

Effects of a 1080 operation on kaka and kereru survival and nesting success, Whirinaki Forest Park

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Abstract: To measure the costs and benefits of an aerial 1080 possum control operation to kereru and kaka in Whirinaki Forest Park, individuals of both species were radio-tagged from October 1998 to June 2002. We monitored birds in one treatment and one non-treatment study area to compare toxin-related mortality, nesting success and survival. The poison operation involved the spreading of non-toxic carrot baits on 1 May 2000, and the toxic baits on 17/18 May 2000. Possums and rats were moderately abundant in both study areas prior to the poison operation, but afterwards few possums and rats remained in the treatment area. All radio-tagged kaka and kereru in the treatment area survived the poison operation. No radio-tagged kereru and too few radio-tagged kaka bred in either study area during the 2000/01 nesting season to show whether reduced possum and rat populations would enable the birds to nest more successfully. A reduction in possum and rat densities in the non-treatment area (and an increase in densities in the treatment area) during 2001/02 meant that during the second nesting season after the poison operation, possum and rat densities were similar in the two study areas. The nesting effort and success of kaka and kereru is described for each of four nesting seasons, with the main cause of nesting failure for both species being predation. While no radio-tagged adult male kaka died during the study, 6 females did, giving them a mean life expectancy of 9.5 years. In contrast, radio-tagged adult kereru suffered high mortality, resulting in a mean life expectancy of just 1.5 years. Predation by introduced mammalian predators was the main cause of mortality of kaka eggs, chicks, fledglings and adult females, and of kereru eggs, chicks, fledglings and adults. Effective control of introduced mammalian predators, including control by aerial 1080 operations, just before mast fruiting events that invariably promote prolific kaka and kereru breeding, should benefit these bird populations.

Keywords: 1080; benefits; costs; kaka; kereru; life expectancy; nesting success; possum poisoning; survival.

Introduction

The introduced brushtail possum (*Trichosurus vulpecula*) is a serious pest throughout New Zealand because of its detrimental impacts on indigenous forest ecosystems (Department of Conservation, 1994; Atkinson *et al.*, 1995; Cowan, 2001), and on agriculture through the spread of bovine tuberculosis to cattle and deer (Livingstone, 1994; Cowan, 2001). The possum's impacts as a folivore on native plants, including changes to the composition of some forest communities, have been well documented (Nugent *et al.*, 2000; Payton, 2000; Cowan, 2001). In addition, it is now recognised that predation by possums may be sufficiently high to have a negative impact on the populations of some native bird species (Brown *et al.*, 1993; Innes, 1995; Sadleir, 2000).

Over the past 30 years the main method used to reduce possum densities over large areas has involved aerial broadcasting of carrot or cereal baits containing sodium monofluoroacetate (compound 1080), which can achieve a reduction of greater than 90% in populations at equilibrium density (Eason *et al.*, 1994; Morgan *et al.*, 1997; Veltman and Pinder, 2001). Native birds, including kereru and kaka, have been poisoned during aerial 1080 operations (Spurr and Powlesland, 1997). Various procedures have been implemented to reduce the number of birds killed during aerial 1080 operations. These include the sieving out of small fragments of bait or 'chaff' that birds are capable of swallowing, dyeing baits green so that they are less attractive to birds, adding cinnamon which acts as a repellent to birds but not possums, and reducing application rates on the assumption that it will reduce

bird-bait encounters (Harrison, 1978a, b; Morgan *et al.*, 1986; Spurr, 1991).

Despite these procedures, dead native birds, especially North Island tomtits (*Petroica macrocephala toitoi*) (Powlesland *et al.*, 2000), have been found after recent aerial 1080 possum poisoning operations. As a consequence, the aerial broadcasting of 1080 baits to control possum populations by the Animal Health Board and Department of Conservation has come under increasing public scrutiny. Thus, information was urgently needed to measure both the costs and benefits of such operations to non-target species. Spurr and Powlesland (1997) reviewed the status of knowledge and research requirements regarding the effects of aerial application of 1080 for possum control on native birds, bats, lizards, frogs and invertebrates. Species identified in the review as highest priority for further research were kaka (*Nestor meridionalis*) and kereru (*Hemiphaga novaeseelandiae*). Thus, the objective of this study, jointly funded by the Department of Conservation and the Animal Health Board, was to measure the costs (mortality during the poison operation) and benefits (improved adult survival and nesting success following poisoning of introduced mammalian predators) of an aerial 1080 possum poison operation to kereru and kaka in Whirinaki Forest Park.

Study areas

Oriuwaka study area

The Oriuwaka study area was about 3000 ha, and was the non-treatment site (Fig. 1). Its altitude ranged from 475 to 600 m a.s.l., and the topography was mainly undulating to moderately steep. It had a nearly continuous cover of dense podocarp or podocarp-

hardwood forest, with dense stands of emergent rimu (*Dacrydium cupressinum*) on some ridges (Morton *et al.*, 1984). Scattered kahikatea (*Dacrycarpus dacrydioides*), matai (*Prumnopitys taxifolia*) and miro (*P. ferruginea*) also occurred as emergents over a mainly tawa (*Beilschmiedia tawa*) canopy. Occasional canopy and understorey species include hinau (*Elaeocarpus dentatus*), kamahi (*Weinmannia racemosa*), mahoe (*Meliclytus ramiflorus*), totara (*Podocarpus totara*), maire species (*Nestegis* spp.), red beech (*Nothofagus fusca*), wheki (*Dicksonia squarrosa*) and soft tree fern (*Cyathea smithii*). In the gullies, valley bottoms and along roads there were pepperwood (*Pseudowintera colorata*), wineberry (*Aristotelia serrata*), kaikomako (*Pennantia corymbosa*) and *Dicksonia* tree ferns.

