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THE RISKS, COSTS AND BENEFITS OF USING BRODIFACOUM TO ERADICATE RATS FROM KAPITI ISLAND, NEW ZEALAND

Summary: In 1996 an eradication operation against two species of rats (*Rattus norvegicus* and *R. exulans* was conducted on Kapiti Island (1965 ha) and its small offshore islands. Trials with non-toxic baits had been carried out to help determine the risks to non-target species, and research was undertaken to collect baseline data for measuring the response of vegetation, invertebrates, reptiles and birds to the removal of rats. Talon 7-20 bait (containing 0.002% brodifacoum) was distributed over Kapiti Island in September and October by helicopter and by hand, while bait stations were used on the offshore islands. Impacts on birds and reef fish were investigated. Although there were non-target bird deaths as a result of the poisoning operation, post-eradication monitoring indicated that the toxin had no deleterious effect on breeding and most losses would be rapidly made up by recruitment of new individuals into the breeding population. There was no evidence that reef fish were negatively affected.

The successful removal of rats has apparently resulted in a significantly improved survival rate for stitchbirds (*Notiomystis cincta*) and saddlebacks (*Philesturnus carunculatus*). Benefits to other taxa are expected and will be documented as follow-up studies are completed.

Keywords: Rat eradication; non-target species; risk assessment; brodifacoum; poisoning impacts; monitoring techniques; benefits; Kapiti Island; birds; reef fish.

Introduction

In 1996, the Department of Conservation undertook the largest rodent-eradication campaign ever attempted in New Zealand, the removal of Norway rat (*Rattus norvegicus*[1]) and Pacific rat (*R. exulans*) from Kapiti Island. The scale of the operation and the importance of Kapiti Island as one of the last major havens for several species made it essential that the risk to non-target species be assessed in fine detail. This paper presents information on trials undertaken to determine risk to, and the short-term effects of the operation on non-target species. The short-term responses of non-target species to rodent removal are also discussed.

Kapiti Island (1965 ha) is located in eastern Cook Strait, 5.2 km from the mainland of the North Island (Fig. 1). Oriented NE-SW it has very steep exposed slopes and cliffs on the western side rising to the 520 m summit, with more gentle slopes and sheltered catchments on the eastern side.

Most of the island is a nature reserve administered by the Department of Conservation under the Reserves Act 1977. Three offshore islands and 14.9 ha of land at the northern end are privately owned, and an additional 190 ha is administered by the Commissioner of Crown Lands under the Land Act 1948.

Kapiti Island has a history of considerable modification. Maori introduced the Pacific rat or kiore probably on or soon after their arrival, and Norway rats are presumed to have been introduced in the early 1800s. Cattle (*Bos taurus*) were also introduced about this time, and the island was farmed for more than a century, with over half of the island cleared and grassland maintained by regular fires. Sheep (*Ovis aries*), goats (*Capra hircus*), pigs (*Sus scrofa*), deer (*Axis axis* and *Dama dama*), cats (*Felis catus*) and brushtail possums (*Trichosurus vulpecula*) have also been present on the island.

Despite the extensive habitat modification, the potential value of Kapiti Island as a bird sanctuary was recognised early and in 1897 the Kapiti Island Public Reserve Act gave protection to the island. From 1906 the island had a caretaker, considerable plantings of various tree species were undertaken and the exotic animals were progressively removed (goats were eradicated in 1928, cats in 1935 and brushtail possums in 1986; Cowan, 1992). By 1990 the two rat species were the only introduced mammals remaining.

[1] Nomenclature for mammals follows King (1990) and for birds follows Turbott (1990).

The most widely reported damage by rats is predation. Rats have been observed eating eggs and chicks of a range of birds in New Zealand and elsewhere (Atkinson, 1985). Rats also eat lizards, invertebrates and a wide range of plant material (flowers, fruit and seedlings). They can influence the abundance and distribution of plants, particularly of those species that they prefer (Campbell, 1978).

Research on Kapiti Island has documented the effects of rats on populations of kaka (*Nestor meridionalis*); Moorhouse, 1991) and saddleback (*Philesturnus carunculatus*); Lovegrove, 1992). Up to 50% of kaka nests within 1 m of the ground were preyed on by rats (Moorhouse, 1991). While survival of saddlebacks on Kapiti Island improved with the use of artificial nest and roost sites, population modelling indicated that recruitment was still insufficient to replace losses, mostly due to rat predation, and that the population was likely to decline gradually to extinction over a period of about 60-70 years (Lovegrove, 1992). Potential benefits of rat removal from Kapiti Island included improved survival and viability of these species and other threatened species present on the island, restoration of more natural ecosystem processes (e.g., regeneration, competition and predation), and increased potential for introductions of other native species, unable to co-exist with rats, that are threatened with extinction elsewhere.

Aerial poisoning operations to eradicate rodents (e.g., on Tiritiri Matangi, Red Mercury and Stanley Islands) have indicated that, although the lethal dose for most birds is unknown, the effect of brodifacoum on many native birds is minimal (Robertson, Colbourne and Nieuwland, 1993; Towns, McFadden and Lovegrove, 1993). However, a ground-based operation on Ulva Island (L. Chadderton, *pers. comm*. Department of Conservation, Invercargill) and an aerial operation in the Chetwode Islands (Brown, 1997a) indicated that the weka (*Gallirallus australis*) is at risk from brodifacoum.

Following a study to determine the feasibility and likely effects of undertaking a rodent eradication operation on Kapiti Island, the eradication programme was carried out in 1996. Mitigation measures to minimise effects on fauna at risk were implemented and included the capture and holding in captivity or release elsewhere of 243 weka, and transfer of 66 New Zealand robins (*Petroica australis*) to nearby Mana Island. The eradication operation entailed distribution of green-dyed 16-mm diameter Talon 7-20 pollard baits (cereal-based pellets containing 0.002% brodifacoum manufactured by Animal Control Products Ltd (ACP), Wanganui) over Kapiti Island and rock stacks by helicopter and by hand, and a bait station operation on each of the three small (<2 ha) offshore islands. Two applications of poison bait were made on Kapiti Island, the first on 19-20 September, and the second on 15 October 1996. The total amount of bait used in the first application was 20 500 kg. At an average aerial discharge rate of 9.16 kg ha^{-1}, the bait density, taking into account slope, averaged 9.0 kg ha^{-1}. The bait density for the second application averaged 5.1 kg ha^{-1}, with a total of 11 400 kg distributed.

Monitoring programmes were implemented to measure the effects of the poison on non-target species and the response of birds, lizards, invertebrates and vegetation to rodent removal. A rodent survey undertaken in 1998 confirmed that the eradication operation was successful.

Methods

Risk assessment

Aerial distribution trials using non-toxic baits

To assess the effects of an aerial operation on non-target species, two trials were undertaken on Kapiti Island in 1993 in two adjacent study areas of *c.* 150 ha each using non-toxic Wanganui # 7 baits (cereal-based pellets manufactured by ACP, Wanganui). The first trial began on 8 March, with aerial distribution of 16-mm diameter baits surface coated with red Rhodamine B biotracer. The second trial began on 31 July with the aerial distribution of 12-mm diameter baits impregnated with Pyranine 120 biotracer and surface coated with green dye. Both Rhodamine B and Pyranine 120 are flourescent under ultraviolet light, even when present in small quantities. Bait consumption by non-target species was assessed by checking mouth-linings of birds caught, and by viewing their faeces under ultraviolet light. Bait was distributed in both trials at a target rate of 5 kg ha^{-1} in one area, and 10 kg ha^{-1} in the other, to determine whether or not there were any differences in bait take by non-target species at the different bait densities. Transect surveys of actual bait density indicated that many of the smaller 12-mm baits got caught in the canopy and did not reach the ground. Steeper slopes received less bait due to their larger surface area exposed to the same nominal distribution rate.

