at 3 kg/ha, suggesting that local bait density is not crucial. Incorporating a deer repellent into bait might also reduce deer mortality.

Most (82%) of the birds found dead in this study belonged to introduced species, but in surveys conducted during the 1980s (Foord 1987) introduced birds comprised only 14% of those counted alive in beech forest. Making the untested assumption that the relative detectability of introduced birds and native birds during such live counts does not differ greatly from that for birds found dead, we suggest that the overall impact of the poisoning on the native bird population was minor.

Numerous television, radio, and newspaper articles during September and October 2001 clearly demonstrate that the reduction in deer numbers in the Blue Mountains had fuelled hunter opposition to the aerial application of 1080 bait for pest control. That opposition adds indirectly but substantially to the cost of using this tool for possum control, nullifying one of its primary advantages over ground-based control (lower cost). Offsetting the loss of hunting resource, the reduction in deer browse pressure will provide some respite from their effects on the native forest. Wild deer are not usually maintenance hosts for Tb at the low densities at which they mostly occur in the wild in New Zealand (Nugent 2001), however, the high densities of carcasses in Tramways posed some risk, as they were similar to the deer densities at which Tb has spread through a wild white-tailed deer herd in Michigan, USA, in the absence of any other vectors (Schmitt et al. 1997). The reduction in deer density, in the Tramways block in particular, will have reduced this unconfirmed risk of Tb spread through the fallow deer population of the Blue Mountains.

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Appendix 1 Recent trends in hunting effort (number of hunting permits issued) in the four blocks searched for carcasses. Data supplied by M. Mawhinney, Department of Conservation, Invercargill. The data for 2001 are for the first 5 months only, before closure for the poisoning operation.

	1996	1997	1998	1999	2000	2001
Packers	125	125	129	90	37	56
Armstrong	110	120	123	88	37	71
Clarks	127	111	111	73	23	42
Tramways	44	45	43	30	16	41
Total	406	401	406	281	113	210
% of 1996 figure	100	99	100	69	28	52