Otupaka study area

The Otupaka study area was 1880 ha within Whirinaki Forest Park (Fig. 1), and was the treatment area for the aerial 1080 possum poison operation. The operational area consisted of 1750 ha of the Otupaka Ecological Area, plus two additional contiguous areas of native forest of 500 ha in total. The two study areas (Oriuwaka and Otupaka) were separated by about four kilometres at their nearest points. The topography of the Otupaka area was much the same as that of the non-treatment area, but its altitude was higher, ranging from 600 to 900 m a.s.l. The forest cover of the Otupaka study area was similar to that of the Oriuwaka study area, rimu and matai being the main emergents, with occasional kahikatea and miro. On the ridges, kamahi, hinau, rewarewa (*Knightia excelsa*) and matipo (*Myrsine australis*) shared dominance in the canopy, but on the terraces tawa predominated. On some slopes above 750 m a.s.l., the podocarp-hardwood forest was replaced by a mixture of rimu, miro, red beech and occasional Hall's totara (*Podocarpus hallii*), emerging above a matrix of kamahi, tawari (*Ixerba brexioides*) and tawherowhero (*Quintinia serrata*) (Morton *et al.*, 1984). Beech formed an almost continuous canopy above 840 m a.s.l., the main species being red beech. Two patches of 'frost flat', covered mainly in 1–2 m tall monoao (*Dracophyllum subulatum*), also occurred in the operational area.

Methods

Experimental design

An unreplicated BACI (Before-After/Control-Intervention) experimental design was used to compare differences in the toxin-related mortality, nesting success and survival of radio-tagged kaka and kereru in treatment and non-treatment study areas. The study

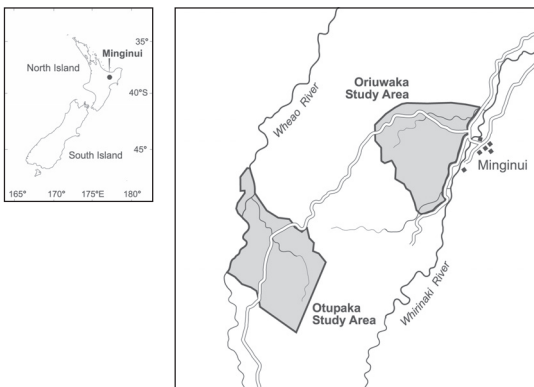


Figure 1. Location of the Oriuwaka (non-treatment) and Otupaka (treatment) study areas in Whirinaki Forest Park, near Minginui.

began in October 1998, enabling bird nesting success and survival to be monitored for 19 months (including two breeding seasons) before the poison operation occurred in May 2000. During the fortnight immediately after the poison operation, the mortality of the tagged birds was monitored intensively (birds checked every 2 to 3 days). Subsequently, the nesting success and survival of the birds was monitored for a further 25 months (again including two breeding seasons) through to June 2002. During the 45-month long project, rat and mustelid populations were monitored concurrently in treatment and non-treatment study areas at 2–3 month intervals, and possum populations were monitored annually. This monitoring was carried out to determine the impact of the poison operation on the target species (possum), plus rats [mainly ship rats (*Rattus rattus*)] and mustelids (*Mustela* spp.), all known to be poisoned during aerial 1080 operations (Innes *et al.*, 1995; Murphy *et al.*, 1999). Possums, rats and mustelids have all been recorded as predators of kaka (Moorhouse *et al.*, 2003) and kereru (Mander *et al.*, 1998).

Aerial 1080 operation

Carrot rather than cereal baits were used in this study because, both kaka and kereru are more likely to eat carrot baits; a specimen of each species has tested positive for 1080 after being found dead following aerial possum poison operations using carrot baits; and many thousands of hectares of kereru and kaka forest habitat are subjected to aerial carrot-bait operations annually (Spurr and Powlesland, 1997). Bait preparation and broadcasting was carried out by Epro Ltd., Taupo. Non-toxic pre-feed carrot baits were aerially broadcast on 1 May 2000 at a rate of 5 kg ha⁻¹ over the 2250 ha operational area. Poison (1080 at 0.08% w/w) carrot baits (6–9 g baits) were spread at 10 kg ha⁻¹ on 17/18 May 2000. Baits were distributed from helicopters using differential GPS (global positioning system) to ensure baits were evenly spread over the entire operational area, were not dropped beyond the operational boundaries, and that sensitive areas within the operational area were excluded. Carrot baits were screened to remove small fragments of carrot, chaff weighing less than 0.5 g, prior to being coated with toxin. The total weight of chaff in each of three 1 kg samples was less than 2 g, much less than the Epro Ltd. standard of a maximum of 15 g per sample.

Bait distribution was determined along 10 lines, each line being one kilometre in length, and orientated at right angles to the direction of the flight paths. The lines were divided into 50 m segments, with the requirement that at least one bait be present in each segment. Monitoring indicated coverage of 99.5%, which was greater than the minimum coverage required of 95%.

Possum population indices

The capture rate of possums in leg-hold traps (number caught 100 trap-nights⁻¹) was used to provide an index of possum abundance using the methods set out in the National Possum Control Agencies' national trap-catch protocol (version IV) (Warburton, 2000). Each monitoring session involved six trap lines being set in the treatment and non-treatment areas, each line consisting of 20 Victor No. 1 traps spaced at 20 m intervals along a taped line. The randomly placed lines were located using GPS equipment. Lure (a mixture of 5 parts by weight of white flour and 1 part of icing sugar, no essence) was smeared on the tree above each trap, and reapplied daily if depleted. The trap lines were operated for three fine nights, and all trapped possums were killed and disposed of at least 10 m from the traps. The index of abundance (captures 100 trap-nights⁻¹) was corrected for traps sprung without a captive, or with a non-target capture (e.g. rats) (Cunningham and Moors, 1996). Statistical comparisons of trap-catch indices for the study areas were made using the chi-square test.

