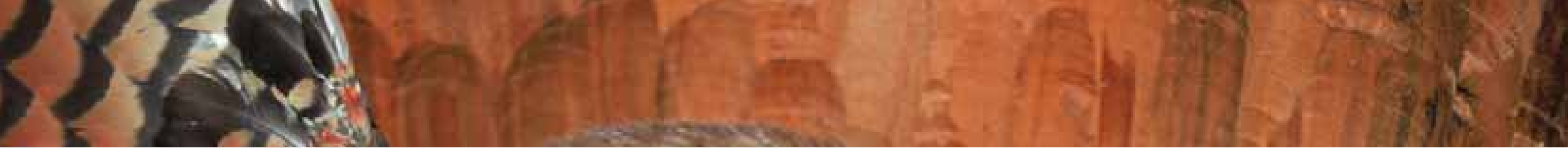

Effect of controlling introduced predators on Kaka (*Nestor meridionalis*) in the Rotoiti Nature Recovery Project

Nelson Lakes National Park, New Zealand

APRIL 2009

Department of Conservation
Te Papa Atawhai

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APRIL 2009

Published by
Department of Conservation
Private Bag 5
Nelson, New Zealand

New Zealand Government

ISSN 0113-3853 (print)
ISSN 1178-4113 (online)
ISBN 978-0-478-14585-4 (print)
ISBN 978-0-478-14586-1 (online)

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1. Abstract

This paper documents the effect of mustelid (in particular stoat, *Mustela erminea*) control on South Island kaka (*Nestor meridionalis*) nesting success and recruitment in the Rotoiti Nature Recovery Project, Nelson Lakes National Park, South Island, New Zealand, from 1997-2006. Fifty-seven percent of kaka nests were successful, and 79% of nesting females survived, at sites with predator control compared to 0.2% nesting success and 16% female survival at sites without predator control. Predator control kept stoat abundance at <5% tracking indices and possum abundance close to 0% Residual Trap Catch/WaxTag® chews. A level of predator control sufficient for the local recovery of a kaka population was achieved through trapping alone, although the use of brodifacoum to control rodents and possums probably killed additional stoats through secondary poisoning. A population model indicated that controlling predators within 825 ha of kaka habitat had a 40% chance of causing a local kaka population recovery whereas controlling predators within 2000 ha of kaka habitat had an 80% chance of doing so. Stoats (*Mustela erminea*) were the main cause of death of nesting adult females, nestlings and fledglings, but possums (*Trichosurus vulpecula*) were also important predators of adult females, eggs and nestlings.

Keywords: Pest monitoring, Fenn™ trapping, honeydew beech (*Nothofagus*) forest, population modelling.

2. Introduction

Stoats were introduced into New Zealand to control rabbits (*Oryctolagus cuniculus*) in the late 19th Century but have since become a major predator of native bird species (King 2005). The South Island kaka is a forest dwelling parrot endemic to the South and Stewart Islands of New Zealand that is declining principally as a result of predation by introduced predators, including stoats (Heather and Robertson 1996; Wilson et al. 1998; Powlesland et al. unpublished).

The Rotoiti Nature Recovery Project (RNRP) is one of six NZ Department of Conservation (DOC) 'Mainland Island' Projects established in 1996 (Saunders 2000). The term 'Mainland Island' is used to designate areas of land on the main islands of New Zealand within which introduced pests are managed so as to create 'islands' of safe habitat for indigenous species, analogous to the offshore island sanctuaries that have provided safe refuge for many endangered New Zealand endemics (See Saunders (2000) for a detailed account of the Mainland Island initiative). The RNRP has the goal of restoration of a beech (*Nothogagus spp.*) forest community, with emphasis on the honeydew cycle (Butler, 1998). The primary objective is to reduce the abundance of certain introduced pest species, including stoats, to levels that allow the recovery of indigenous species, including the kaka (Butler, 1998). The RNRP has associated 'non-treatment' sites where no pest management is undertaken, which provide a control for management within the RNRP (after Butler, 1998). For information on kaka ecology and breeding biology see Heather and Robertson (1996), Wilson (et al. 1998) and Powlesland (et al. unpublished). For information on stoat ecology in New Zealand see King (2005).

From 1984 to 1996 Landcare Research scientists investigated the decline of South Island kaka in beech forest in the Duckpond Stream catchment of Big Bush Conservation Area (DPS), an area subsequently incorporated into the RNRP in November 2001 (Wilson et al. 1998). This study concluded that introduced predators, particularly the stoat, were the probable main cause of the decline of kaka populations on the main islands of New Zealand.

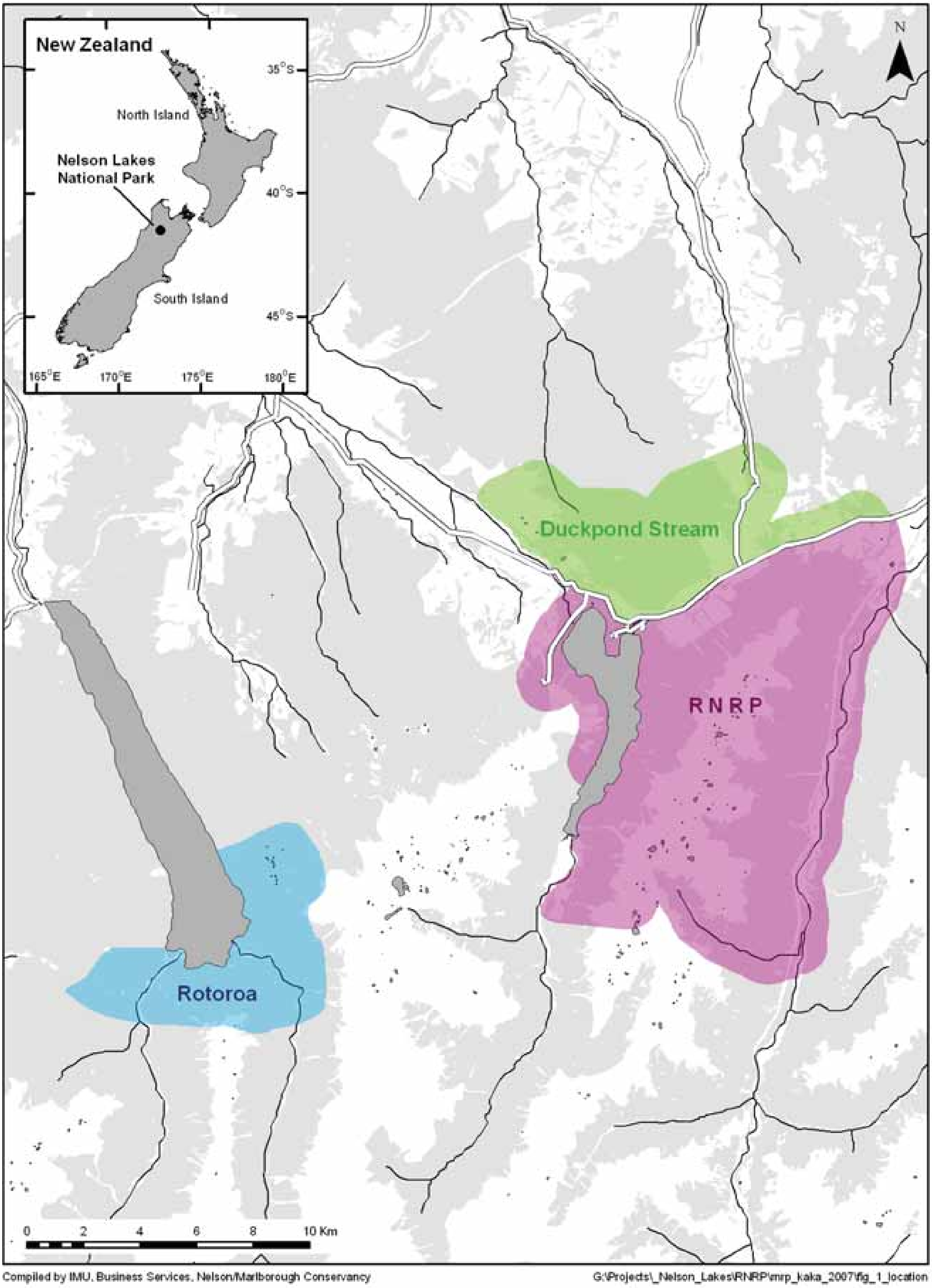
From 1997 to 2006, nesting success of the South Island kaka within the RNRP was monitored to assess the effect of mustelid (specifically stoat) control undertaken there. Kaka were selected for monitoring because they were known to be vulnerable to stoat predation (Wilson et al. 1998) and therefore would be expected to benefit from effective stoat control.

3. Methods

3.1 STUDY AREAS

Kaka nesting success was monitored at three sites: the RNRP ('treatment'), the Duckpond Stream (DPS; initially 'non-treatment', and later 'treatment') and Rotoroa ('non-treatment') site (Figure 1).

FIGURE 1. LOCATIONS OF KAKA STUDY SITES



Topography in this area is mountainous, rising from 600m to c. 1400m at alpine tree-line. The vegetation of all three sites is comprised of mixed *Nothofagus* forests dominated by red beech (*N. fusca*), silver beech (*N. menziesii*) and mountain beech (*N. solandri*) extending to the tree-line, with *Chionochloa* dominated grasslands above at the RNRP and Rotoroa sites (Beggs and Wilson, 1991; Norton, et al. 2000). Beech trees in these forests are heavily parasitised by native honeydew-producing scale insects (*Ultracoelostoma assimile* and *U. brittani*) (Butler, 1998; Wilson, et al. 1998).