The first trial assessed the risk of bait take by weka and little spotted kiwi (*Apteryx owenii*) by catching a sample of birds from each study area after bait distribution, and examining their faeces for biotracer to determine whether or not they had eaten the bait. The second trial assessed the risk of bait take by New Zealand robins and saddlebacks in addition to weka and little spotted kiwi. Weka were caught with hand-nets and in baited cage-traps; kiwi were caught by tracking radio-tagged birds to their day-time roosts and by hand-capture at night; robins were caught with clap-nets baited with mealworms (*Tenebrio molitor* L.); and saddlebacks were caught with mist-nets. Sample sizes for all four species are given in Table 1. Faeces from supplementary feeding stations located within the study area and visited by up to 50 different kaka were also examined.

Aquarium and bait disintegration trials

There is no known information on the toxicity of brodifacoum to marine fish. The fate of any baits dropped into the sea was assessed to determine whether or not there was likely to be any consumption by fish. Non-toxic baits were distributed into the sea about 30 m offshore at 10 m depth and monitored by a diver (P. de Monchy *pers. comm.*). Fish that approached the baits were observed until the baits had disintegrated.

The risk to three marine fish species (blue cod *Parapercis colias* (Bloch and Schneider), spotty *Notolabrus celidotus* (Bloch and Schneider), and variable triplefin *Forsterygion varium* (Bloch and Schneider)) was assessed by undertaking aquarium trials. Live fish were caught and held in experimental fish tanks at the National Institute of Water and Atmospheric Research's (NIWA) Mahanga Bay laboratory for 24 h without food, before being exposed to baits. Fish were held solitarily (15 spotties, 12 triplefins, 9 blue cod) or in groups of 5 (30 spotties) or 4 (24 triplefins). Fish were exposed to baits (either toxic or non-toxic) for one hour before being transferred to clean communal holding tanks for 23-31 days. Solitary fish were exposed to a single bait while groups of fish were exposed to three baits. Fish from different treatments were kept separate after the feeding trial and maintained by daily feeding with green-lipped mussels (*Perna canalicus* (Gmelin)).The spotty experiment was terminated after 23 days when the water supply to their tanks was accidentally turned off and all remaining fish died. The other experiments were terminated after 30 days (blue cod) and 31 days (triplefin) when the fish were anaesthetised and killed. All fish were examined internally for signs of brodifacoum poisoning and liver samples from 15 fish were collected for brodifacoum analysis.

Assessment of the effects of the poisoning operations on non-target organisms

Call counts of nocturnal species

Counts of little spotted kiwi, weka and morepork (*Ninox novaeseelandiae*) calls were collected from four sites on Kapiti Island before and after the poisoning operations to determine whether or not there were any detectable changes in call rates.The sites monitored were selected as part of a national kiwi monitoring programme (Waiorua Valley, Rangatira Helipad, Trig/Wilkinson Junction and Seismometer Hut; see Fig. 1 for locations). The weka and morepork counts were carried out at the same time as the kiwi counts. All kiwi, weka and morepork calls heard in the first two hours after sunset were counted, and counts were repeated for at least six nights per site between January and April. No attempt was made to obtain baseline counts of calls of weka remaining in the wild following the capture and removal of 243 birds in July 1996 and before the poisoning operations in September-October 1996. Changes in call rates at the same sites at the same time of year before and after the poison drops were compared using paired Student's *t*-tests.

Five-minute counts of diurnal forest birds

To determine whether or not the rat eradication operation had any adverse effect on conspicuousness of diurnal forest birds, 5-minute bird counts were conducted by members of the Ornithological Society of New Zealand (OSNZ) and Department of Conservation staff. Counts were conducted before

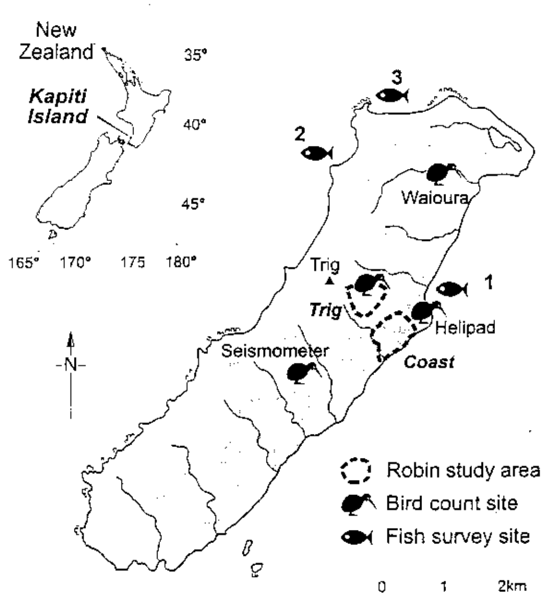

Figure 1: *Map of Kapiti Island, with locations of study areas of New Zealand robins, nocturnal bird count sites and marine fish survey sites shown.*

the poisoning operations on 6-7 July 1996, and afterwards on 25-28 October 1996 and 18-19 January 1997, to allow comparisons with counts undertaken in July, October and January between July 1991 and January 1994 by members of OSNZ. During each count session 256 standard 5-minute counts (Dawson and Bull, 1975) were conducted at 64 stations located on six tracks traversing all the main forest types on Kapiti Island. All birds seen and heard during each 5 minutes were identified and counted, with separate tallies kept for species seen or heard. The proportion of birds heard against those seen in 1996/97 was compared with previous years to investigate the possibility that a decline in numbers following poisoning might have led to an increase in call rates, for example to attract new mates or to establish new territorial boundaries.

Changes in conspicuousness, and the proportion of each species heard versus seen for diurnal forest birds at the same time of the year before and after the poison drop were compared using χ^2 tests. Analyses are presented for the 11 bird species recorded most frequently; these were (in descending order of conspicuousness in the 5-minute counts): whitehead (*Mohoua albicilla*), bellbird (*Anthornis melanura*), tui (*Prosthemadera novaeseelandiae*), New Zealand robin, kaka, red-crowned parakeet (*Cyanoramphus novaezelandiae*), New Zealand fantail (*Rhipidura fuliginosa*), New Zealand pigeon (*Hemiphaga novaeseelandiae*), New Zealand tomtit (*Petroica macrocephala*), silvereye (*Zosterops lateralis*), weka, saddleback, and blackbird (*Turdus merula*).

Radiotelemetry studies

To determine the actual effect of the poisoning operations on kaka and kokako, a sample of each population had transmitters attached prior to the operation so that they could be monitored during and after the poisoning.

Twenty kaka fitted with mortality transmitters were monitored after the first toxic operation and for at least 12 weeks following the second toxic drop. When any dead bird was located, the cause of death was determined where possible. Three kokako (*Callaeas cinerea*) released on Kapiti Island early in 1996 still had functioning transmitters at the time of the poisoning operation, and these birds were regularly monitored during and after the poisoning operation. Results of a telemetry study on little spotted kiwi will be reported elsewhere.

Surveys of banded birds

Searches for banded non-radio-tagged kokako were undertaken before and after the poisoning operation using standard survey methodology - birds were located at dawn by listening for their territorial calls and their identity confirmed by sight if possible. Other, usually non-territorial, birds were surveyed using taped calls played at regular intervals to evoke a response and facilitate the identification of the bird(s) concerned.

Supplementary feeders for stitchbirds (*Notiomystis cincta*) were installed from July 1996 and regularly checked to determine the identity of birds using these feeders before and after the poisoning operations.

The survival and breeding of New Zealand robins on Kapiti Island was monitored in two study areas: coastal forest just south of Rangatira, and mid-altitude forest east of the trig station at Tuteremoana (Fig. 1). Robins within both these areas were caught and individually colour banded, and survival and breeding success were monitored before and after the poisoning operation.