Rat and mustelid population indices

The proportion of baited tracking tunnels containing rat and mustelid foot-prints was used to provide an index of rat and mustelid abundance (Innes *et al.*, 1995). We assumed that there was a correlation between these indices and the actual population densities, as found by Brown *et al.* (1996a) for rats, but see Blackwell *et al.* (2002). The randomised layout and method of operation of the monitoring followed the protocol developed by C.A. Gillies, Science and Research Unit, Department of Conservation, Hamilton, New Zealand. The layout consisted of 10 tracking-tunnel lines, each line consisting of 10 tunnels spaced at 50 m intervals. The location, ensuring at least one kilometre between the starting points of lines, and compass direction of each line were randomised. Each tunnel was baited with peanut butter at both ends and 'set' for one night. The next day, while removing the papers and any remaining peanut butter, the odd numbered tunnels were 're-set' with rabbit meat in the centre of the tunnel and fresh papers for mustelid monitoring inserted. These papers were collected after three nights. All 20 lines in the two study areas were operated simultaneously. The lines were operated at three-monthly intervals, except just before (April 2000) and after (June 2000) the May 2000 poison operation. Data are expressed as percent 'available' tunnels with foot-prints; those interfered with, such as tipped over, were deleted from analyses. The chi-square test was used to compare rodent and mustelid indices between the study areas.

Capturing, marking and monitoring of kaka and kereru

Both species were captured in canopy-height mist-nets (Dilks *et al.*, 1995). Kaka were attracted into mist-nets using play-back of calls of the local kaka dialect. Some females were caught in mist-nets erected a few metres from their nests. Kereru were attracted into mist-nets using play-back of alarm calls and the wing-flapping sounds made when birds were striking each other during fights.

Adult kaka are sexually dimorphic, particularly in culmen length (Moorhouse *et al.*, 1999), but kereru are not (Clout *et al.*, 1995). Prior to August 2001, a few of the tagged kereru were sexed by either observing when they were incubating [males incubate from late morning till late afternoon, and females from late afternoon till late morning (Clout *et al.*, 1995; Flux *et al.*, 2001)], or by dissection if adequate remains were found following predation. However, after August 2001, a few small contour feathers were collected from each kereru at capture so its gender could be determined from extracted DNA.

A unique, numbered metal band was fitted to each kaka (size L) and kereru (size K). In addition, male kaka that were not radio-tagged were banded with two half-sized, painted metal bands to enable individual identification. Because of their feathered legs, kereru were individually marked with coloured leg-flags (jesses) of nylon-reinforced PVC. Transmitters were fitted to all kereru, all female kaka, and some male kaka. Two-stage Sirtrack® transmitters were attached to the birds using a back-mounted harness design (Karl and Clout, 1987). The transmitter, based on a 7PN battery, and harness together weighed 24–29 g. To extend battery life, the pulse rate of transmitters was set at 20 pulses per minute, and the transmitter incorporated a duty cycle of 12 hours on/12 hours off, giving a potential field-life of 42 months. Because of the poor survival of the tagged kereru early in the study, lighter two-stage Sirtrack transmitters containing 3PN batteries were attached to every second kereru from November 2000 to compare the impact of transmitter weight on survival. These transmitters (20 pulses minute^{-1} , duty cycle of 8 h on/16 h off, a potential field-life of 21 months) and the same harness type together weighed *c.* 18 g.

We attempted to locate each radio-tagged bird once a week to monitor survival and breeding. Finding tagged kereru and kaka involved approaching them on foot using a radio-receiver (Telonics TR4®) and a hand-held yagi antenna (Sirtrack) until the individual was sighted, or was known to be directly above but unsighted in a tree. Locating birds that moved several kilometres involved radio-tracking from high-points or occasionally from a helicopter. During breeding seasons, accessible kereru of unknown sex were

checked both in the middle of the day and in the early morning. This was to ensure that nests would be found during incubation at any time of day, i.e. regardless of whether the radio-tagged bird was a male or a female.

Survival analysis was carried out on data for birds carrying active transmitters only. Thus sightings of tagged birds whose transmitters had stopped or fallen off were excluded from the analyses. Because kereru sometimes suffer post-handling shock (Clout *et al.*, 1995), deaths within the first fortnight after release were excluded from the analyses. The cause of death of tagged birds was attributed to a particular species of predator only when either a predator was found feeding on a freshly killed kereru or kaka, or there was species-distinctive sign on the carcass [e.g. paired canine punctures of size and spread consistent with that of a stoat (*Mustela erminea*)].

When determining mean survival (life expectancy) of tagged birds that were not relocated (e.g. where the bird emigrated, the transmitter signal was not detected, or the transmitter failed), the duration of monitoring was conservatively taken from a fortnight after release to when each bird was last known to be alive. Statistical comparisons of survivorship data for radio-tagged birds from the two study areas or for different times of year were tested using a log-rank (Mantel-Haentzel) test in SPSS® (SPSS Inc., 1999).

Most nests were checked twice a week to determine whether they were occupied. For kereru nests (platforms of twigs on branches, often in the canopy), this usually involved observing from the ground to see whether there was an adult or nestling in the nest. For those that were hidden by foliage, checks involved use of single-rope techniques to reach the nest vicinity at weekly to monthly intervals. For kaka nests (invariably in cavities within large trees), occupancy checks involved determining whether the signal of the radio-tagged female indicated she was in the cavity, or observing her entry or exit from the cavity. To determine the species responsible for predation at nests, some kereru and kaka nests were monitored day and night using time-lapse video equipment (Brown *et al.*, 1998; Lyver, 2000). Alternatively, predator identity was determined from sign found on recovered prey remains and about nests (Brown *et al.*, 1996b). When sign was used to indicate predator identity, some doubt existed because of the possibility of scavenging by a different species following predation.