3.1.1 Rotoiti Nature Recovery Project

The RNRP occupies the western slopes of the St Arnaud Range which runs along the eastern side of Lake Rotoiti in the Nelson Lakes National Park (Butler, 1998) (Figure 1). Altitude ranges from 620m at lake edge to about 1400m asl. at the tree-line. Lower slopes are dominated by red (*N. fusca*) and silver (*N. menziesii*) beech with mountain beech (*N. solandri* var. *cliffortoides*) and kanuka (*Kunzea erocoides*) at sites with poor drainage; and upper slopes with silver and mountain beech grading to pure mountain beech at the tree-line (Butler, 1998).

3.1.2 Duckpond Stream

The DPS occupies the southern slopes of the Big Bush Conservation Area, a dome of glacial debris rising from 600m to 1000m asl. (Figure 1) (Beggs & Wilson, 1991).Vegetation is similar in type to that on the lower slopes of the RNRP.

3.1.3 Rotoroa non-treatment

The Rotoroa non-treatment site is situated at Lake Rotoroa, 18km west of Lake Rotoiti in Nelson Lakes National Park (Figure 1). Kaka monitoring centred on the western slopes of the Muntz Range (Butler, 2003). The lower slopes are dominated by silver beech, red beech, matai (*Prumnopitys taxifolia*), five finger (*Pseudopanax colensoi*), and *Coprosma microcarpa*; and the upper slopes by silver and mountain beech, grading to mountain beech and *Coprosma* forest at the highest altitudes (Norton et al. 2000). Altitude ranges from 460m at lake edge to 1045m at the tree-line.

3.2 PREDATOR CONTROL AND MONITORING

3.2.1 Rotoiti Nature Recovery Project

Pest control programmes within the RNRP target ship rats (*Rattus rattus*), stoats, feral cats (*Felis catus*), common wasps (*Vespula vulgaris*), possums (*Trichosurus vulpecula*), red deer (*Cervus elaphus*), chamois (*Rupicapra rupicapra*) and feral pigs (*Sus scrofa*).

Because a mustelid control regime was not established until November 1998, stoat numbers were not reduced prior to the 1997/98 kaka breeding season. Therefore, in the absence of a mustelid control regime to test, all kaka nests detected within the RNRP in the 1997/98 kaka breeding season were individually protected with aluminium bands below and above the nest hole (after Greene & Jones, 2003). For extra protection, a network of 25 Mk IV Fenn™ traps baited with hen's eggs or rabbit meat was placed at a radius of 25m around each nest site (Butler, 2000). Similarly, several kaka nests detected outside the RNRP boundaries in subsequent breeding seasons were, where possible, protected with aluminium bands, and a ring of 5 Mk VI Fenn™ traps baited with hen's eggs. The aim of these measures was to preserve breeding females and their female offspring so that these birds might nest within in the RNRP in the future thereby increasing the number of nesting attempts available for monitoring.

From November 1998 to August 2001 the primary means of mustelid control consisted of 298 single entry Mk VI Fenn™ traps deployed on trap-lines within 825ha of the western slopes of the St Arnaud Range (Figure 2). Along the RNRP's northern and southern boundaries traps were spaced at 25m intervals for the first 250m uphill, then at 50m intervals to the top of the hill. Along the ridgeline, lakeshore and on two internal trap-lines, traps were spaced at 100m intervals (Butler, 2000). Trap covers alternated between wire cages, and wooden tunnels with wire mesh ends, at each trap-site. Bait alternated between white and brown chicken (*Gallus domesticus*) eggs and white and brown plastic imitation eggs at each trap. Higher stoat capture rates were recorded in wooden tunnels baited with real, white chicken eggs (Butler 2003). As a result, from July 2000 all traps were covered by a single entry wooden tunnel with wire mesh ends and baited with fresh, white, chicken eggs. All traps were checked once a week. Starting in August 2001, traps were removed from the two internal lines and the project's mustelid control area was expanded to 5000ha, encompassing the western slopes of the St Arnaud Range, the Duckpond Stream catchment and the immediate environs of the Big Bush Conservation area (Figure 3).

FIGURE 2. FENN™ TRAP-LINES USED TO CONTROL STOATS WITHIN THE RNRP BETWEEN NOVEMBER 1998 AND AUGUST 2001

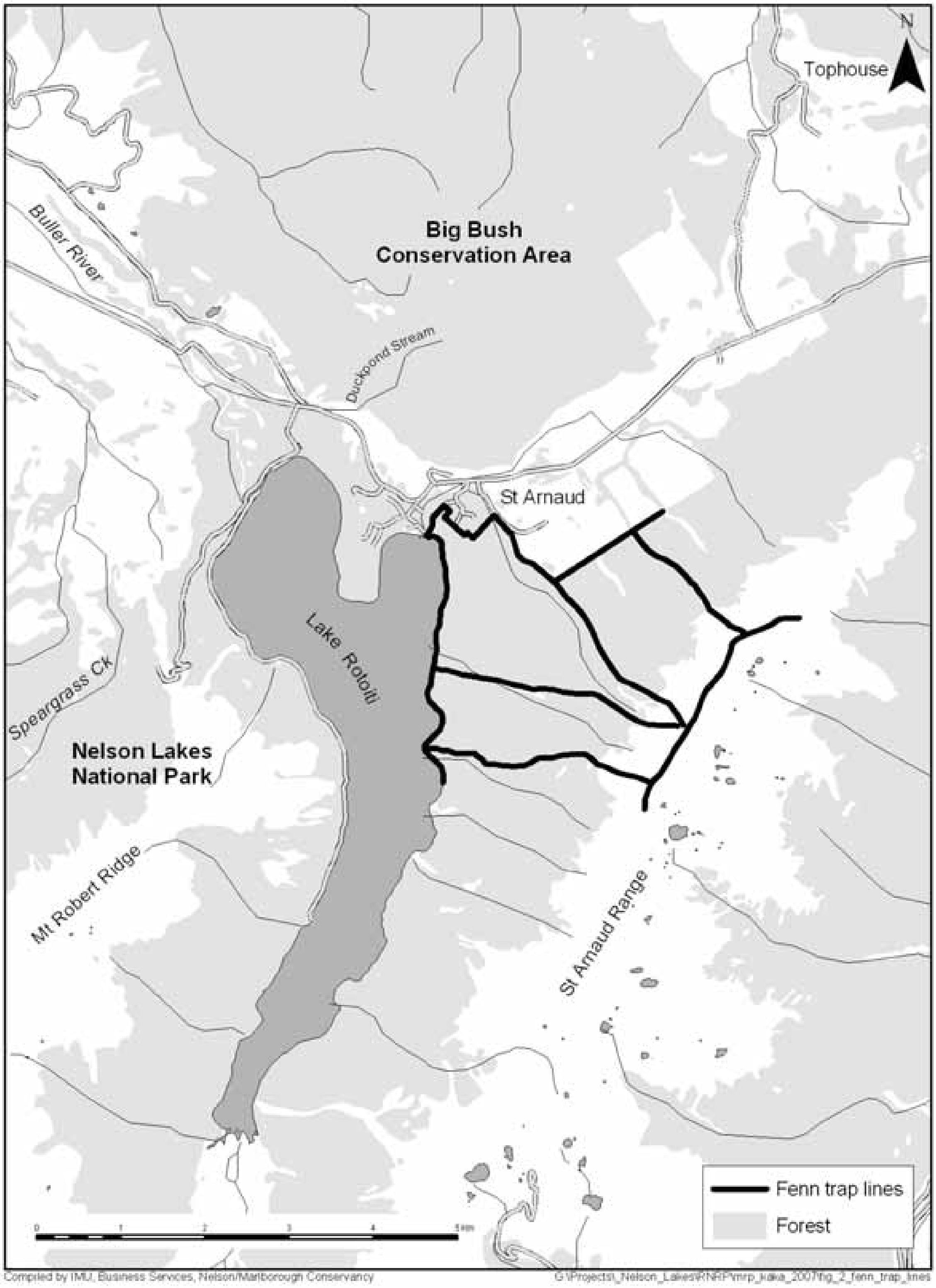
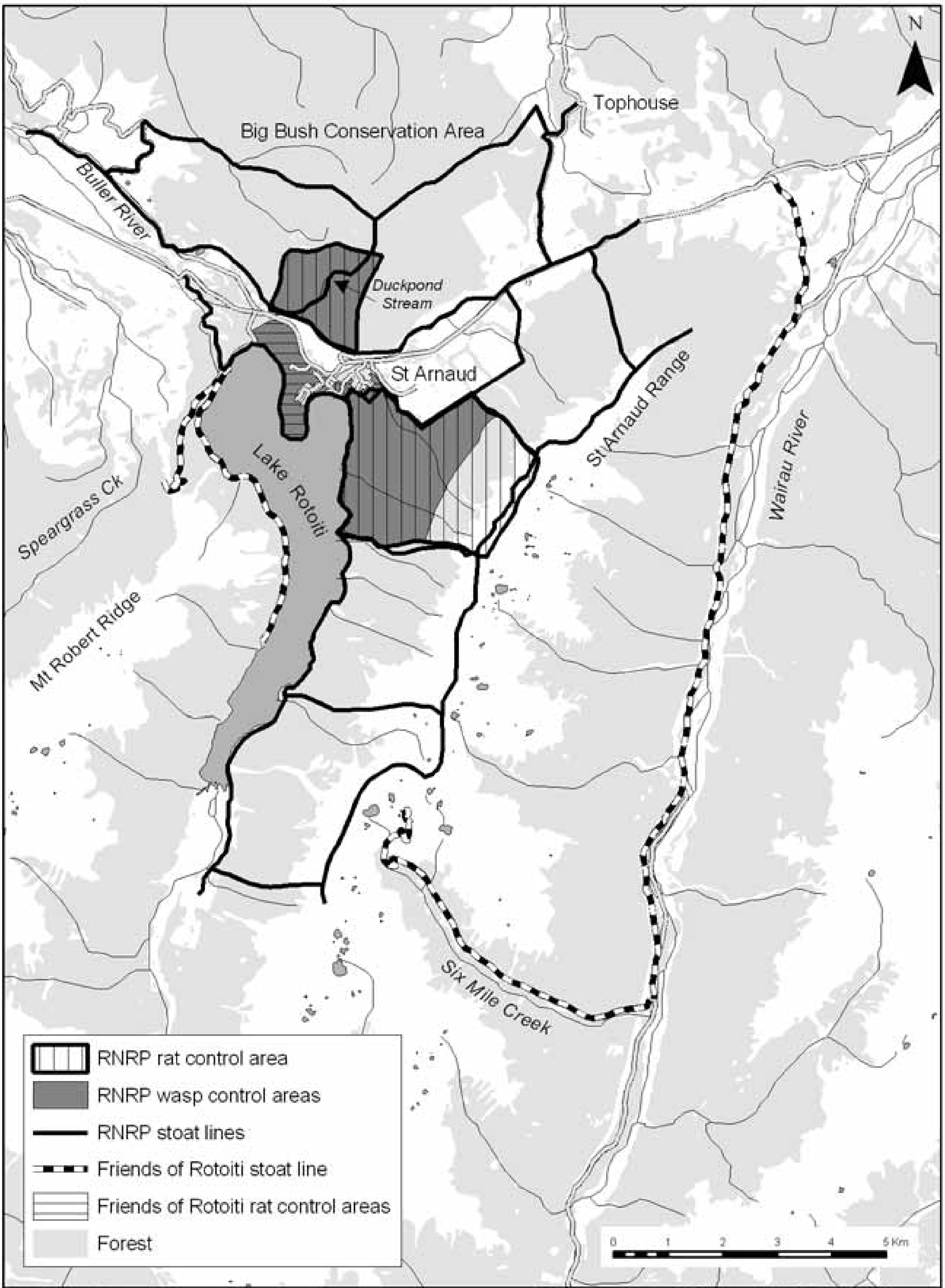