Marine fish surveys

Attempts to quantify the impacts of the poisoning operations on marine fish were complicated by the low densities of most fish species at the three study sites selected within Kapiti Marine Reserve (Fig. 1). A power analysis of results from a previous fish survey (C.N. Battershill *et al., unpubl. data;* NIWA, Wellington, N.Z.) indicated that only spotties were sufficiently abundant to detect a change in density of 50% or more if 15 transects were undertaken at each site. Spotties are known to scavenge on a wide variety of food types (Ayling and Cox, 1982) and were expected to feed on baits if any fell into the sea. Counts were undertaken by the same diver within 25 m x 2 m x 2 m tape transects, with 15 transects per site for the first survey, and 16 per site for subsequent surveys. Surveys were undertaken on 16 July (Site 1) and 19 September (Sites 1-3) (before the poisoning operation) and compared with data collected at the three sites after the poisoning operations on 6 December and 16 December 1996 (R.G. Cole and R.J. Singleton, *unpubl. data*; NIWA, Nelson, N.Z.).

Short term benefits of rat eradication

Stitchbird monitoring

Stitchbirds were monitored on Kapiti Island as part of a PhD study between late 1991 and early 1994 (Castro, 1995). Since then a monitoring regime has been implemented as part of a management programme involving supplementary feeding. As many juveniles as possible have been individually banded each year to maintain a banded population for on-going monitoring. Survival and breeding outcomes were determined by identifying birds visiting the supplementary feeders, and by locating nests and recording their fate.

Saddleback monitoring

Saddlebacks were monitored on Kapiti Island as part of a release programme and PhD study in the 1980s and early 1990s (Lovegrove, 1992). Two surveys were carried out after the eradication operation to assess numbers of adult saddlebacks surviving the operation and subsequent survival of young. The surveys involved searching all areas where saddlebacks had previously been found. Birds were located by listening for song, particularly in the early morning, and playing back taped song to elicit responses. One hour was spent with single birds to confirm their status.

New Zealand robin monitoring

The survival and breeding success of robins before and after rat eradication was determined by monitoring banded birds in the two study areas described earlier.

Results

Risk assessment

Aerial trials

The majority of weka (70%) and robins (56%) monitored, plus three saddleback (27%) and two little spotted kiwi (7%) took the non-toxic bait during the aerial trials (Table 1). Only a few flecks of biotracer were found in kaka faeces at supplementary feeders used by up to 50 kaka after both aerial trials, indicating that most kaka did not eat the bait.

Aquarium and bait disintegration trials

The non-toxic baits distributed in the sea disintegrated within 15 minutes. Assuming that accidental discharges were likely to occur only in the coastal fringe, it seemed unlikely that baits would withstand wave action and remain intact for more than a few minutes. Three species of fish were seen to eat non-toxic baits in the sea: spotties, banded wrasse (*Notolabrus fucicola* Richardson) and unidentified triplefins (*Forsterygion* sp.) (P. de Monchy *pers. comm.*). No blue cod were present at the study site during this trial.

None of the three species of fish tested in the aquarium feeding trials showed much interest in the pollard baits (Table 2), but they all readily consumed mussel flesh immediately after the trials. Although 6 of 24 (25%) of the triplefins exposed to toxic baits died, none was observed to eat the bait and no brodifacoum was detected in livers of the 5 triplefins analysed. Six spotties ate toxic bait, but only one of them died of brodifacoum poisoning. Two other spotties that showed clinical signs of brodifacoum poisoning after death were not seen to eat toxic baits

Table 1: *Percentage of birds showing positive signs of bait consumption relative to average estimated density of non-toxic baits and bait colour. L.s. kiwi = little spotted kiwi. Sample sizes in parentheses.*

Bait colour & density	Species Weka	L.s. kiwi	N.Z. robin	Saddleback
Red, 5.4 kg ha^{-1}	70 (n = 10)	10 (n = 10)	-	-
Red, 11.6 kg ha^{-1}	80 (n = 10)	0 (n = 4)	-	-
Green, 2.9 kg ha^{-1}	100 (n = 2)	0 (n = 9)	60 (n = 20)	33 (n = 6)
Green, 5.9 kg ha^{-1}	50 (n = 8)	17 (n = 6)	50 (n = 14)	20 (n = 5)
Total	70 (n = 30)	7 (n = 29)	56 (n = 34)	27 (n = 11)

Table 2: *Summary of aquarium feeding trials. "No. poisoned" are the number of fish that showed clinical signs of brodifacoum poisoning and had brodifacoum residue in their livers. V. triplefin = variable triplefin.*

		Fish species V. triplefin	Spotty	Blue cod
	Duration of trial, days	31	23	30
Non-toxic bait	No. fish exposed	12	15	3
	No. that died	0	1	1
	No. seen to eat bait	1	1	0
	No. poisoned	0	0	0
Toxic bait	No. fish exposed	24	30	6
	No. that died	6	2	1
	No. seen to eat bait	0	6	0
	No. poisoned	0	2	1

and are thought to have absorbed the toxin through their skin or gills, an unlikely outcome in the sea where toxin would be quickly and considerably diluted.

The results indicated that populations of three of the commonest fish species around Kapiti Island were unlikely to be significantly affected by the poisoning operations.

Effects of the poisoning operations on non-target organisms

Call counts of nocturnal species

There was no significant difference in little spotted kiwi call rates following the poisoning operation. The mean call rate in 1994 - 1996 was 12.4 calls h^{-1} (155 h) compared with a mean call rate in 1997 of 13.7 calls h^{-1} (54 h) (paired *t*-test, P=0.27) (Table 3a).

Mean weka call rates dropped from 12.8 calls h^{-1} to 2.3 calls h^{-1} in 1997 (paired *t*-test, P=0.05) (Table 3b). This indicated that weka call rates were substantially affected by the weka removal and/or the poisoning operation, but because no monitoring was done in the period between the removal and the poisoning it is not possible to determine the relative importance of these two effects. However, no weka had been released from captivity before the monitoring began in 1997, and these results showed that some weka survived the poisoning operation. Before the call counts were completed, several weka were released in two areas (Waiorua and Helipad) and the call rates in these areas showed a marked increase (Table 3b).

Mean morepork call rates dropped from 15.6 calls h^{-1} (68 h) before the poisoning operation, to 11.9 calls h^{-1} (54 h) (paired t-test, P=0.57) after the operation (Table 3c). One dead morepork was found following the second poison drop and brodifacoum in the liver (0.8 mg kg^{-1}) confirmed a necropsy examination suggesting brodifacoum poisoning as the cause of death.

Five-minute counts of diurnal forest birds

Counts of birds in July 1996 before the poisoning operations were similar to those recorded in July 1991-93 (Table 4a), with the exception of tui, New Zealand pigeon and kaka, which were all recorded significantly less often in 1996. The October 1996 counts were conducted 36-39 days after the first poisoning operation, and 10-13 days after the second. The only species that had declined significantly in conspicuousness compared to October 1991-93 was weka (none recorded during 5-minute counts in October 1996; Table 4b). Five species were significantly more conspicuous in October 1996 compared to previous years: kaka,

Table 3: *Average number of nocturnal bird calls heard at four sites on Kapiti Island, expressed as calls h^{-1} (total no. hours listened). The 1997 counts were undertaken 3-6 months after the poisoning operations.*

Species, location	1994	1995	1996	1997
A. Little spotted kiwi				
Waiorua	12.5 (12)	7.3 (12)	13.6 (14)	11.6 (12)
Helipad	6.7 (12)	10.0 (14)	6.3 (12)	10.9 (14)
Junction	9.4 (14)	8.8 (13)	8.5 (14)	8.3 (14)
Seismometer	23.2 (12)	23.3 (13)	19.6 (13)	23.6 (14)
Total	12.8 (50)	12.4 (52)	12.1 (53)	13.7 (54)
B. Weka				
Waiorua	-	17.5 (8)	9.4 (12)	0.5 (8) / 5.8 (4)[1]
Helipad	-	10.0 (8)	9.3 (12)	3.6 (10) / 9.5 (4)[2]
Junction	-	7.0 (2)	6.0 (12)	1.1 (14)
Seismometer	-	7.8 (4)	29.3 (12)	3.6 (14)
Total	-	11.4 (22)	13.5 (48)	2.3 (46)[3]
C. Morepork				
Waiorua	-	18.4 (8)	24.3 (12)	6.6 (12)
Helipad	-	14.7 (6)	17.0 (12)	21.0 (14)
Junction	-	1.5 (2)	3.0 (12)	7.5 (14)
Seismometer	-	7.5 (4)	21.7 (12)	11.7 (14)
Total	-	13.4 (20)	16.5 (48)	11.9 (54)

[1] 1997 weka counts = separate averages of counts pre/post release of 2 weka (remaining in area)
[2] 1997 weka counts = separate averages of counts pre/post release of 8 weka (remaining in area)
[3]Total 1997 weka count excludes 8 hours of counts undertaken post release of 10 weka at two of the sites.

robin, red-crowned parakeet, tomtit and New Zealand pigeon (Table 4b). These latter five species had returned to baseline levels of conspicuousness by January 1997, when no species was recorded more often than in 1992-94, and only weka and whitehead were recorded significantly less often (Table 4c).