Results

Possom population indices

Possom population indices prior to the poison operation were moderately high and similar in the two study areas, at 27–33 captures 100 trap-nights⁻¹ (Fig. 2).

Monitoring during 12–16 June 2000 in the treatment area, following the poison operation, resulted in 4.4 captures 100 trap-nights⁻¹ (86% reduction). Subsequently, possum abundance increased gradually in the treatment area, reaching 9.5 captures 100 trap-nights⁻¹ by February 2002. In contrast, possum abundance declined markedly in the non-treatment area between February 2001 (30.8 captures 100 trap-nights⁻¹) and February 2002 (11.5) (Fig. 2), such that there was no significant difference in trap-catch rate between the two study areas by February 2002 ($\chi^2 = 0.59$ with Yates' correction, d.f. = 1, $P = 0.44$).

Rat population indices

Prior to the poison operation, tracking-tunnel monitoring indicated that rat indices in the two study areas were similar seasonally (Fig. 3), except in September 1999 when they were greater in the non-treatment area ($\chi^2 = 11.6$ with Yates' correction, d.f. = 1, $P < 0.05$). Immediately following the poison operation, indices of rat abundance in the treatment area declined markedly from 43% to 5%. It is noteworthy that the only tunnel line where rats were evident immediately after the operation was at the edge of the operational area, and it was not until February 2001 that rat footprints were recorded well within the treatment area. Rat indices for the treatment area remained at 11% or less for the following 21 months, but had increased to 32% by May 2002 (Fig. 3). In the non-treatment area, rat indices were 73–76% in June and August 2000, and then declined to 19–36% during November 2000 to August 2001. Rat indices were significantly greater in the non-treatment area during June 2000 to August 2001 (Fig. 3). However, in November 2001, and February and May 2002, there was no significant difference in the rat indices between the two study areas.

Mustelid population indices

In general, mustelid population indices for the two study areas were low (less than 10%) (Fig. 4). There was no significant decline in mustelid indices for the treatment area following the poison operation, and no significant difference in mustelid indices between the two study areas for any monitoring session (Fig. 4).

Toxin-related mortality of kaka and kereru

None of 17 radio-tagged kaka (10 male, 7 female) in the treatment area, and 20 (9 male, 11 female) in the non-treatment area died during the fortnight following the poison operation. Similarly, none of 15 radio-tagged kereru in the treatment area died after the poison operation, but one of 11 (9.1%) died in the non-treatment area.

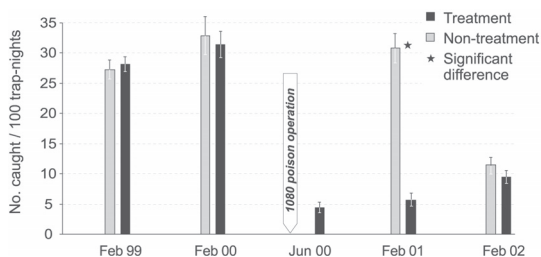


Figure 2. Indices of possum abundance (captures 100 trap-nights⁻¹) in treatment and non-treatment study areas before and after an aerial 1080 possum poison operation on 17/18 May 2000 in Whirinaki Forest. Bars are standard errors for the six 100 trap lines per study area.

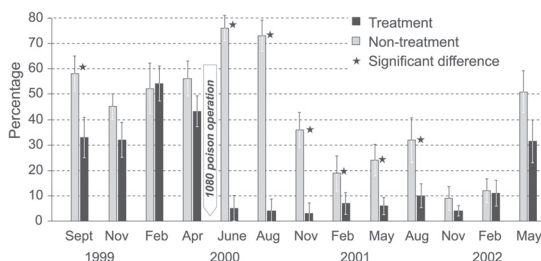


Figure 3. Tracking indices for rat abundance (% of tunnels with foot-prints) in the treatment and non-treatment study areas before and after an aerial 1080 possum poison operation on 17/18 May 2000 in Whirinaki Forest. Bars are standard errors for the 10 lines per study area.

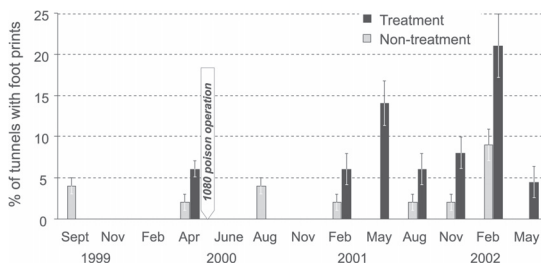


Figure 4. Tracking indices for mustelid abundance (% of tunnels with foot-prints) in the treatment and non-treatment study areas before and after an aerial 1080 possum poison operation on 17/18 May 2000 in Whirinaki Forest. Bars are standard errors for the 10 lines per study area.

Kaka nesting success

Combining data for treatment and non-treatment areas, in the 1998/99 and 2001/02 breeding seasons, a large proportion of radio-tagged female kaka nested, with none or few nesting in the other two seasons (Table 1). At least one female was preyed upon when nesting occurred. Nesting success (at least one nestling fledging per nesting attempt) was similar (33–40%) for the three seasons when nesting occurred, however the mean number of fledglings per pair varied from 0.6 to 1.6 (Table 1). Survival of radio-tagged fledglings varied between nesting seasons (Table 1), with 44% ($n = 18$) survival overall. Of the 19 failed nests where the cause was known, 13 (68.4%) were attributed to predation, of which six (31.6%) were by possums, only one by mustelids, and six by unidentified predators.