FIGURE 3. EXTENT OF PREDATOR CONTROL IN AND AROUND THE RNRP AFTER AUGUST 2001.



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Therefore references to the 'RNRP' post September 2001, unless otherwise specified, include the Duckpond Stream catchment and immediate environs. The expanded regime was completed in November 2002, and from that point on a total of 897 single entry Mk VI Fenn™ traps were set and checked once a week during December – February, once a fortnight during March – April and October – November, and once a month during May – September. The variation in the frequency at which traps were checked reflected seasonal fluctuations in stoat capture rates.

Fenn trapping for mustelids was also undertaken by the 'Friends of Rotoiti' volunteer group in several adjacent areas to serve as a buffer zone for the RNRP (Figure 3). The trapping system was identical to that used by the RNRP except for the inclusion of 10 DOC 200™ traps along the West Bay – Whisky Falls line, operational since August 2005 (Paton et al. 2007). The Wairau Valley/SH 63 junction – Rainbow Valley skifield line has been operational since January 2002 (Butler et al. 2003) and the Mt Robert Road line since January 2003 (Paton et al. 2004).

An initial poisoning was conducted in November 1997 using 1080 (sodium monofluoroacetate, 0.15% W/W lured with cinnamon at 5%) in Philproof bait stations, with 1000g per station (Butler 2000). Following this, possum and ship rat numbers were controlled from December 1997 to July 2000 using brodifacoum poison (Talon 20WP™) in Philproof bait stations (Butler, 2000). Bait stations were spaced on a 100m x 100m grid in the lower slopes of the RNRP, 100m x 150m above 900m a.s.l. and 150m x 150m in the c. 450m before the tree-line (Butler, 2000). It is likely that a significant number of stoats were killed through secondary poisoning from 1080 and brodifacoum, however this effect was not quantifiable (see Butler {2000} for further discussion on secondary poisoning of stoats in the RNRP, and Spurr {et al. 2005} for discussion on the incidence and persistence of brodifacoum in target and non-target species caught in the RNRP). From July 2000 rodent control was undertaken using a single Victor Professional rat trap placed at the former site of each Philproof bait station (Butler, 2003). Various toxins were used by some land-owners within the St Arnaud village from July 2000 to control rodents (Spurr et al. 2005) but this is unlikely to have had a significant impact on the mustelid population.

Quarterly monitoring of mustelid activity through the use of inked, baited, run-through 'tracking tunnels' was initiated in December 2002 (after Gillies & Williams, 2002). Mustelid footprints recorded in tracking tunnels were not identified to the species level.

3.2.2 Duckpond Stream

Prior to September 2001 the only pest control undertaken in the DPS was the banding of two trees to protect the females nesting in them (Wilson et al. 1998), andabout six months of trapping using 24 Mk VI Fenn™ traps in wire covers, baited with fresh hen eggs and checked at least once a week in early 1999. No stoats were caught during this period (M. Pengelly, pers. comm.). The RNRP trap network was completed on 18 November 2001, except for a buffer line extending north along State Highway 63, which was completed in November 2002. The first kaka nests in this area were located on October 31, 2001; and by the end of November nine radio-tagged adult female kaka had established nests in this area. Because kaka started breeding in the DPS in 2001/2002, before the completion of the trapping network in that area, it's likely that trapping in the DPS part of the RNRP had been in operation for too short a time to have had a significant impact on stoat abundance before kaka nest monitoring began (Paton et al. 2003). Therefore, we have regarded the DPS area of the RNRP as a non-treatment site during the 2001/2002 kaka breeding season, and as a treatment site thereafter. Monitoring of mustelid activity using tracking tunnels was initiated in December 2002 (Paton et al. 2004), after Fenn™ trapping was extended into the DPS area.

3.2.3 Rotoroa

No pest control was undertaken at Rotoroa. Monitoring of mustelid activity using tracking tunnels was initiated in December 2002 (after monitoring of kaka breeding success at Rotoroa ceased). The tracking tunnel network is centred on the north and western flanks of Mt Misery and extends north from there to the southern end of the Muntz range (Paton et al. 2004).

3.3 KAKA NESTING SUCCESS OBSERVATIONS

Kaka were caught in canopy-high mist net rigs in the forest (as per Dilks et al. 2003). From 1996-99 and 2000-2002, 127 kaka were caught and banded in the RNRP, Big Bush Conservation Area and at Rotoroa. Of these, 70 were radio-tagged with two-stage Sirtrack® transmitters attached with a backpack harness system (after Karl & Clout, 1987); 30 in the RNRP, 13 in Big Bush and 27 at Rotoroa. An additional four adult females (captured on Whenua Hou/Codfish island; see Butler 2003 for detail) and three adult birds (one female and two males transferred from the Isaac Trust, Christchurch, but originally from the DPS) were radio-tagged and released into the project area in February 1999 and May 2000 respectively.

From November 1997 to April 2006 in the RNRP, and from November 1998 to March 2000 at Rotoroa, radio-tagged birds in each study area were tracked using a Telonics TR4® hand-held receiver and aerial in order to locate their nests. All nests found at Rotoroa, and all nests found within and up to 1km outside the RNRP Fenn™ trapping network, were regularly checked from the time each nest was located until chicks had fledged or the eggs or chicks had been killed by predators or abandoned. Nests were checked, on average, once every second day, from Monday to Friday in the RNRP, and once a week at Rotoroa. Since the effects of predator control are likely to extend beyond the RNRP boundaries, nests up to 1km outside the RNRP were included in the sample.

In 1997/98 nests were checked by waiting outside the nest until the nesting female was seen entering, or exiting, the nest. Such activity indicated that the eggs or chicks were still alive and that the nest was still in progress. If no activity was observed within the space of three hours, or if the birds' behaviour suggested the nest had failed, the tree was climbed and the nest visually inspected. In subsequent breeding seasons, infra-red cameras were inserted into nest cavities and nests checked with the aid of a portable monitor connected to the camera by a cable. A few nests were placed under 24 hour video surveillance using a time-lapse VHS recorder.

After the outcome of each nest attempt had been determined, the following data were collected: height above ground of the nest entrance, dimensions of entrance, depth of nest from base of entrance, tree species, height, tree health (alive or dead) and aspect of nest entrance (DOCDM-254423).

3.4 NEST PREDATOR IDENTIFICATION

A few nests were monitored continually with a time-lapse video recorder and camera inserted in the nest cavity. This allowed definitive identification of predators when the contents of such nests were preyed on. In the absence of video monitoring the cause of nest failure was determined by examining predator sign or other clues as to why the nest had failed. Any bird or egg remains were collected for autopsy. Some carcasses were forwarded to Massey University or DOC specialists for further autopsy. The top layer of nest litter was collected from every nest in 1998/99 and 1999/2000 and searched for hair and scat remains. Nest entrances were checked for hair and the situation in which remains were found was closely examined.