Comparisons of the proportion of birds heard to seen for each species in 1996 revealed some more subtle apparent effects of the poisoning operations than shown by the total counts (seen + heard) alone. Call rates for most species in July 1996 (expressed as percentage of birds recorded that were heard but not seen; Table 4a) were comparable with 1991-93 baseline counts. The only exception was tui, which were relatively more vocal in July 1996, although less conspicuous overall. However, by October 1996, four species were relatively more vocal than in previous years: kaka, tui, robin and whitehead (Table 4b). Kaka and robin were both far more conspicuous in October 1996 than in previous years (78.4% and 67.9% increases, respectively; Table 4b); the highly significant increase in "percent heard" for both these species clearly shows that their increased conspicuousness following the poisoning operations was due to an increase in vocalising rather than any population increase *per se*. Tui maintained their pre-poisoning pattern of being 11-12% relatively more vocal in 1996 than in previous years (Table 4a, b), while the increased vocalisation rate of whiteheads in October 1996 was only marginally significant ($P= 0.041$; Table 4b).

By January 1997, none of the species recorded in the 5-minute bird counts had call rates that deviated significantly from the baselines established in January 1992-94 (Table 4c; though note that only a single weka was recorded during the January 1997 counts).

In summary, the 5-minute bird counts revealed that the poisoning operations, combined with the capture of birds for translocation and temporary holding in captivity, had a catastrophic impact on the weka population on Kapiti Island. Impacts on other species were more subtle, but the poisoning operations apparently caused increased call rates in kaka and robin. These effects were either minor or were masked by successful breeding in 1996-97, as by January 1997 only weka and whitehead were recorded as being less conspicuous than previously, and no species was relatively more vocal. The results of these 5-minute bird counts will be presented more fully elsewhere.

Radiotelemetry studies

Twenty-seven kaka were captured between May and September 1996; 20 of these were carrying transmitters and were known to be alive at the time of the first poison drop.

All 20 kaka were alive at the time of the second drop but four birds were found dead on 25, 26, and 29 October and 10 December 1996 (H. Aikman, *unpubl. data*; Department of Conservation, Wellington, N.Z.). The livers of the three birds found in October were analysed for brodifacoum and confirmed the necropsy assessment that brodifacoum poisoning was likely. These kaka had 4.1, 3.3 and 1.2 mg kg^{-1} of brodifacoum detected in their livers and those with the highest levels of brodifacoum died first. The fourth bird that died (an adult female) was too decomposed to be assessed for brodifacoum poisoning. It was last recorded as alive on 14 November 1996 but was not located until December. The cause of death of this bird is unknown. All 16 remaining transmittered kaka were known to be alive at least 3 months after the final drop. At least 11 of these birds were alive in 1997, when caught to have transmitters removed (three in March, six in July and two in August 1997).

More adult kaka died (1/6 possibly 2/6) than juveniles (2/14) but there is no apparent correlation of kaka deaths with sex, with 1/8 (possibly 2/8) females and 2/12 males monitored succumbing to brodifacoum poisoning.

All three kokako with transmitters were located alive at least 14 weeks after the second aerial operation, although one bird was detected by radiotelemetry only in late January 1997. The other two birds have been seen as recently as November 1997 and February 1998 (T. Thurley, *unpubl. data*; Nelson, N.Z.).

Surveys of banded birds

Ten non-radiotagged kokako were identified in the month before the first poison drop. However, two of these (a territorial pair), were not relocated after 31 August 1996, 19 days before the first drop, and so their status at the time of the drop was uncertain and therefore they were excluded from the assessment. Two birds were alive on 16 September 1996, but have not been seen since and so are presumed to have been accidentally poisoned. Six birds were confirmed alive following the second poison drop and an additional two birds have been located in surveys since then. This brought the known survivors, including the radiotagged birds, to 11/13 birds (or 85% survival). All five captive-bred birds known to have been exposed to the poisoning operation survived, so their origin and previous exposure to unnatural food items did not appear to increase their risk of accidental poisoning.

Table 4: *Summary of 5-minute bird counts undertaken before and after the Kapiti Island rat poisoning operations in September/October 1996 compared to baseline counts undertaken between July 1991 and January 1994. "% difference from 1991-93" (or 1992-94) shows whether (and how much) the 1996/97 total count fell outside the range recorded in the same month in 1991-94. "% heard in 1996"(or 1997) gives the proportion of each species that was heard but not seen during the counts. "D in % heard from 1991-93" (or 1992-94) shows whether (and how much) the 1996/97 percent heard fell outside the range recorded in the same month in 1991-94.*

A. July	Total recorded in 1996	% difference from 1991-93	X^2	P	% heard in 1996	D in % heard from 1991-93	X^2	P
Weka	97	-	-	n.s.	-	-	-	-
New Zealand pigeon	46	- 54.9	30.75	< 0.001	45.6	- 9.8	1.78	n.s.
Kaka	88	- 29.6	10.95	0.001	87.5	-	-	n.s.
Red-crowned parakeet	122	- 15.3	3.36	n.s.	89.3	-	-	n.s.
Blackbird	8	- 11.1	0.11	n.s.	75.0	- 1.9	0.03	n.s.
Whitehead	768	-	-	n.s.	70.4	-	-	n.s.
New Zealand fantail	104	-	-	n.s.	69.2	-	-	n.s.
New Zealand tomtit	29	- 12.1	0.48	n.s.	83.3	-	-	n.s.
New Zealand robin	148	-	-	n.s.	68.2	-	-	n.s.
Silvereye	111	-	-	n.s.	68.5	-	-	n.s.
Bellbird	549	-	-	n.s.	92.2	+ 2.0	2.32	n.s.
Tui	313	- 29.8	39.66	< 0.001	86.6	+ 11.7	22.65	< 0.001
Saddleback	10	-	-	n.s.	90.0	-	-	n.s.
B. October	**Total recorded in 1996**	**% difference from 1991-93**	**X^2**	**P**	**% heard in 1996**	**D in % heard from 1991-93**	**X^2**	**P**
Weka	0	- 100.0	80.0	< 0.001	-	-	-	-
New Zealand pigeon	115	+ 23.7	5.20	0.023	59.1	-	-	n.s.
Kaka	248	+ 78.4	85.47	< 0.001	93.9	+ 14.7	32.65	< 0.001
Red-crowned parakeet	140	+ 70.7	41.02	< 0.001	90.1	-	-	n.s.
Blackbird	26	+ 8.3	0.17	n.s.	92.3	+ 1.4	0.07	n.s.
Whitehead	1119	-	-	n.s.	87.4	+ 2.2	4.19	0.041
New Zealand fantail	71	- 1.4	0.01	n.s.	71.8	-	-	n.s.
New Zealand tomtit	130	+ 28.7	8.33	0.004	93.8	+ 2.7	1.23	n.s.
New Zealand robin	262	+ 67.9	72.03	<0.001	80.1	+ 9.3	11.16	0.001
Silvereye	41	-	-	n.s.	78.0	+ 3.5	0.25	n.s.
Bellbird	573	+ 3.6	0.72	n.s.	94.8	+ 2.2	3.81	n.s.
Tui	284	-	-	n.s.	86.3	+ 11.4	19.43	< 0.001
Saddleback	25	-	-	n.s.	92.0	-	-	n.s.
C. January	**Total recorded in 1997**	**% difference from 1992-94**	**X^2**	**P**	**% heard in 1997**	**D in % heard from 1992-94**	**X^2**	**P**
Weka	1	- 98.6	72.01	< 0.001	-	-	-	-
New Zealand pigeon	73	- 5.19	0.21	n.s.	57.5	-	-	n.s.
Kaka	162	-	-	n.s.	94.4	+ 3.6	2.53	n.s.
Red-crowned parakeet	135	-	-	n.s.	89.6	-	-	n.s.
Blackbird	8	-	-	n.s.	100	-	-	n.s.
Whitehead	871	- 13.07	17.13	< 0.001	90.0	-	-	n.s.
New Zealand fantail	112	+ 15.5	2.31	n.s.	60.7	-	-	n.s.
New Zealand tomtit	65	+ 8.3	0.41	n.s.	75.4	-	-	n.s.
New Zealand robin	143	-	-	n.s.	68.5	+ 2.4	0.38	n.s.
Silvereye	25	-	-	n.s.	64.0	- 4.0	0.18	n.s.
Bellbird	400	+ 4.7	0.84	n.s.	90.5	-	-	n.s.
Tui	323	- 8.0	2.23	n.s.	54.5	-	-	n.s.
Saddleback	12	- 14.29	0.29	n.s.	100	+ 6.3	0.80	n.s.