In the 2000/01 season, when possum and rodent population indices differed significantly for the two study areas, there was no difference in nesting success for kaka between the areas (non-treatment: 1 of 3 nests successful, both fledglings preyed upon; treatment: 1 of 2 nests successful, only fledgling preyed upon). However, sample sizes were too small to make a meaningful comparison.

Of 10 radio-tagged fledgling kaka that were found dead during 1998–2002, seven on leaving the nest

ended up on the ground and were dead within five days. Five of these fledglings were preyed upon and two died without obvious injuries. The other three were seen in the canopy soon after fledging but were preyed upon within three months. Of the seven that were preyed upon, one was being eaten by a falcon (*Falco novaeseelandiae*) when located, one had sign consistent with being killed by a possum, and the meagre remains of four were located in narrow cavities underground suggesting they were killed by mustelids.

Kereru nesting success

Combining data from both study areas, radio-tagged kereru bred only in the 1998/99 nesting season (with 47% of 17 tagged birds attempting to nest) and in the 2001/02 nesting season (62% of 16) (Table 2). Nesting success (% of nests that fledged a chick) differed significantly between the two seasons; 25% in 1998/99, and 75% in 2001/02 (Fisher Exact test, $P = 0.037$). Also, the mean number of fledglings per pair differed markedly, from 0.3 in 1998/99 to 0.8 in 2001/02. Of the six failed nesting attempts in 1998/99, one failed when an adult died on the nest apparently of a natural cause, and the other five due to unidentified predators, one during incubation and the rest during chick rearing. Of the three failed nesting attempts during 2001/02,

Table 1. Kaka nesting effort, nesting success, female mortality, and fledgling survival in Whirinaki Forest Park (combined data for treatment and non-treatment areas) during four nesting seasons, 1998/99 to 2001/02.

	1998/99	1999/00	2000/01	2001/02
% of tagged females that nested	87% of 8	0% of 14	29% of 17	70% of 17
No. of first nests	8 ¹		5	13 ¹
No. of replacement nests	2		0	5
No. of females killed during nesting	1		1	2
% successful nests	40%		40%	33%
Mean no. of fledglings pair ⁻¹	1.6		0.6	1.1
% of tagged fledglings surviving after 2 months	60% of 5		0% of 3	50% of 10

¹One nest of an untagged female found

Table 2. Kereru nesting effort, nesting success, mortality, and fledgling survival in Whirinaki Forest Park (combined data for treatment and non-treatment areas) during four nesting seasons, 1998/99 to 2001/02.

	1998/99	1999/00	2000/01	2001/02
% of tagged birds that nested	47% of 17	0% of 26	0% of 17	62% of 16
No. of first nests	7 ¹	0	0	12 ²
No. of replacement nests	1			2
No. of birds killed during nesting	0			1
% successful nests	25%			75%
Mean no. of fledglings pair ⁻¹	0.3			0.8
% of tagged fledglings surviving after 2 months	-			57% of 7

¹One nest of an untagged kereru found

²Two nests of untagged kereru found, and in addition two nests were abandoned during video camera placement.

one egg was infertile, one egg became slightly crushed against a branch when the nest tilted, and a chick was preyed upon by an unidentified mammal. Four of seven fledglings, all radio-tagged in the 2001/02 breeding season, survived for more than two months. Of the three fledglings that died, two appeared to have been preyed upon, but the third may have died, then been scavenged, since little of the soft tissues had been eaten.

Survival of radio-tagged adult kaka

Twenty-six male and 35 female adult kaka were radio-tagged during the project. For males, the monitoring period for individuals varied from 384 to 1392 days (mean = 911.9, SD = 212.5). No radio-tagged male kaka was found dead, and so it is not possible to calculate their mean life expectancy. The duration of monitoring for individual radio-tagged females ranged from 15 to 1402 days (mean = 594.9, SD = 376.4). During this period there were six deaths; these occurred 15, 28, 156, 616, 637 and 869 days after radio-tagging. These deaths represent a mortality rate of 0.10 per bird per year or a mean life expectancy of 9.5 years. Four females died during the breeding season; two while incubating in nest cavities [tooth punctures of the appropriate size and spacing on the remains suggested one was killed by a stoat and one by a possum (Lyver, 2000)], the remains of one female could not be retrieved from a cavity to determine cause of death, and the fourth was apparently preyed upon while caring for fledglings. The other two females died during the non-breeding season, one killed by an unknown predator, and the other apparently shot by a poacher. Four of the females were in the non-treatment area, and of the two in the treatment area, one was found before the poison operation, and the other 17 months afterwards.

Survival of radio-tagged adult kereru

During 2000/01, seven kereru were fitted with 7PN transmitters, and another seven with the smaller 3PN transmitters. The survival of these two groups of birds through to the end of the study (June 2002) did not differ significantly [7PN transmitters: 2285 bird-days, 1 death, mean life expectancy of 6.26 years; 3PN transmitters: 1575 bird-days, 2 deaths, mean life expectancy of 2.16 years (log-rank test, $\chi^2 = 0.42$, d.f. = 1, $P = 0.52$)]. Given this result, survival data for all radio-tagged kereru have been lumped for the following analyses.