3.5 JUVENILE SURVIVAL AND DISPERSAL, ADULT SURVIVAL (EXCLUDING DURING BREEDING SEASONS)

A sample of at least 10 kaka nestlings from nests within and nearby the RNRP was radio-tagged each breeding season except in 2005/06. All radio-tagged juveniles were monitored to detect their approximate location and survival status from fixed telemetry sites in the St Arnaud area. Fledglings were monitored every second day for the first two months post fledging, then once a week for as long as signals were detectable from the fixed telemetry sites. Adult birds were monitored once a week. Following the guidelines set out in Gasson (2001, unpublished), radio-tracking was conducted from a light plane in the summers of 2001 and 2002, and in June 2005, in an attempt to locate birds that had dispersed outside the area covered by the standard telemetry sites.

All carcasses retrieved were autopsied. In some cases carcasses were sent to Massey University for further autopsy and microbiology work, and or to Landcare Research, Lincoln, for toxicological assays.

3.6 NEST SAMPLE SIZE AND CONTINGENCY PROTOCOL

Using data collected over the 1998/99 and 1999/2000 seasons in the RNRP and from Wilson et al. (1998), it was estimated that the outcome of 30 nesting attempts would need to be monitored to determine if predator control was effective enough to allow a viable kaka population to be maintained within the RNRP (Moorhouse 2000b, unpublished). A mortality level of two nesting female deaths was also identified as the level at which it was unlikely that predator control was providing adequate protection for nesting adult female kaka in the RNRP. If mortality reached this threshold all remaining nest sites would be protected by banding nest trees and localised trapping. Re-assessment of the predator control regime would then be undertaken before the next breeding season. This contingency protocol was intended to preserve nesting females for future breeding seasons and minimise negative publicity for this high profile project. Following the extension of mustelid control into the DPS this threshold was revised to two nesting female kaka killed in each of the two treatment areas: the DPS area of the RNRP and the St Arnaud range area of the RNRP, allowing a total loss of four birds altogether. This was to allow for the greater number of birds being monitored under the expanded regime.

4. Results

4.1 STOAT CONTROL AND MONITORING

Stoat captures increased dramatically during the summers of 1999/00 and 2000/01, following beech mast years in the preceding autumns (Figure 4a); beech seed-fall in autumn 2000 was the highest in the Nelson Lakes National Park since records began in 1974 (Appendix 1). Without comparing actual capture totals (and ignoring the August 2001 to November 2002 period of increasing numbers of Fenn™ traps being operated), these dramatic fluctuations in peak stoat captures associated with heavy beech seed-fall events between years disappeared following the increase in the area under management in August 2001.This was despite relatively heavy beech seed-fall in 2002 and 2004 (Figures 4 a, c and d). Captures in all years displayed a summer peak, usually in January, reflecting an influx of juvenile animals dispersing from dens

(Figures 4 a, b, c and d) (King, 1983; Dilks et al. 2003). In 2001/02 and 2004/05, stoat numbers peaked in December instead of January (Figure 4 b and d). Mustelids were often undetectable in tracking tunnels, and even when detected, the mean mustelid tracking rate per line remained < 5% (Table 1).

Figure 4. RNRP monthly total stoat captures (after Paton et al. 2004b, 2005 and 2007). Note that the total number of traps operated differed between years: 298 from November 1998 to August 2001 but 897 since December 2002. August 2001 to November 2002 data are presented separately as they coincide with a period when the number of Fenn™ traps was increasing, thus changing stoat capture potential.

FIGURE 4(A)

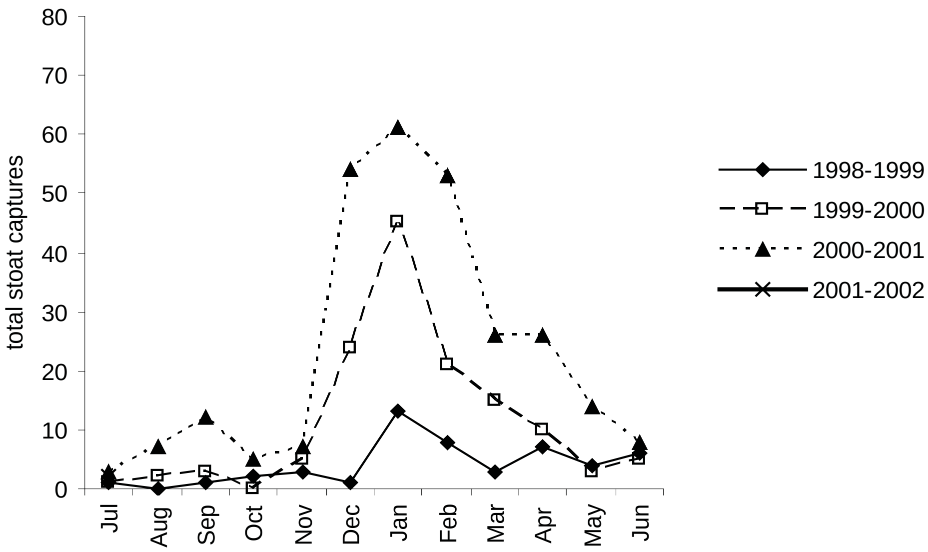


FIGURE 4(B)

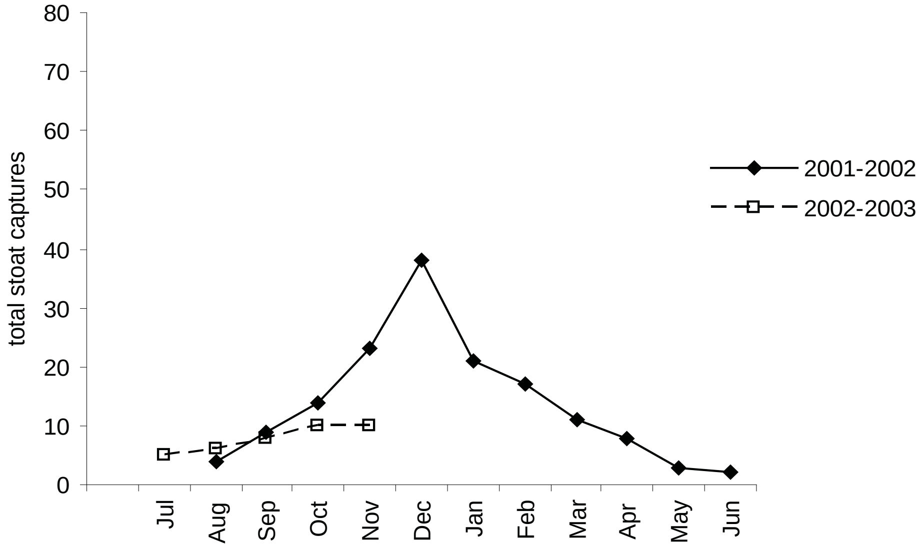


FIGURE 4(C)

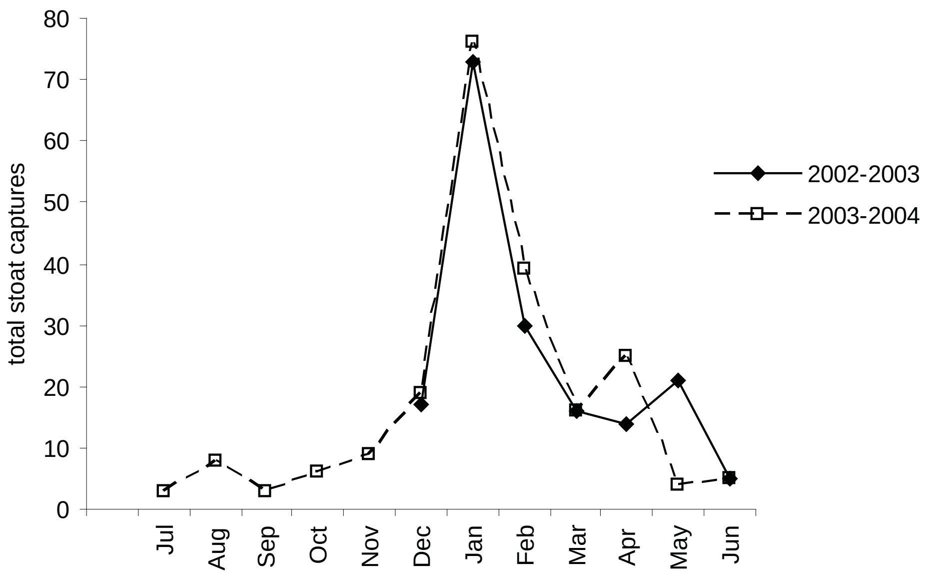


FIGURE 4(D)