Of 16 adult stitchbirds known to be alive at the time of the toxic operation, one female disappeared shortly after the first drop (she was last seen 28 September 1996) and a male disappeared in early December (Table 5). This survival rate is not significantly different from that recorded during 1992-1995 (χ^2= 1.99, P= 0.16). Three juveniles known to be alive at the time of the operation all survived until the end of December 1996. One additional juvenile was alive at the beginning of September 1996, but was not seen after 3 September, prior to the operation, and so its status at the time of the poisoning operation is unknown. The juvenile survival rate (75%) for the period September to December 1996 was identical to the mean survival rate of the previous three years (Table 5).

New Zealand robin survival data in the presence of toxic baits (1996) and in the absence of toxic baits (1994 to 1995) are given in Table 6. Survival rate in the Coast study area after poisoning was not significantly different from the mean for 1994 and 1995 (χ^2= 1.33, P=0.25). Survival rate in the Trig study area was significantly lower than the mean for 1994 and 1995 (χ^2= 55.77, P<0.001) and significantly worse than in the coastal area in 1996 (χ^2= 35.3, P<0.001).

The majority of robins that disappeared following the poisoning operation disappeared after the first drop: 90% in the Coast study area (n=10) and 94% in the Trig study area (n=33). Prior to the poisoning operation it had been observed that robins along public tracks were more willing to sample new foods (such as cheese) than robins away from these areas. The majority of robins in the Trig study area were close to public tracks, whereas about a third of robins in the coastal area were located well away from these influences. To try to determine why there should be such a difference in survival between the two study areas, the survival of coast birds relative to exposure to public tracks was examined. Sixty percent of robins adjacent to tracks (n=25) survived until the end of December, more than two months after the second drop, compared with 100% of robins away from tracks (n=13).

Table 5: *Survival of adult and juvenile stitchbirds on Kapiti Island during the period September - December. Toxic baits were present in 1996. The table excludes unbanded birds and birds transferred in the same year.*

	Adults alive		Juveniles alive	
Year	Sept.	Dec.	Sept.	Dec.
1992	19	13	5	3
1993	26	22	1	1
1994	20	16	-	-
1995	18	15	2	2
1996	16	14	4	3
1997	17	16	7	7

Table 6: *Survival of New Zealand robins in the Coast and Trig Track study areas on Kapiti Island during the period September to December in years with (1996), and without the presence of toxic baits.*

	Study areas			
	No. alive on Coast		No. alive on Trig Track	
Year	Sept.	Dec.	Sept.	Dec.
1994	24	20	37	37
1995	34	27	46	43
1996	38	28	50	17

Marine fish surveys

The surveys carried out on 16 July and 19 September 1996 were undertaken before fish could have been affected by the poisoning operations, while the last two surveys were carried out 1-2 months after the poisoning operations were completed. At Site 1 spotty densities declined over the first 3 surveys and then increased in the fourth survey to levels greater than those initially recorded (Table 7). At Site 2 spotty densities remained fairly constant throughout the three surveys. At Site 3 spotty density decreased from the second to the third survey and then increased in the fourth survey (Table 7). The surveys provided no evidence that spotty densities were affected by the poisoning operations. At the one site where spotty densities did apparently decline (Site 1), this decline was already occurring before the first poisoning operation. Furthermore, the divers noted no dead or moribund organisms, nor changes to benthic assemblages suggestive of poison entering the food webs. Incidental observations of other fish species did not suggest any alterations in densities of those species either (R.G. Cole and R.J. Singleton, NIWA, *unpubl. data*).

Table 7: *Densities of spotties (fish 100 m^{-3}) recorded at three sites in Kapiti Marine Reserve during surveys before and after poisoning operations in September and October 1996. Results of 15-16 transects per site are given as mean density (standard error). The first two surveys were undertaken before the poisoning operations. Unpubl.data provided by R.G.Cole and R.J. Singleton, NIWA.*

	16 July	19 Sept.	6 Dec.	16 Dec.
Site 1	4.4 (2.0)	2.0 (0.62)	0.13 (0.09)	5.56 (1.21)
Site 2	-	7.60 (3.11)	7.94 (2.02)	6.88 (2.35)
Site 3	-	13.07 (2.44)	9.38 (1.77)	14.75 (2.83)

Table 8: *Annual survival of adult and juvenile stitchbirds on Kapiti Island in the presence (1992-96) or absence (1997) of rats. Table excludes unbanded birds and birds transferred in the same year.*

Year	Adult No. alive Jan.	Adult No. alive Dec.	Juvenile No. alive Jan.	Juvenile No. alive Dec.
1992	26	13	9	3
1993	37	22	4	1
1994	24	16	-	-
1995	19	15	6	2
1996	21	14	9	3
1997	18	16	9	7

Short-term benefits of rat eradication

Stitchbird monitoring

Both adult and juvenile stitchbirds had significantly higher survival rates in 1997 than in the previous five years (Table 8). Adult survival in 1997 was 88.9% compared to a mean of 63.0% during 1992-96 (χ^2=5.17, P=0.02). Juvenile survival in 1997 was 77.8% compared to a mean of 32.1% in previous years (χ^2=8.61, P=0.003)

Stitchbird nesting success and productivity from 1994/95 onwards has improved compared with previous years, with the least successful years being 1992/93 -1993/94 (Table 9). This may be due to stress associated with food availability, particularly the supplementary feeding regime - in 1994/95 the number and distribution of feeders was increased and has been maintained since. Nesting success in 1996/97 immediately after the poisoning was one of the best recorded on Kapiti Island, with an increase in the percentage of females attempting to breed and 100% nesting success. Nesting success in 1997/98 was 73%, lower than expected.

Saddleback monitoring

In the first post-eradication survey of saddlebacks undertaken in March 1997, T.G. Lovegrove (*unpubl. data;* Auckland Regional Council Parks Service, Auckland, N.Z.) found 41 birds, including 9 pairs, 10 juveniles and 13 single males. He concluded that there should be sufficient birds on Kapiti Island to form the nucleus of a new population.

M. North (*unpubl. data;* Nelson, N.Z.) found 60-65 birds, including 20 pairs, 14 juveniles and 9-11 single males during a survey undertaken in January 1998, a 120% increase in the number of pairs and the first significant natural population increase since saddleback were released on Kapiti Island. The increased numbers of pairs in 1998 indicated that survival of juveniles in 1997 (after the rat eradication) was good.