Seventy-four kereru survived being radio-tagged for greater than a fortnight. For the 28 kereru for whom we were able to determine the gender, there was no bias in the sex ratio (16 male:12 female, χ^2 with Yates' correction = 0.07, d.f. = 1, $P = 0.79$). The time individuals were monitored varied from 17 to 1210

days (mean = 313.2, SD = 291.8). The 74 kereru were monitored for a total of 23 175 bird-days, during which there were 41 deaths; these occurred 17 to 985 days after being radio-tagged. These deaths represent a mortality rate of 0.48 deaths per bird-year, or a mean life expectancy of 1.55 years. Of the radio-tagged kereru that were found dead, eight died of unknown causes, two were found being eaten by falcons, 26 were apparently preyed upon (all or most of the soft tissues were eaten, and remaining major bones and flight feathers were usually found in cavities underground or under fallen trunks), four were taken by poachers, and one probably died of poor condition or disease. In addition to the remains of radio-tagged kereru found, the remains of 26 non-tagged kereru were found. The likely causes of mortality of 15 of the 26 birds could not be determined because either the remains were too old or too few, but of the other 11, seven were considered to be the result of mammal predation.

Although life expectancy differed from year to year, overall it was significantly greater during spring-summer (3.34 years) than autumn-winter (1.10 years) (log rank test, $\chi^2 = 6.21$, d.f. = 1, $P = 0.013$) (Table 3). A comparison was made of the life expectancy of radio-tagged kereru in the treatment and non-treatment study areas following the poison operation (1 June 2000) through to 1 March 2001. The 1 March 2001 date was chosen as the end of this comparison period because, following the poison operation, possum and rat indices differed significantly for the two study areas only up until that date (Figs. 2 and 3). The mean life expectancy of tagged kereru in the treatment area, at 1.79 years (16 kereru, 5.37 bird-years, 3 deaths), was not significantly greater than that of tagged kereru in the non-treatment area, at 1.15 years (15 kereru, 5.75 bird-years, 5 deaths) (log rank test, $\chi^2 = 0.08$, d.f. = 1, $P = 0.78$).

Discussion

Predatory mammal population indices

The 86% reduction in the possum population in the treatment area following the aerial 1080 operation was typical of results from previous poison operations (Eason *et al.*, 1994; Morgan *et al.*, 1997; Veltman and Pinder, 2001). However, in spite of the high kill, the residual level of 4.4% trap-catch was greater than the recommendation that possum populations be managed to <1% trap-catch to recover North Island kokako (*Callaeas cinerea wilsoni*) populations (Innes *et al.*, 1999), and only just below the recommendation of <5% trap-catch to recover kereru populations (Innes *et al.*, 2003).

We believe the decline of the possum population

Table 3. Comparison of the life expectancy of radio-tagged kereru during spring-summer and autumn-winter in 1998–2002, Whirinaki Forest Park. Spring-summer is 1 November to 31 March, and autumn-winter is 1 April to 31 October.

	No. of birds	Bird-years	No. of deaths	Life expectancy (years)
Spring-summer				
1998/99	19	3.65	3	1.22
1999/00	32	9.56	2	4.78
2000/01	20	6.14	0	-
2001/02	20	7.37	3	2.43
Total	60	26.72	8	3.34
Autumn-winter				
1999	44	13.47	14	0.96
2000	33	11.44	16	0.72
2001	24	10.34	3	3.45
2002	15	1.21	0	-
Total	70	36.46	33	1.10

in the non-treatment area between February 2001 and February 2002 (Fig. 2) happened because people hunted possums in the Oriuwaka Ecological Area for their fur. In 2001, we regularly saw evidence of possums being poisoned with cyanide along the Oriuwaka roads, and we occasionally saw harvesting of possums within the forest too. We assume that the main reason for the decline in rat abundance in our non-treatment area at Whirinaki from June 2000 to February 2002 was the low production of fruit (R. Powlesland, *unpubl. data*), because ship rat breeding and survival in New Zealand forests is, in part, mediated by fruit abundance (Innes, 1990). This, in conjunction with the harvesting of possums from the non-treatment area, meant that rat and possum population indices were similar for the two study areas, and so we were unable to measure benefits of the 1080 operation to the kereru and kaka populations during the 2001/02 season.

Tracking rates of mustelids in our study areas at Whirinaki were generally less than 10%, both before and after the poison operation (Fig. 4). Although mustelids are known to be killed during 1080 operations through secondary poisoning (Gillies and Pierce, 1999; Murphy *et al.*, 1999), poisoned areas are soon re-invaded by neighbouring adult stoats and dispersing juveniles that may use scent to detect unoccupied habitat (King, 1990). The apparent low density of mustelids, and the ability of stoats to rapidly recolonise an area may explain the lack of an obvious impact of the poison operation on mustelid tracking rates in the treatment area. However, stoat tracking rates provide only a gross index of abundance because they can be confounded by variation in food availability (Alterio *et al.*, 1999).

Toxin-related mortality of kaka and kereru

At Whirinaki there were no deaths of radio-tagged kaka or kereru (no costs), and no improvement in survival as a result of the aerial 1080 possum control

operation. Therefore, these species appear no worse off, as a result of being exposed to the autumn 1080 operation using carrot baits. However, the improved nesting success of kereru in 2001/02 nesting season may have occurred, in part, as a result of the low rat and possum abundance in the treatment area caused by the aerial 1080 operation in May 2000.

To date, including our study, radio-tagged kaka have been monitored during four aerial 1080 operations. In 1994, in the Waihaha Ecological Area, Pureora, 21 kaka were monitored during an operation using carrot baits (Greene, 1998). In 1998, in the Windbag Valley, West Coast, 15 kaka were monitored during an operation using Wanganui no. 7 cereal baits (L. Moran, Department of Conservation, Invercargill, N.Z., *pers. comm.*). In 2000, at Whirinaki 17 kaka were monitored during an operation using carrot baits. Lastly, in 2001 in the Waipapa Ecological Area, Pureora, 20 kaka were monitored during an operation using Wanganui no. 7 cereal baits (A. Jones, Department of Conservation, Pureora, N.Z., *pers. comm.*). Thus, 73 radio-tagged kaka have been monitored during aerial 1080 operations, and all survived subsequently for at least a fortnight. The kaka at Whirinaki (2000) and Pureora (2001) were monitored for at least a year after the operations, and still no toxin-related deaths were recorded. Given these results it is likely that few, if any, kaka will be poisoned during future aerial 1080 possum poison operations, and as a consequence there will be minimal impact on kaka populations.