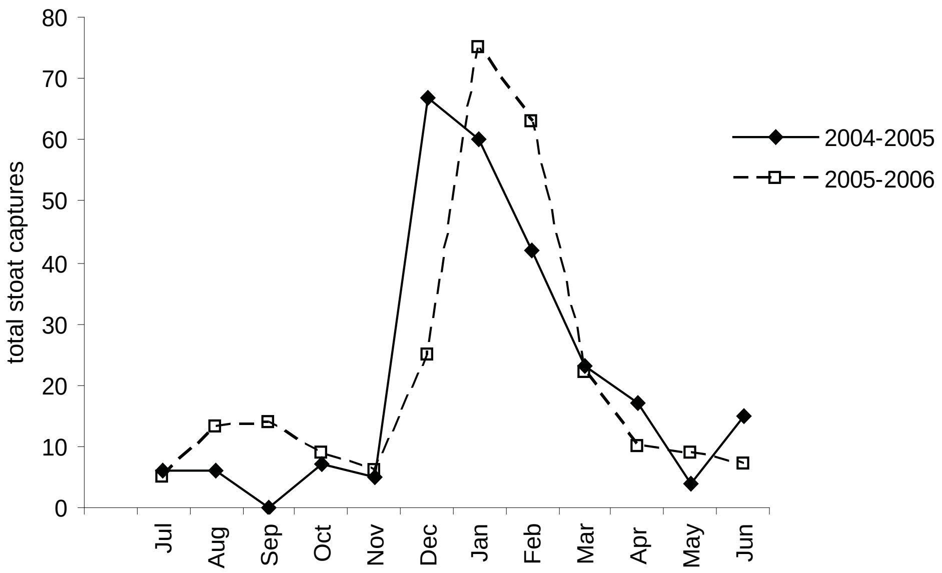


TABLE 1. MUSTELID TRACKING RESULTS, KAKA BREEDING SEASONS ONLY (AFTER PATON ET AL. 2004B AND 2005)

SURVEY	RNRP		ROTOROA	
	% LINES TRACKED	MEAN TRACKING RATE/LINE	% LINES TRACKED	MEAN TRACKING RATE/LINE
Nov 2003	7	4	27	17
Feb 2004	13	3	45	33
May 2004	0	0	No survey	No survey
Nov 2005	0	0	82	55
Feb 2006	0	0	55	50
May 2006	7	1	No survey	No survey

Mustelid tracking results show consistently higher tracking rates and a wider geographic spread of mustelid activity at Rotoroa. Prior to mustelid monitoring incidental mustelid tracks were recorded in rodent tracking tunnels. During this period mustelid tracks were seen frequently at Rotoroa but rarely in the RNRP (Matt Maitland, pers. comm.)

4.2 KAKA NESTING SUCCESS

From 1996-1999 a ratio of 2:1 male:female kaka were caught in the RNRP, the same sex ratio as in the Landcare Research study (Beggs & Wilson, 1991). However, in 2000-02, a ratio of 1.0:1.1 male:female kaka were caught in the RNRP and Big Bush.

Kaka bred in six of the nine years they were monitored in the RNRP (1997/98, 1998/99, 1999/00, 2001/02, 2003/04 and 2005/06) (Table 2).

TABLE 2. NESTING SUCCESS RESULTS, RNRP (AFTER BUTLER, 2003; BUTLER ET AL. 2003; PATON ET AL. 2004B AND 2007)

	1997/98[1]	1998/99	1999/00	2001/02	2003/04	2005/06	TOTAL
# females[2]	4	4	4	4	7	9	14
# nests	4	4	6	5	9	11	35
# successful nests	4	3	5	2	6	6	22
# chicks fledged	10	9	14	3	18	16	70

[1] Data not included in nesting success statistics because of aluminium banding of nest trees.

[2] The same females were sometimes monitored over several breeding seasons.

Kaka breeding at non-treatment sites was monitored from 1985-1996 in the DPS by Landcare Research, and from 1998-2000 at Rotoroa and 2001/02 in the DPS by the DOC Science and Research Division (Table 3).

TABLE 3. NESTING SUCCESS RESULTS, NON-TREATMENT (AFTER BUTLER, 2003; BUTLER ET AL. 2003)

	DPS 1985-96[1]	ROTOROA 1998/99-1999/00	DPS 2001/02	TOTAL
# females	7	5	7[2]	19
# nests	19	11	8	38
# successful nests	1	1	0	2
# chicks fledged	2	4	0	6

[1] Data set (first published in Butler, 2003) differs from that published in Wilson (et al. 1998) because, at Dr. Beggs's suggestion, nest trees banded with aluminium (which included one of the two successful nests) have been removed, and a failed nesting attempt recorded in the RNRP in 1996 has been included.

[2] Data excludes two females whose nest trees were banded with aluminium to further protect them from stoats.

Nesting failures were recorded and grouped according to the phase of nesting in which the nest failed (Table 4). Nesting success was 63% in the RNRP and 5% at all non-treatment sites.

TABLE 4. NESTING FAILURES (NUMBER IN BRACKETS DENOTES TOTAL NUMBER OF NESTING ADULT FEMALES MONITORED) (AFTER BUTLER, 2003; BUTLER ET AL. 2003; PATON ET AL. 2004B AND IN PRESS)

	BIG BUSH 1985-96	BIG BUSH 2001/02	RNRP 1998/99-1999/00	RNRP 2001/02-2005/06	ROTOROA 1998/99-1999/00
# adult females killed on nest	5 (7)	7 (7)[1]	0 (5)	3 (13)	4 (5)[2]
# nests failed in incubation	12	0	1	3	5
# nests failed in nestling period	1	1	1	5	1

[1] Two birds were killed during their second nesting attempt. Data exclude nest trees banded with aluminium.

[2] Data differs from that published in Butler (2003) because previously missing data became available during the writing of this report.

One of the four adult female kaka translocated to the RNRP from Codfish island nested within the RNRP, the others dispersed beyond the range of standard telemetry monitoring sites. The female reintroduced from The Isaac Trust nested in the Duckpond stream area.

Twenty-one percent of adult females were killed on the nest by predators in the RNRP, compared with 84% at all non-treatment sites combined.

4.3 NEST SURVIVAL ANALYSIS

Nest survival was calculated using a daily survivorship technique implemented in Program MARK (White & Burnham 1999, Dinsmore *et al.* 2002). These methods involve logistic-regression modelling using maximum likelihood methods to estimate deviance. The effects of covariates of nest survival, such as mustelid control, are assessed by comparing different logistic-regression models using Akaike's Information Criterion (AIC) (Burnham & Anderson 2002). AIC is a measure of how well each model is supported by the data. Models with a lower AIC are better than models with a higher AIC. Models with AIC differences of less than two are thought of as being similarly supported.

4.3.1 Nest survival analysis: stage 1

We compared a model that distinguished the two phases of mustelid control (the more intensive, pre-August 2001, 825ha control programme versus the post-August 2001, extensive 5000ha control programme) (model 'A') with one that assumed that both phases of mustelid control were equivalent (model 'B') and one assuming no effect of mustelid control (model 'C') (Table 5).

TABLE 5. AIC VALUES FOR RNRP DATA (A)

MODEL	AICC	DELTA AICC	AICC WEIGHTS	MODEL LIKELIHOOD	NUM. PAR	DEVIANCE
Model A	249.5194	0	0.58647	1	3	243.50921
Model B	250.2182	0.6988	0.41353	0.7051	2	246.21315
Model C	288.7733	39.2539	0	0	1	286.77158

Model A, which distinguished 'intensive' mustelid control from 'extensive' mustelid trapping received the most support (Table 5). Under this model, nest survival under intensive mustelid control is estimated at 78% (95% Confidence Interval = 38% - 94%) versus 47% (95% CI = 26% - 66%) under the extensive trapping regime. However, model B, which considered both types of mustelid control as the same was a reasonably strong competitor. Under this model, nest survival is estimated to be 57% with mustelid control (95% CI = 38% - 72%).

Nest survival without mustelid control is estimated to be virtually zero; 0.0016% (95% CI = <0.02%).

4.3.2 Nest survival analysis: stage 2

A second stage of nest survival analysis used only the data that was obtained during the extensive trapping phase of the RNRP programme, the objective being to gain some insight into ways to optimise this.

Within this reduced data set, we explored four questions, as follows:

1. Was nest survival in different breeding seasons (2001/02, 2003/04 and 2005/06) significantly different?
2. Is the risk of nesting failure related to nest age (i.e. do nests containing large nestlings tend to fail more, or less, than nests at the egg or young chick stage)?
3. Does the prevailing mustelid density at the time of a nesting attempt influence its survival chances? To do this, we partitioned each nest into monthly segments, and used the total number of stoats captured in the trap network during the month as a covariate.
4. Does nest survival increase with proximity to a mustelid trap?

Table 6 shows how these models compared.

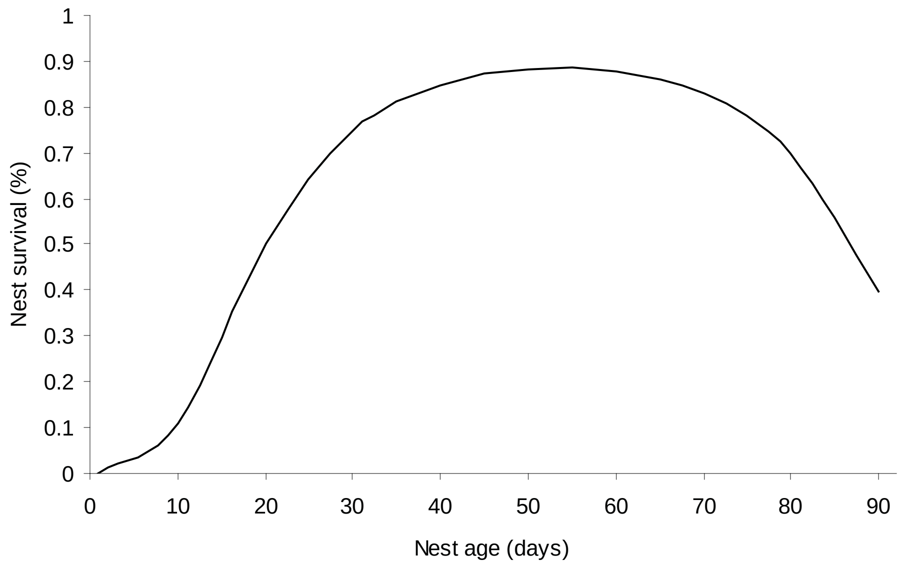
TABLE 6. AIC VALUES FOR RNRP DATA (B).