New Zealand robin monitoring

Survival of robins in the presence and absence of rats is given in Table 10. Robin survival in 1997 was not significantly different from that in 1995-1996; either in the Coast (χ^2=0.520, P=0.47) or in the Trig study areas (χ^2=1.285, P= 0.26).

Even though robin survival appears to have been affected by the use of brodifacoum, there is no evidence that the eradication operation had a deleterious effect on breeding success. Both areas had improved nesting outcomes in 1996/7 and there was an increase in the number of nests per female in the Trig study area (Table 11).

Table 10: *Survival of New Zealand robins (January to August inclusive) in the Coast and Trig study areas in the presence (1995-6) or absence of rats (1997). The period September to December has been excluded to eliminate the effects on survival of robins from the poisoning operation in September/October 1996.*

Year	No. alive on Coast Jan.	No. alive on Coast Sept.	No. alive on Trig Jan.	No. alive on Trig Sept.
1995	20	17	38	33
1996	37	31	50	33
1997	29	23	22	18

Table 9: *Stitchbird breeding success before and after a poisoning operation in September/October 1996 on Kapiti Island.*

Breeding season	% females attempting to nest	Average no. nests/nesting female	Nest success, %[1]	Productivity[2]
1991/92	82 (n=11)	1.0 (n=9)	78 (n=9)	2.3 (n=7)
1992/93	56 (n=27)	1.4 (n=15)	60 (n=15)	1.8 (n=9)
1993/94	72 (n=18)	1.0 (n=12)	70 (n=10)	1.4 (n=7)
1994/95	66 (n=12)	1.4 (n=8)	100 (n=4)	2.3 (n=4)
1995/96	60 (n=15)	1.0 (n=9)	88 (n=8)	2.8 (n=5)
1996/97	91 (n=11)	1.2 (n=9)	100 (n=9)	2.9 (n=8)
1997/98	94 (n=18)	0.9 (n=17)	73 (n=15)	2.3 (n=11)

[1]Of known outcomes only
[2]Measured as average number of fledglings per successful nest

Table 11: *New Zealand robin breeding success before and after a poisoning operation in September/October 1996 on Kapiti Island.*

	Trig study area		Coast study area	
Breeding season	Average no. nests/nesting female	Nest success, %*	Average no. nests/nesting female	Nest success, %*
1994/95	1.1 (*n*=10)	40 (*n*=10)	-	33 (*n*=3)
1995/96	1.1 (*n*=16)	83 (*n*=12)	1.7 (*n*=15)	50 (*n*=10)
1996/97	1.4 (*n*=9)	100 (*n*=11)	1.7 (*n*=13)	57 (*n*=21)
1997/98	1.9 (*n*=11)	33 (*n*=21)	1.9 (*n*=16)	57 (*n*=30)

* Of known outcomes only

New Zealand robin breeding success was different from year to year and between study areas (see Table 11) with fewer successes and more nesting attempts in the Coast study area between 1994 and 1997. The least successful year in both areas before eradication was in 1994/95. The Trig study area had poorer than usual nesting success in 1997/98, although the number of nests per female increased.

Discussion

Risk assessment

The lethal dose of brodifacoum for most native birds is unknown, but the results of poisoning operations on Ulva Island and the Chetwode Islands indicated that an aerial or ground based operation would pose a significant risk to weka (Brown, 1997a; L. Chadderton, *pers. comm.*). The risk to little spotted kiwi, robins, kaka and saddlebacks was deemed to be minimal based on poisoning operations at Tiritiri Matangi, Red Mercury, Whatapuke, the Chetwodes, and Stanley Islands (Robertson *et al.*, 1993; Towns *et al.*, 1993; Pierce and Moorhouse, 1994; Walker and Elliott, 1997).

Pre-eradication trials were undertaken to identify which species found on Kapiti Island were at risk from a poisoning operation. Of particular interest were threatened species such as kaka and kiwi, and the trials were useful in indicating the level of risk, even though we were unable to distinguish birds that would consume a sublethal dose of toxin from those that would eat enough bait to receive a lethal dose. The trials identified which species needed mitigation measures (such as robins and weka), and which ones required monitoring through the poisoning operation (such as robins and kiwi). Most species were thought to be at minimal risk but species of particular interest (such as kaka, kokako, stitchbirds and reef-fish) were monitored to confirm the risk assessment and document any changes due to the operation.

Minimal risks were predicted for marine fish based on trials undertaken before the rat eradication. Follow-up surveys confirmed that the poisoning operation had no discernable effect on reef fish, although quantifiable surveys were only possible for a single species (spotty).

Effects of the poisoning operations on birds

Non-target bird deaths occurred, but estimated mortality rates differed depending on sample size and monitoring method. For example, radiotelemetry data on 10 little spotted kiwi indicated a mortality rate of 10-20%, whereas recapture data from a search for 50 banded birds gave an estimated mortality of 2-5% (H.A. Robertson and R.M. Colbourne, *pers. comm.*). This indicated that caution is required in interpreting results of short-term monitoring studies where sample size is small and/or only a single method is used for measuring the effects of a poisoning operation.

The results of the 5-minute bird counts and nocturnal bird call counts should be interpreted cautiously. As the entire island was treated with brodifacoum simultaneously and there was no appropriate control site available, it is not possible to determine whether changes in conspicuousness of both nocturnal and diurnal birds over time were due entirely or in part to the poisoning operations.

Five-minute counts detected a change in kaka and robin behaviour in October 1996, following the second drop, but by January 1997 counts for these species were back to normal. An increased proportion of birds heard for these species probably resulted from an increase in vocalisation by birds trying to attract mates or establish new territories following the deaths of resident birds. Behaviour of both species had returned to normal levels by January 1997 and there was no detectable decline in the kaka population even though it was too early for replacement by breeding to occur. Any robin losses due to the poisoning operation or tasks associated with it (such as the robin transfer) may have been replaced by January 1997, when there was no detectable difference in robin behaviour and conspicuousness from previous counts. This indicates that results of five-minute counts need to be viewed with caution unless they are undertaken soon after the likely time-frame for bird deaths, c. 10-20 days after a poisoning operation using brodifacoum, and there is a good baseline for comparison. These criteria were met on Kapiti Island, and the results of five-minute counts indicated that populations of most bird species, with the exception of weka, were relatively unaffected by the poisoning operation.

Call counts of nocturnal species undertaken between January and April 1997 recorded a significant decline in overall call rates of weka but no significant change in call rates for little spotted kiwi or morepork. However, changes in call rates differed from site to site for morepork and kiwi, with increases at two sites for both species. A decrease for both species was detected at one of the two lowland sites (Waiorua), and an increase was detected at the other (Helipad); neither of the higher altitude sites (Junction and Seismometer) had consistent trends. Interpretation of the results of call counts for these species is problematic but they at least confirmed the survival of many birds of both species following the operation.

The risk to kaka was assessed as minimal because trials on Kapiti Island indicated that few kaka were likely to take the baits, and poisoning operations elsewhere supported this assumption (Robertson *et al.*, 1993; Pierce and Moorhouse, 1994). However, although all kaka on Kapiti Island that had a transmitter fitted survived the first poison drop, 15-20% of radiotagged kaka died after the second poison drop. The reasons for the later susceptibility to poisoning on Kapiti Island are unknown.

The risk to kokako was underestimated. It was regarded as minimal because non-toxic bait trials elsewhere indicated that kokako rejected green-dyed cinnamon-lured bait by sight rather than by taste; of a total of 215 kokako individually monitored through 1080 operations using pollard baits, only 2 birds appear to have been accidentally poisoned (J. Innes, *pers. comm.*; Landcare Research, Hamilton, N.Z.). The probable loss of 15% of kokako in the Kapiti Island poisoning operation compared with minimal losses in 1080 operations using pollard bait might be due to the fact that mainland 1080 operations use pollard baits laced with cinnamon lure for the target species (possums), while no cinnamon lure was incorporated in the pollard baits used on Kapiti Island. Despite the assessment that kokako rejected baits visually and thus were unlikely to take baits even without cinnamon lure (J. Innes, *pers. comm.*), the absence of cinnamon may have increased the risk to kokako on Kapiti Island. Alternatively, kokako may be more susceptible to brodifacoum poisoning than to 1080.