This study was the first time that radio-tagged kereru were monitored during an aerial 1080 operation. None of the 15 birds in the treatment area died following the operation. Given the abundance of ripe miro fruit, a sought-after food of kereru (McEwen, 1978; Clout and Hay, 1989) at the time of the poison drop, it would have been surprising if any kereru had fed on carrot baits. However, kereru are known to have eaten carrot

baits (Spurr and Powlesland, 1997) and small pieces of cereal baits at bait stations (R. Powlesland, *unpubl. data*). Also, one kereru found dead after an aerial 1080 operation tested positive for the toxin (Spurr and Powlesland, 1997). Consequently, further studies of the survival of kereru during aerial 1080 operations are warranted, as is an investigation of when kereru are likely to switch from eating natural foods to baits.

Kaka nesting success

There are three results of note from our study of kaka nesting. First was the annual variation in nesting effort, from no nesting in 1999/00 to most females nesting in 1998/99 and 2001/02 (Table 1). A feature of the years when most female kaka nested was the abundant crops on mast-fruiting podocarp species; kahikatea in 1998/99 and rimu in 2001/02.

Secondly, the poor breeding success of kaka at Whirinaki, both at the nest and fledgling stages (Table 1), is similar to results for other sites where there was no control of introduced mammalian predators (Wilson *et al.*, 1998; Moorhouse *et al.*, 2003). Not only was a high proportion of eggs, chicks and fledglings preyed upon at Whirinaki, but more seriously some nesting females were killed as well.

The third feature was the impact of possums on kaka nesting. Video footage was obtained of a possum eating a brood of kaka nestlings. In addition, sign on egg shells and carcasses indicated that possums were responsible for predation of eggs, nestlings, fledglings and an incubating female. While in South Island beech forests stoats have been considered the main kaka predator (Wilson *et al.*, 1998), results from our study and others (Veltman, 2000) suggest that in some other forest types possums may be a critical threat to kaka conservation. Although just one of 13 failed nesting attempts at Whirinaki was attributable to mustelids, six were considered to be the direct result of possum predation. This finding is in line with the growing weight of evidence that possums prey on the eggs and nestlings of a variety of forest bird species (Brown *et al.*, 1993, 1996b; Garnett *et al.*, 1999; Sadleir, 2000; Innes *et al.*, 2003).

In addition, there is evidence that possums may affect kaka at the population level. Following the eradication of possums from Kapiti Island, there was a marked increase in kaka abundance (H.A. Robertson and A.J. Beauchamp, *in* Moorhouse and Greene, 1998; Veltman, 2000). Similarly, kaka abundance was much greater in West Coast forests where possums were absent, or where possums had been present for less than 10 years and were at low density compared to where possums had been present for 10 or more years and were at moderate to high density (Veltman, 2000). Likewise, Powlesland *et al.* (1999) found that very high kills of possums and rats greatly improved robin

(*Petroica australis*) nesting success, resulting in greater numbers and a greater proportion of females being present one year after the operation than before it.

Few kaka bred in the 2000/01 nesting season and so no such benefit could be detected for the kaka population at Whirinaki following the 1080 operation. Also populations of the two main kaka predators, possums and stoats, remained too high after the operation, and/or the treatment area was too small, enabling mustelids to re-colonise within a few months. Moorhouse *et al.* (2003) found that intensive on-going possum and stoat control was required to enhance kaka nesting success and female survival. We believe enhanced kaka nesting success, and potentially kaka population recovery, is possible following aerial 1080 poisoning operations if they are carried out over large areas (5000+ ha) just before kaka start breeding (November), in years when mast-fruiting of a podocarp is expected.

Kereru nesting success

Kereru nesting at Whirinaki coincided with mast fruiting of podocarps during the summer-autumn periods of 1998/99 and 2001/02. Little or no nesting occurred during the same periods in the intervening years when there was little fruit present. Similarly, Clout *et al.* (1995) found that no or few kereru nested when little fruit was available in summer at Nelson and Hawkes Bay. Even though ample food was available at Whirinaki during 1998/99 (mast fruiting of kahikatea) and 2001/02 (mast fruiting of rimu), only 47% and 62% of the radio-tagged kereru were found nesting (Table 2). It is likely that a greater proportion of tagged kereru did nest, particularly during 1998/99, but that a few nests went undetected before their contents were preyed upon as some birds were checked at only weekly intervals.

The significant difference in nesting success between 1998/99 (25%) and 2001/02 (75%) is of note. Previous studies of kereru at five mainland sites without predator control have indicated that few nesting attempts were successful, varying from 0 to 22% (Clout *et al.*, 1995; Pierce and Graham, 1995; Innes *et al.*, 2003). Therefore, it is the 2001/02 Whirinaki result that is at variance with the norm. Presumably this occurred because possum and rat indices for both study sites were less than 12% for much of the 2001/02 breeding season (November-June) (Figs. 2 and 3). Similarly, the results from two mainland studies have shown that when both possum and rat populations were reduced to low densities (< 5%), kereru nesting success improved dramatically; 0 to 100% at Motatau (Innes *et al.*, 2003), and 0 to 45% at Wenderholm (Clout *et al.*, 1995).

Survival of radio-tagged adult kaka and kereru

The relatively poor survival of radio-tagged female kaka compared to males at Whirinaki has been found for other populations of kaka where predators were not controlled (Moorhouse *et al.*, 2003), and is consistent with records of unmanaged populations where there are more males than females (Greene and Fraser, 1998). Predation of nesting females has been suggested as the cause of this sex imbalance (Wilson *et al.*, 1998; Moorhouse *et al.*, 2003) because only females enter cavities to incubate eggs and brood chicks.