MODEL	AICC	DELTA AICC	AICC WEIGHTS	MODEL LIKELIHOOD	NUM. PAR	DEVIANCE
Curvilinear age trend	106.0613	0	0.93463	1	3	100.04366
Linear age trend	111.3963	5.335	0.06489	0.0694	2	107.3875
Constant survival	122.6065	16.5452	0.00024	0.0003	1	120.60358
Trap distance	124.5326	18.4713	0.00009	0.0001	2	120.52373
Stoat captures	124.5802	18.5189	0.00009	0.0001	2	120.57135
Breeding season	125.3371	19.2758	0.00006	0.0001	3	119.31946

There is no evidence that nest survival differed significantly between breeding seasons during this phase of the RNRP programme. There was no significant relationship between proximity to a mustelid trap or stoat capture rate and nest survival.

Nest age, however, had a very strong effect on nest survival. Within our data set, nests tended to fail either very early, or very late, with a long period of relative safety during the middle stages of development (Figure 5).

FIGURE 5. NEST AGE EFFECT ON NEST SURVIVAL



4.4 NEST PREDATOR IDENTIFICATION

Wilson (et al. 1998) identified stoats as the main predator of kaka nestlings and, most importantly, breeding females in Big Bush 1985-96. In the RNRP and at Rotoroa, identification of predators was achieved mainly through a 'best guess' process, with the situation in which remains were found contributing most clues as to the species of predator (appendix 2) . However, in some cases the measurement between canine puncture marks fell within the stoat size range (Ratz et al. 1999) and in others video footage definitively identified the species of predator responsible. Most nests failed because eggs or chicks were preyed on by stoats (Table 7).

TABLE 7. PROBABLE CAUSE OF NEST FAILURE

BIG BUSH 2001/02	
# adult females killed on nest	6 stoat 1 unknown (stoat suspected)
# nests failed in nestling period	1 nest of 2 chicks died from hypothermia
RNRP 1998/99 - 1999/00	
# nests failed in incubation	1 unidentified predator
# nests failed in nestling period	1 stoat

RNRP 2001/02 – 2005/06	
# adult females killed on nest[1]	2 stoat , 1 possum
# nests failed in incubation	1 possum, 2 unknown
# nests failed in nestling period	3 stoat, 1 possum, 1 unknown

[1] The banding protocol contingency was not implemented in 2005/06 because the project only suffered a 'partial loss' (Paton et al. in press) and because it failed to provide adequate protection in 2001/02. Also, since 2005/06 was expected to be the last year of monitoring it was decided not to intervene so as to observe true nesting success (Maitland, pers. comm.).

ROTOROA 1998/99 – 1999/00	
# adult females killed on nest	2 stoat, 2 possum
# nests failed in incubation	5 unknown predator
# nests failed in nestling period	1 stoat

4.5 JUVENILE SURVIVAL AND DISPERSAL, ADULT SURVIVAL (EXCLUDING DURING BREEDING SEASONS)

Post-fledging survival (Table 8) and dispersal was monitored for 42 radio-tagged fledglings from nests inside the RNRP, including trees banded with aluminium in 1997/98 and in the DPS area of the RNRP in 2001/02.

TABLE 8. SURVIVAL (TO ONE YEAR) OF FLEDGLINGS FLEDGED WITHIN THE RNRP (INCLUDES TREES BANDED WITH ALUMINIUM IN 1997/98 AND THE DPS AREA OF THE RNRP 2001/02).

	SURVIVAL TO 1 YR POST FLEDGING	DIED WITHIN 3 MONTHS POST FLEDGING	UNKNOWN (TRANSMITTER FAILED OR DISPERSED BEYOND MONITORING RANGE)
Number	23 (55%)	11 (26%)	8 (19%)
Cause of death	-	2 cached[1] 7 unknown but predator implicated[2] 2 non-predator related causes[3]	-

[1] Two fledglings killed by predators at 16 (cached) and 18 (unidentified predator) months post fledging.

[2] One of these fledglings was found dead the same day it fledged and 0.01µg/g of brodifacoum was detected in its liver.

[3] One chick fledged in early 2000 had 0.09µg/g of brodifacoum detected in its liver, with associated haemorrhage of liver and lungs and blood stained fluid over half the length of the small intestine (Maurice Alley, pers. comm.). One chick fledged in May 2004 died of starvation two weeks post-fledging (Maurice Alley, pers. comm.).

Five female chicks fledged in the RNRP survived to breed within it; one bred at just two years of age, but most did not breed until they were three-four years old. Of these, three were killed by stoats during their first nesting attempt.

Survival data on all chicks fledged within the RNRP, and the locations of all detectable transmitters on chicks fledged within and outside the RNRP were used to develop a model to predict the area of predator control required to protect a self-sustaining kaka population in Nelson Lakes National Park.

One non-nesting adult female died inside the RNRP, in May 2006 (unknown predator). Three non-nesting adult females died outside the RNRP, one in May 1999 and one in July 2004 (stoat kills) and one in February 2006 (unknown non-predator related cause). These data contributed to the model mentioned above.

4.6 NEST SAMPLE SIZE AND CONTINGENCY PROTOCOL

2001/02 was the only breeding season in which the individual nest protection protocol was instigated, and then only in the DPS area of the RNRP. Although this area was considered a non-treatment site during the 2001/02 breeding season we decided to instigate the contingency protocol in this season to try and protect remaining adult females so that they might survive to breed in the DPS in the future. Two of the nine radio-tagged adult females that nested in the DPS area of the RNRP were killed in their nests by stoats in early November. From then on, all radio-tagged adult females were monitored twice daily to ascertain if they were nesting or not. Birds within the DPS area of the RNRP were visually checked on the day nesting was detected, and if so, nest trees were banded with aluminium below the nest entrance. Only two of the seven surviving radio-tagged adult females resident in the DPS area of the RNRP were still alive when their nests were located. These nests were later banded above the nest entrance. In one case, a female bird was confirmed alive in the morning but was killed by a stoat later that day. The two radio-tagged adult females resident in Big Bush outside the trapped area both survived their first nesting attempts, the nest-tree of one of these was banded with aluminium below the nest entrance until prolonged brooding of nestlings had finished. Both these birds re-nested outside the RNRP area and were subsequently killed in their nests by stoats.

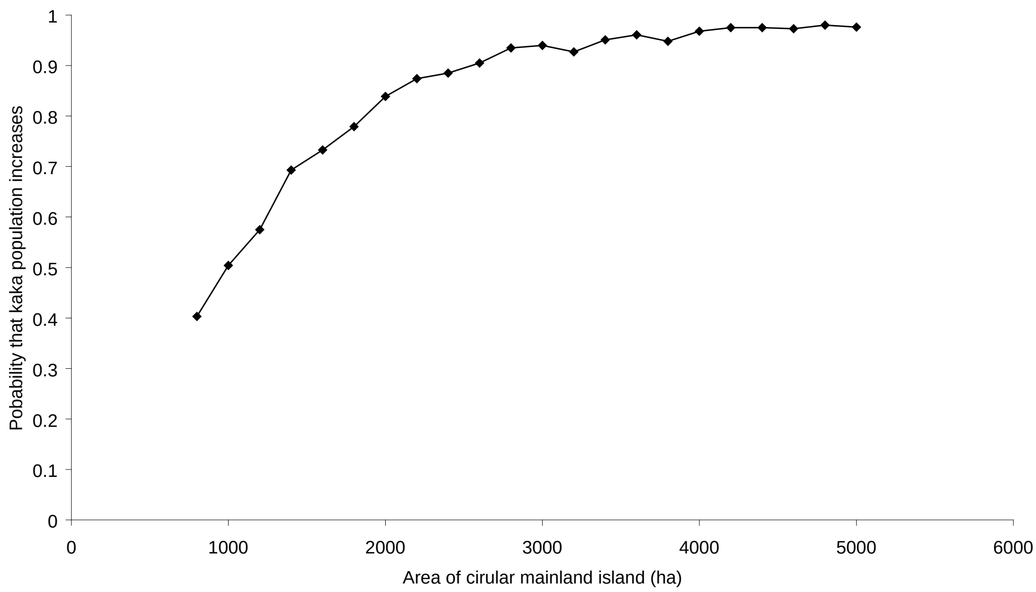
4.7 DEVELOPMENT OF A MODEL TO ESTIMATE THE RATE OF POPULATION RECOVERY AND THE AREA REQUIRED TO SUSTAIN A SELF-SUSTAINING KAKA POPULATION

We constructed a simple stage-structured Leslie matrix and inserted productivity (female chicks per adult female per year) and survival (survival to one year, survival to two years and adult female survival) estimates. The matrix assumes that all female kaka are able to breed at three years of age, but not at one or two. The population growth rate (lambda) was taken to be the dominant eigenvalue of the matrix. To estimate an error distribution for the estimate of lambda we ran 10,000 monte-carlo simulations where productivity and survival parameters were randomly selected from appropriate beta distributions and lambdas estimated for each set of parameters.