The risk to New Zealand robins and the actual losses may have been overestimated because the trials and most banded birds monitored during the poisoning operation were located adjacent to public tracks. The survival rates for robins differed in the two study areas, and the difference in behaviour of robins adjacent to or away from public tracks may have been a major contributing factor. Therefore robin survival on Kapiti Island as a whole is likely to have been far higher than the 51% recorded in the two study areas, as most of Kapiti Island is not accessible to the public. This was supported by the five-minute bird count results, where there was no significant difference in the number of robins recorded in October 1996 compared to October 1991-93 (although call rates increased).

Weka were expected to be affected by the poisoning operation due to primary and secondary poisoning, and so precautions were taken to ensure that a population of weka would survive on Kapiti Island after the rat eradication programme. It is not possible to estimate the number of weka that perished due to the poisoning operation, but at least some weka survived and they, together with the birds released after the operation are now distributed throughout Kapiti Island and breeding prolifically.

Short-term benefits of rat eradication

Fecundity did not appear to be negatively affected by the toxic operation. Stitchbirds and robins had highly successful breeding seasons immediately after the operation and the increased number of saddleback pairs detected in 1998 indicates that this species too had a good breeding season in 1996/97.

Stitchbirds had a less successful breeding season in 1997/98 (Table 9) but there are several possible reasons:

- 1997/98 was an El Niño year and there was poor breeding for other species such as kaka, kereru and kokako. Stitchbirds may have been similarly affected, although a higher number of females attempted to nest than ever before;
- The ratio of females:males was 2:1, a ratio not previously recorded on Kapiti Island. Most males had two mates but only provided nest assistance (chick feeding) at one nest site. The high survival of juveniles, mostly females, resulted in a greater

proportion of inexperienced females in the population compared to previous years. The inexperienced females tended to nest later than their older conspecifics, and most received no assistance from the already occupied males. The number of fledglings produced per successful nest was 2.0 fledglings per nest for the young females compared to 2.5 fledglings per nest for the experienced females.

New Zealand robin breeding success varied from season to season and between study areas. Nesting outcomes improved immediately after the eradication operation, but nesting outcomes in 1997/98 were less successful (Table 11). The reasons for this are unclear but might be due to several factors:

- Considerably more morepork, a predator at robin nests (Brown, 1997b), were counted in the lowland coastal forest than the higher altitude forest (Table 3c where counts for the Helipad and Junction are indicative of the Coast and Trig study areas, respectively).
- The 1997/98 breeding season coincided with an El Niño year and the poorer breeding success in the Trig study area in this season may be a reflection of this. However, the increase in nesting attempts suggests that there was an improved food supply for robins compared with previous years.

The rat eradication operation was successful. There were losses of kaka, kiwi, robins, morepork and possibly kokako, but none was catastrophic. Weka also died as a result of the poisoning operation, but no pre-eradication counts were undertaken after the removal of weka, so the effect of the poisoning operation on weka is not quantifiable. The loss of kaka was unexpected but only occurred after the second poison application in October, and the impact on robins is likely to have been overestimated. Any losses that have occurred due to the poisoning operation will be offset by the removal of two significant predators of eggs and chicks, which is likely to result in improved productivity and recruitment.

Mitigation measures to ensure that sufficient weka survived to recolonise the island were successful, and weka are now present throughout Kapiti Island. Fecundity does not appear to have been affected by the poisoning operation, with improved breeding success for those species monitored closely (robins and stitchbirds) immediately after the poisoning of rats. Improved survival of juvenile stitchbirds and saddlebacks may also be due to the eradication of the rats. Benefits to other taxa will become clearer as follow-up studies are completed or undertaken in the future.

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ERADICATION OF INTRODUCED ANIMALS FROM THE ISLANDS OF NEW ZEALAND

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ABSTRACT

A wide range of exotic animals has been introduced deliberately or accidentally by humans to the majority of offshore and outlying islands in the New Zealand region. We consider most of these to be detrimental to the original biota of the islands. The eradication of 12 mammals and one bird (the weka) from 60 islands, continuing work on 17 operations and the failure or stopping of nine is recorded.

Eradication of these animals makes sense only for islands beyond the animals' natural swimming range. Future eradications may be considered where changes can be made to the island or adjacent mainland which will prevent migration and re-invasion. The reasons for success of operations to eradicate animals from islands are discussed and some principles for future eradication projects proposed.

INTRODUCTION

Since the beginning of human occupation of New Zealand, animals have been introduced either deliberately or accidentally to the mainland and to the offshore islands. The accidental liberations were mostly the smaller rodents and invertebrates. Cats commonly accompanied European colonisation and also readily became feral, as did some farm animals. Deliberate liberations were primarily to provide emergency food, although some animals were released for the fur industry or recreational hunting. Liberations of indigenous species have been made in attempts to conserve the species.

Around New Zealand there are more than 700 islands, over 273 of which are larger than 5 ha (Atkinson 1989). Most of these islands now have exotic animals which have either been introduced deliberately or accidentally by humans or which have swum from mainland New Zealand.

Without exception, mammals have harmed the biota (Gibb and Flux 1973). Evidence of changes caused by the earliest introduction, kiore, is based on circumstantial comparisons (Atkinson 1978); effects of more recent introductions to islands are based mainly on observations, with little quantitative data (Bell 1978). Following the eradication of introduced species dramatic changes to islands have been reported but have seldom been quantified.

For this paper, a wide group of people was canvassed for data in a standardised form. We collected information beyond our expectations. We include here all known instances of intentional removal of animals from New Zealand islands. We record some instances of removal before breeding started and also refer to instances where introduced animals died out without human intervention. The features of successful and failed eradication projects are given, and principles and methods for future projects discussed.

DATA SUMMARY

Some 21 exotic mammals, 18 endemic and 18 exotic birds, two endemic and one exotic snails, two endemic and one exotic lizard, and an unknown number of insect taxa have been introduced to and established viable populations on the offshore and outlying islands of New Zealand. Some introductions may be "natural" extensions of a species range from the mainland or an adjacent island which was colonised with human assistance. In this paper we consider the successful or attempted eradications of 14 vertebrates from all except the two main islands of New Zealand.

There have been a number of deliberate introductions which failed. Taylor (1968) shows 26 instances of failure for the Auckland Islands alone, including such species as goats, cattle and pigs. Some have survived from subsequent liberations or on other islands within the group. Rudge (1976) adds Snares, Antipodes and Campbell islands as places where goats were liberated but failed to establish. If all attempts to introduce animals to islands were documented we could well see that relatively few were successful.

A total of 13 species have been intentionally eradicated from 60 islands in 85 distinct operations (Table 1). A further nine eradication operations have been planned, and begun, but they failed or were stopped (Table 2). Work is continuing on 17 eradication projects (Table 2).

WHY OR HOW WERE ANIMALS INTRODUCED

Four of the species listed were placed on islands for food or for farming. In the 1890s it was government policy to establish animals on remote islands as food for shipwrecked mariners. Rabbits may have been introduced for either food or fur or, as in the case of Whale Island, baits for rock lobster pots (Paul Jansen pers. comm.). Possums were put on islands for the fur trade. Almost without exception, cats accompanied European settlement. Kiore were taken to islands for food or accidentally transported in canoes, while European rats and mice arrived accidentally from vessels hauled ashore, vessels tied up overnight, shipwrecks and possibly on drifting rubbish (Atkinson 1986). The weka was introduced for food and/or aesthetic reasons.