The significantly shorter life expectancy of radio-tagged kereru at Whirinaki during autumn-winter than in spring-summer was related to predation associated with eating miro fruit and feeding among low shrubs. In early autumn each year, ripe miro fruit usually became available. It is much sought after by kereru at Whirinaki, as elsewhere (McEwen, 1978; Clout and Hay, 1989). Although kereru are not particularly vulnerable to mammalian predators while feeding on miro fruit in the canopy, a diet of mainly miro fruit results in kereru getting thirsty. It is when they drink at puddles and streams that they become vulnerable to predation by stoats and feral cats (*Felis catus*). Early Maori were also well aware that kereru feeding on miro fruit needed to drink regularly, and snared large numbers at such sites or by providing water in specially made troughs, called whaka-kereru, surrounded by snares sited in the canopy (Best, 1942). Once fruit sources have been exhausted in autumn, kereru in many areas subsist on foliage during winter and spring (McEwen, 1978; Clout and Hay, 1989). Some of the foliage sources they fed on at Whirinaki were understorey shrubs less than three metres tall, and seedlings and shrubs less than a metre tall along roadsides. These low feeding sites again enabled cats and stoats to ambush kereru, with such an incident between a cat and a kereru at Whirinaki being seen (D. Wills, *pers. obs.*).

Given their relatively large size (*c.* 600 g) and slow reproductive rate (1-egg clutch, not breeding every year), kereru would be expected to have a longevity of 20–30 years. The closely-related parea (*Hemiphaga chathamensis*) had an annual survival rate of 0.96 and mean life expectancy 24.5 years when feral cats and possums were intensively controlled (Grant *et al.*, 1997). In comparison, the mean life expectancy of 1.55 years of kereru in Whirinaki is similar to that of kereru at mainland sites without predator control: 5.4 years (Pelorus Bridge, Marlborough), 1.9 years (Mohi Bush, Hawkes Bay), 5.5 years (Wenderholm, Auckland), and 1.2 years (Whangarei, Northland) (Clout *et al.*, 1995; Pierce and Graham, 1995).

The mean mortality rate of 0.48 deaths per bird-year at Whirinaki is not compensated by a greater mean productivity rate of 0.29 fledglings following pest

control. This productivity rate does not take into account the absence of breeding during two years, and the high mortality of radio-tagged fledglings in 2001/02. These figures clearly suggest the population is in decline. Given the significant increase in kereru populations at several mainland sites following intensive and sustained control of introduced mammalian predators [Te Urewera (Jones, 2000); Trounson Kauri Park (Coad, 2001); Motatau Forest (Innes *et al.*, 2003); Waipapa Ecological Area, Pureora (H. Speed, Department of Conservation, Auckland, N.Z. and A. Holzapfel, Department of Conservation, Hamilton, N.Z., *pers. comm.*)], a similar response could be expected at Whirinaki with an appropriate predator control regime. However, whether management for kereru conservation in Whirinaki is started or not, it would be prudent to monitor the status of the population over several years using the distance sampling method (Buckland *et al.*, 2001), as has been carried out in the Waipapa Ecological Area, Pureora (T.C. Greene, Department of Conservation, Christchurch, N.Z., *pers. comm.*), to ensure numbers do not decline to such a critically low level that local extinction is inevitable.

To maximise the benefits of an aerial 1080 operation for as many forest bird species as possible it would be important to identify the priority species from the outset. If kaka and kereru at a central North Island site were the priority, then low population densities of mammalian predator species would be required during their entire four-month long breeding cycle (December-March) because of the vulnerability of kaka and kereru eggs, nestlings and fledglings to predation. As evident from this study, and particularly another at Pureora Forest Park (Powlesland *et al.*, 1999), when large areas are involved (several thousand ha), possum and rodent densities in the core of the treatment area often remain low for several months after an aerial 1080 operation. This can result in significant improvement to the nesting success and recruitment of forest passerines, such as robins (*Petroica australis*) (Powlesland *et al.*, 1999), that regularly produce two, and sometimes three, broods per breeding season. However, although most insectivorous forest passerines start nesting in September, if the priority is to maximise the productivity of kaka and kereru, it would be better to conduct the poison operation in late October or early November. This would ensure that mammalian predator populations remain low for as long as possible given the vulnerability of kaka and kereru fledglings to mustelids, and possibly also to cats and possums. Under such a regime, passerine populations would still benefit, but only during the second half of their nesting season.

In conclusion, introduced mammalian predators were the main cause of kaka and kereru mortality,

including the loss of eggs, chicks, fledglings and adults. The losses were such that it is likely that both kereru and kaka populations in Whirinaki Forest are in decline (Moorhouse *et al.*, 2003; this study). Aerial 1080 operations carried out just before kaka and kereru start breeding (normally in November for North Island podocarp forests) that result in low density populations of possums (< 5% residual trap catch (Warburton, 2000)), rats (< 5% of tracking tunnels tracked), and stoats (< 0.5 per 100 trap-nights or < 5% of tracking tunnels tracked) in years of podocarp mast fruiting would greatly benefit both kaka and kereru populations through improved nesting success and fledgling survival. Such benefits were not demonstrated in this study because the 1080 operation occurred in a non-mast fruiting year when little breeding occurred. However, this study did not detect any toxin-related mortality of kereru and kaka. A repeat study of an aerial 1080 operation over a large area (5000+ ha) just prior to mast-fruiting of a podocarp species is recommended to assess the toxin-related mortality of kereru, and to better determine the benefits of such operations to kaka and kereru breeding and survival.

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