The median population growth rate for all the simulations was 1.190425, with 95% of all simulations falling between 1.048687 and 1.308953. 99.55% percent of the simulations had growth rates >1 indicating that populations were increasing.

In addition we developed a slightly more complex model that incorporated an estimate of the probability that young kaka would migrate out of the mainland island. This estimate was based on the distance that 12 young kaka moved before they became sedentary. For the purposes of this model it was assumed that the mainland island was circular, that kaka migrated in random directions, and that those kaka that moved out of the mainland island made no further contribution to the population. The results of this model are shown in Figure 6. A mainland island of only 800 ha has only a 40% chance of allowing a kaka population to increase. Increasing the area under management to 1000 ha increases the chance of a kaka population growing to 50%, but it is not until the area under management exceeds c. 2000ha that we can be more than 80% confident that the population will increase.

FIGURE 6. PROBABILITY OF KAKA POPULATION INCREASING VERSUS AREA OF HYPOTHETICAL CIRCULAR MAINLAND ISLAND (HA).



We can thus be reasonably confident that the current predator-controlled area is large enough to support the recovery of a self-sustaining kaka population.

5. Discussion

Population modelling indicates that predator control in the RNRP can reverse the decline of the resident kaka population, and that the area under predator control is large enough to allow this population to increase.

5.1 MODELLING

The nest age effect (Figure 5) shows that nests were much more likely to fail at an early, or a late, stage of development. Virtually all nest failures were due to stoats killing the adult female and/or nestlings. Why nests should be vulnerable in the early stages of development is unknown, perhaps this result was due to some nests, by chance, being situated near, or within, the core foraging range of individual stoats. The fact that nesting success models incorporating distance to nearest trap and monthly stoat indices were relatively unsupported by the data suggests that the location of traps did not affect the distribution of stoats. Stoats are highly mobile (King, 2005): some individuals miss traps by chance, or are trap shy, and were as likely to have reached the centre of the RNRP as to remain near the perimeter. Some of these stoats will encounter kaka nests. It is possible that nests became more vulnerable late in development as nestlings became bigger, noisier and smellier and therefore more easily detected by stoats.

5.2 NESTING ADULT FEMALE SURVIVAL

Population modelling suggests that predation of adult females is the most damaging kind of mortality for kaka populations (Moorhouse et al. 2003). As in other studies (Moorhouse et al. 2003) predator control in the RNRP has significantly reduced the incidence of adult female mortality, compared to unmanaged sites.

5.3 MUSTELID TRACKING RATES

It is notable that the 2005/06 breeding season was the only season in which nesting adult females were killed by stoats in a treatment area. This occurred despite the fact that mustelids were undetected by tracking tunnels in the RNRP for most of this season. Since the traditional timing of mustelid tracking monitoring misses the January peak in mustelid numbers, tracking in January is recommended (Craig Gillies, pers. comm.). Overall, our results support those of Greene et al. (2004) who found that maintaining a <5% mustelid tracking index was beneficial to kaka populations.

5.4 RELATIVE IMPORTANCE OF DIFFERENT PREDATOR SPECIES

As in other studies (Wilson et al. 1998; Moorhouse et al. 2003), stoats were the most important predator of nesting adult females and nestlings. Wilson (et al. 1998) predicted that stoats would cause the extinction of kaka on mainland New Zealand unless managed. The traditional beech-mast model of stoat population dynamics suggests that most kaka breeding in beech forest occurs in beech-mast years when stoat numbers are low (Wilson et al. 1998). However, despite very low beech seed-fall in autumn, stoat captures were relatively high in the Nelson Lakes area in the spring of 2001, and during the 2001/02 breeding season all monitored adult female kaka that nested in non-banded trees in the DPS area of the RNRP were preyed on: stoats were implicated in all cases. It is likely that the relatively high stoat abundance observed in 2001/02 was a residual effect of the major stoat irruption recorded the previous year, which was the highest stoat capture year on record (Butler, 2003). The heavy beech seed-falls believed to have precipitated the 2001/02 stoat irruption were also followed by predator irruptions that caused the extinction of mohua (*Mohoua ochrocephala*) at Mt Stokes (Gaze, 2001) and Eglinton (O'Donnell et al. 2002), significant mohua declines in the Hurunui, Hawdon, Dart and Rowallan (O'Donnell et al. 2002) and serious decline of orange fronted parakeet (*Cyanoramphus malherbi*) in the South Branch of the Hurunui (Grant & Kearvell, 2001).

Possums were the only other identifiable predator of nesting adult females and nestlings. The sample size is too small to gauge the significance of their impact on kaka populations but this could be significant (Greene et al. 2004). There was no evidence to suggest that ship rats, ferrets or weasels had any impact on kaka nesting success.

5.5 TREE BANDING AS A MEANS OF PREDATOR CONTROL

The outcome of the 2001/02 breeding season in the DPS area of the RNRP indicates that tree-banding is not an effective means of protecting nesting kaka. It may have some value when used in conjunction with other predator control to protect a small population of local importance.

5.6 INTENSIVE VERSUS EXTENSIVE MUSTELID CONTROL REGIMES

Two different mustelid control regimes were in place over the years that kaka were monitored in the RNRP:

1. An intensive trapping network (twice as many traps/ha were operated during the 1998/99 and 1999/2000 kaka breeding seasons compared to post-August 2001) combined with a bait station operation (brodifacoum; Talon 20WP™) for possums.
2. A less intensive, but more extensive (6.25 times larger), trapping only regime from August 2001 to June 2006.

While sample sizes for the two different mustelid control regimes are very small, kaka nesting success during the intensive mustelid control regime was estimated to have been higher, (78%, no nesting adult females killed) than during the extensive regime (47%, three nesting adult females killed, two of these by stoats and one by a possum). However, modelling suggests that, because of the smaller area under management, the intensive regime had only a 40% chance of increasing the kaka population, compared to an 80% chance for the extensive regime. The key difference between the two regimes is greater juvenile recruitment within the boundaries of the extensive regime.

It is impossible to quantify how much impact secondary poisoning had on stoat numbers. Twenty-seven percent of stoats caught while brodifacoum was in use were tested for brodifacoum residues. Of these, 71% were found to have detectable residues of this toxin (Spurr et al. 2005). Secondary poisoning by brodifacoum is known to have killed some, or all, radio-tagged stoats in several New Zealand studies (eg. Alterio, 1996 (coastal grasslands); Alterio & Brown, 1997; Brown et al. 1998; (*Nothofagus* forest); Alterio & Moller, 2000 (Podocarp forest)). Brodifacoum residues detected in RNRP stoat livers ranged from 0.0 – 0.74µg/g (Spurr et al. 2005), within the range of residues detected by Brown et al. (1998) (0.32 – 0.81µg/g). These results suggest that secondary poisoning could have significantly reduced stoat abundance during the 1998/99 and 1999/2000 kaka breeding seasons.

Despite relatively heavy beech seed-fall in 2002 and 2004, the dramatic fluctuations in peak stoat captures between years disappeared following the expansion of the managed area in August 2001. The reason for this is not clear. The energy input from beech seed-fall was high in 2000, but relatively low after 2001 (Appendix 3). This pattern is reflected in total mouse, and to a lesser extent rat, captures in the RNRP (RNRP data published in annual reports from 2001–2006). It is possible that stoat captures also followed this trend.

In contrast, in the Eglinton Valley, 13 000ha of stoat control was undertaken by Fenn™ trapping only, with 0.015 trap-sites/ha and monthly checks of all traps except during stoat irruption years when traps were checked at two-weekly intervals during December and January. Kaka nesting success was 80%, with 100% juvenile survival (Dilks et al. 2003). This is markedly higher than in the RNRP, despite the greater intensity of mustelid control there (0.18 trap-sites/ha and higher frequency of trap checking). The apparently lower effectiveness of mustelid control in the RNRP is possibly due to landscape differences between the two sites. The Eglinton is a glaciated valley with steep sides rising to about 1500m a.s.l., which may act as barriers to stoat immigration, causing most animals to enter at the valley ends (Dilks et al. 2003). The RNRP has rolling hillside in the west, rising to a 1500–1800m a.s.l. mountain range on the eastern edge, and has no obvious barriers to stoat immigration other than the six kilometres of lake edge along the western side of the St Arnaud Range. Stoats are caught throughout the area, including on top of the St Arnaud Range. The RNRP's relative absence of physical barriers to stoat immigration is supported by the fact that nesting success there was not affected by the distance between nests and the nearest trap site although nesting success in the Eglinton appeared to show such an effect (Dilks et al. 2003).

5.7 POST FLEDGING SURVIVAL, DISPERSAL AND RECRUITMENT

Predators were the most important cause of death of kaka fledglings in the RNRP. Only two deaths could, however, definitely be attributed to stoats, what killed the others is unknown. Many potential predators of kaka fledglings exist in the RNRP, including ferrets (*Mustela furo*), feral cats (*Felis catus*), feral pigs (*Sus scrofa*), possums (*Trichosurus vulpecula*) and New Zealand falcon (*Falco novaeseelandiae*). Fledgling survival to one year was lower in the RNRP (55%) than at other control sites (61% in the Waipapa Ecological Area (Moorhouse et al. 2003) and 100% in the Eglinton (Dilks et al. 2003)). Fledglings also tended to die later in the RNRP than at other sites (Moorhouse et al. 2003); seven

(64%) died between 50 and 89 days after fledging, the remaining four (36%) died between one and eleven days after fledging. Moorhouse (et al. 2003) speculate that fledglings in the RNRP may have become more vulnerable to predators after ingesting brodifacoum. Because this is most likely to happen after fledglings begin to forage for themselves, it may also explain why fledglings tended to die later in the RNRP than in other study sites. Fledgling survival to one year certainly increased in the RNRP once brodifacoum use ceased (69% survival (n=29) 1997-2000, 85% survival (n=13) 2001-2004). Fledgling mortality in the RNRP also occurred earlier following the cessation of brodifacoum use; two fledglings that died in 2001-2004 were found dead at 10 and 11 days, consistent with observations at Big Bush, Waipapa Ecological Area, Rotoroa and Whirinaki (Moorhouse et al. 2003). Dilks (et al. 2003) suggest that between site differences in post-fledging survival were caused by the size of area controlled: all Eglinton Valley fledglings stayed within the protected area until at least four to six months after fledging whereas the RNRP has extensive areas of adjacent un-trapped habitat for fledglings to disperse into. However, only two fledglings were found dead outside the RNRP boundaries during the intensive regime.

Causes of fledgling mortality other than predation were few (two of 11 deaths). Two fledgling carcasses were found to contain detectable levels of brodifacoum; the implications of this for kaka management have been discussed elsewhere (Moorhouse et al. 2003; Spurr et al. 2005). It is not known how the two fledglings with detectable brodifacoum residues in their livers ingested the poison, but both primary and secondary poisoning pathways are a possibility. It is interesting to note that the fledgling with 0.01µg/g of brodifacoum in its liver was found dead on the day it fledged. Kaka fledglings appear entirely dependent on adults for food in their first month out of the nest (Moorhouse & Greene, 1995); thus it is likely that this bird received brodifacoum in food regurgitated by an adult. The parents of this fledgling are known to have survived for at least three months and 2.6 years respectively after fledging this particular chick after which their transmitters failed. It is not known if these adults contained detectable traces of brodifacoum in their livers.

6. Conclusion/recommendations

Sustained predator control is essential if viable kaka populations are to be maintained on the main islands of New Zealand. To ensure the success of such operations stoats need to be kept to <5% tracking indices, and possums should be kept as close as possible to 0% Residual Trap Catch (technique after Warburton, 1997) or 0% chews on wax tags (technique after Anon, 2005). During the early stages of such projects, and when kaka numbers are small and almost certainly male biased, efforts should be made to keep stoat tracking indices as close to 0% as possible.

Effective stoat control can be achieved through trapping alone but greater effectiveness can be gained from secondary poisoning through the use of brodifacoum to control rodents and possums. Trap densities of 0.18 trap-sites/ha with virtually no physical boundaries to stoat re-invasion except six kilometres of lakeshore, proved adequate in the RNRP. Tracking tunnel monitoring can aid in achieving appropriate trap densities and distribution; for best results monitoring should include months with peak stoat densities (January in the RNRP).

In homogenous honeydew-beech forest such as the RNRP, where kaka do not travel long distances to localised food sources, an area of at least 2000ha under predator control is necessary to accommodate dispersing juveniles.

As with all predator management on the New Zealand mainland, a high standard of trap and bait-station operation must be maintained and control needs to be ongoing to prevent re-invasion of predators from surrounding unmanaged land.

7. Acknowledgements

We thank in particular: Darren Peters, who established the original mustelid control regime and spent many hours trapping; Andrew Taylor, for tremendous trapping effort and technical help monitoring kaka; and the many other trappers who made this work possible by providing us with a mustelid control regime to test and assisting with the kaka monitoring: Lindy Peters, Mark Pengelley, Nic Etheridge, Dave Butler, Matt Maitland, Jimbo McConchie, Dan Chisnall, Michel Boulay, Jeanette Winn, Bruce Waddell, Jasmine Braidwood, Brett Thompson, Stu Bennett, Logan Martin. Thanks to Kirsty Moran, Jack van Hal and Mike North for help with kaka monitoring. Thank you to the Friends of Rotoiti volunteer group, Kimberley Parlane and Sally Leggett for co-ordinating this group, and other volunteers and short term staff too numerous to acknowledge individually. Phil and Fiona Borlase allowed us access to the study site over their adjacent farm. The RNRP Technical advisory group provided support and advice throughout the project. Thanks to Craig Gillies for answers to various queries and Matt Maitland for helpful comments on an earlier draft. Garry Holz, Doug Anderson and Alice van der Bruggen from DOC Nelson created the maps. Kaka monitoring was funded in part by the DOC S&R Division from 1997-2002. The 1999 kaka translocation was funded by the DOC S&R Division.

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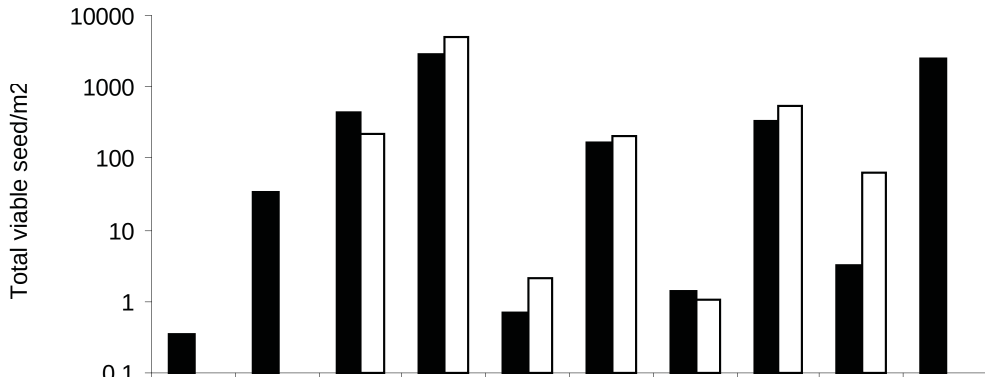
Appendix 1

BEECH SEED-FALL DATA



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
■ RNRP	0.3571	35	447.5	2778.9	0.7143	166.43	1.4286	345.36	3.2143	2527.4
□ Misery			225.89	4883	2.1429	212.68	1.0714	536.25	61.429	

Appendix 2

PROBABLE CAUSE OF NEST FAILURE

BIG BUSH 2001/02	
# adult females killed on nest	6 stoat (4 birds cached within nest hole; 2 on nest floor, skeletons complete but eaten out). 1 unknown (only transmitter found, bands, feathers and 1 broken egg in nest).
# nests failed in nestling period	1 chick died due to hypothermia (nest open and death occurred during spring rains (Butler et. al., 2003)).
RNRP 1998/99 - 1999/00	
# nests failed in incubation	1 unidentified predator (1999/00, Moorhouse 2000).
# nests failed in nestling period	1 stoat (1998/99, spacing between canine puncture marks on nestling skulls and vertebrae were within the stoat size range (Moorhouse, 1999).
RNRP 2001/02 – 2005/06	
# adult females killed on nest[1]	2 stoat (both in 2005/06, one bird cached in nest; one bird dead on surface of nest, on back with wings splayed and one intact egg next to carcass, stoat and possum hair found in nest). 1 possum (2005/06, tarsus bones broken, possum hair in nest, bird dismembered and partially covered in loose nesting material).
# nests failed in incubation	1 possum (2003/04, eggs crushed and possum fur around nest entrance). 2 unknown (2005/06, no evidence of predator found)
# nests failed in nestling period	3 stoats (2 nests in the 2001/02 season, captured on video by Science & Research team (Butler et. al, 2003); 1 nest in 2003/04 season, spacing between canine puncture marks on skulls within the stoat size range (Paton et. al, 2004)). 1 possum (2003/04, extensive damage to front of skull and bruising all over body, possum fur found around nest entrance (Paton et. al, 2004)). 1 unknown (2001/02, chick carcasses never found (Butler et. al, 2003)).

[1]Banding protocol contingency was not instigated in 2005/06 because the project only suffered a 'partial loss' (Paton et al. in press) and because it failed to provide adequate protection in 2001/02. Also, since 2005/06 was expected to be the last year of monitoring it was decided not to intervene so as to observe true nesting success (Maitland, pers. comm.).

ROTOROA 1998/99 – 1999/00	
# adult females killed on nest	2 stoat (1999/00, spacing between canine puncture marks on skull was within stoat size range, damage to base of skull typical of stoat kills (Moorhouse, 2000)). 2 possum (1999/00, canine puncture marks on one skull fitted teeth on a possum skull, puncture marks on the other were larger than could be inflicted by a stoat. (Moorhouse, pers. comm.).
# nests failed in incubation	5 (1 in 1998/99, 4 in 1999/00. Unknown predator (Moorhouse, 2000)).
# nests failed in nestling period	1 stoat (1998/99, dismembered carcasses in nest chamber. (Moorhouse, pers. comm.).

Appendix 3

BEECH SEED-FALL ENERGY INPUT BY SITE (PATON ET AL. 2005)