Some examples of introductions which have not established populations and hence are not included in the tables:

> Twice at Mana Island, a rat was intercepted on the barge. One jumped overboard and reached the shore, where it was killed (Mike Meads pers. comm.). While stores were being unloaded at Raoul Island a pregnant female mouse was killed (Chris Smuts-Kennedy pers. comm.). After kiore were eradicated from Korapuki Island, a ship rat was caught in a monitoring trap (Ian McFadden pers. comm.). During snap-trapping to monitor kiore on Codfish Island, a Norway rat was killed (Andy Cox pers. comm.).
>
> Twice there appeared to be a single rat on Takangaroa (near Kawau) (Taylor 1989) and Poutama (Southwest Stewart Island) (Andy Cox pers. comm.). Breeding populations apparently did not establish, and no further signs were seen after poison baits were laid.
>
> During her studies of endoparasites of kiore Mere Roberts (pers. comm.) found evidence that European rats may have reached islands that have only kiore now, so there may have been many more instances of rats and mice reaching islands without becoming established.
>
> Rock wallabies (*Petrogale penicillata*) were deliberately introduced to Great Barrier Island and then eradicated before breeding occurred (Warburton 1986).

IMPACT ON ECOSYSTEMS

The larger browsing species make a more noticeable impact and hence have been a more frequent target for eradication. Combinations of problem species also appear to make a greater impact than they do separately. The impact of cats and goats on parakeets (*Cyanoramphus* spp.) is an example. Where cats and kiore (as on Little Barrier) or goats and kiore (Macauley Island) co-exist, parakeets survive; when goats, cats and kiore are present, such as on Raoul Island in the 1880s, the parakeets disappeared (Cheeseman 1887).

Removal of problem species does not always allow a return towards a natural ecosystem without further management. This is particularly so with severely browsed islands such as Motunau, where invasion by weeds was a problem after the rabbits were eradicated.

There are few instances where data on the abundance or effects of pest species have been collected before the eradication attempt, and there appear to be few instances where data on the condition of the ecosystem were collected for a long period beforehand. Data have been collected after several eradications and these in general verify the very visible change to the ecosystem.

REASONS FOR ERADICATION

The main reason should be to restore the intrinsic values of islands. Every island has its own plant and animal species, sometimes including endemic ones. No modified habitat will return to its pristine condition after introduced animals have been eradicated, but it can in time resemble it. Immediate results may be spectacular but a long time is required for a maturity and mixture of vegetation similar to that of the original community to develop.

In addition to protecting and enhancing the island's own values, eradication of animals can provide habitats for threatened indigenous plant or animal species. Some islands have a very high ecological value now and should not have new indigenous species introduced to them. If an island is to be used for more intense management, one of the heavily modified islands where animals and people have had a long and profound influence would be a better choice.

The objective must be clearly set at the beginning and it must be attainable. Usually this will be eradication (complete removal of the target species); only rarely should control (sustained reduction in numbers) be considered. Even if eradication is initially more costly, in the long term it will be less expensive. On the other hand, control could be justified to protect a threatened species until other measures can be taken.

PLANNING AN ERADICATION PROGRAMME

Few of the early eradication operations were planned as we would plan them today. However, detailed planning is not by itself a recipe for success. Knowledge, ability and dedication of staff have, in a number of successful operations, made up for limited planning. While some projects have been stopped because of changes in work priorities or conflict with other projects, the majority of failed eradications have been due to a lack of adequate planning, resulting in failure to recognise all the problems or to commit sufficient resources to the task.

The better the planning the more chance of success. Knowledge of the general topography, plant cover, availability of water, climate, wet and dry seasons and temperature will assist in deciding the best time to conduct a campaign, either so that the task will be more amenable for the work force, or so that natural forces may concentrate the animals into specific areas, make them hungry or attract them to a particular food source.

The operators should be aware of all the methods which are available and they should be prepared to use any or all of these methods. Life cycles of possible non-target species must be well known so that operations can be planned to eliminate or reduce the possibility of trapping or poisoning non-target species. When using poisons consideration has to be given to secondary poisoning.

Some islands have a single animal problem; others have several. In the latter case it is important to remove the animals in the correct order. The removal of one may trigger an increase of the second or may make the second more difficult to find or remove. Likely changes to the ecosystem following the initial knockdown of numbers of the introduced animals should be recognised. This is important for herbivores in particular, as vegetation can quickly grow and become a problem for hunters trying to find the last few animals.

The plan must recognise that a daily record of the eradication work should be made and that time is needed following completion of the project to record and report on the success or otherwise of the operation.

ERADICATION METHODS

The methods used for the 84 successful operations that are listed have been reasonably consistent from species to species. Many operations have been successfully completed by only one method. Of the eight failed eradication operations there were four instances of the animals swimming back, incidents that increased our knowledge of the ability of animals to invade islands. A further four eradications failed due to insufficient planning and hence an inadequate commitment of resources.

Methods will vary from species to species and may vary even between very similar species, such as the two European rats. There are few commercially available methods for the eradication of introduced animals from islands. Previously proven methods have to be used or new methods have to be designed. For some animals though, particularly rodents, there are very effective commercial poisons available.

There is still room for improvement to methods for almost all species. Research is continuing, and during each operation improvements continue to be made. Staff doing the work should be given the flexibility to change as the task proceeds.

NECESSITY FOR TOTAL COMMITMENT

Once the objectives are established and eradication plan approved there must be a total commitment to make the necessary funds and staff available to achieve them. The selection of staff is extremely important, because they must have, above everything else, commitment and persistence. The challenge is as much mental as physical. It is relatively easy to maintain interest and application when the kill rate is high but much more difficult in the later stages of the campaign when few animals remain. For example, the capture rate of cats on Little Barrier Island was 35 cats for 5459 trap nights, about one cat per 156 trap nights in 1979; in the final year, 1980, only five cats were caught for 32 165 trap nights, one cat per 6500 trap nights. Only the right mental approach and a dedication to the objective gives a successful result.

PUBLICITY AND PUBLIC RELATIONS

It is essential that any eradication programme be discussed with the appropriate people and agencies from the beginning of planning. This will reduce misunderstanding and undesirable or ill informed publicity. Should opposition remain then opponents should be asked to put forward a viable alternative; that should be fully discussed. This often helps the public realise how well considered the original proposal is.

MONITORING

Monitoring the impact of introduced species on ecosystems is desirable if priorities are to be established for eradication projects or changes following eradication are to be documented. The absence of such monitoring should not, however, be seen as a reason for delaying an eradication project.

Independent programmes monitoring effectiveness are not usually required, since the hunters will know where animals are, whether or not they are successfully removing these animals, and when none remain. Recording the cost and effort required to achieve eradication can be beneficial when planning future operations. If a person or organisation wishes to obtain data during the course of an eradication operation which may be of interest or use later, but which has no immediate benefit to the operation, then this should be permitted, provided it does not interfere with the actual work of hunting.

Monitoring is needed, either to detect undesirable changes (such as weeds) or to determine when the habitat is suitable for the introduction of new species. Monitoring for these purposes may need to be

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Table 1: Eradications.

ISLAND	AREA (ha)	DATE INTRODUCED	ERADICATION LEADER	START ERADICATION	METHODS	COMPLETED ERADICATION	REFERENCE
<u>MAMMALS</u>							
<u>POSSUM</u> (*Trichosurus vulpecula*)							
Codfish	1336	<1925	Andy Cox, Gary Aburn	1984	Poison, traps & dogs	1987	Andy Cox pers. comm.
Kapiti	2023	1894	G Alexander, B Cairns	1980	Poison, traps & dogs	1986	Peter Daniel pers. comm.
<u>RABBIT</u> (*Oryctolagus cuniculus*)							
Korapuki	17	c1900	I McFadden	1986	Poison, shooting	1988	Ian McFadden pers. comm.
Mangere	130	<1890	?		Cats	?	Brian Bell
Mokopuna (Leper)	<1	1946	Logan Bell	1947	Poison & traps	1954	Anon 1951
Motunau	3.5	<1867	Motunau Rabbit Bd.	1958	Poison & shooting	1962	Cox et al 1967
Native (Stewart)	66	c1942	Snow Corboy	c1949	Traps & shooting	1950	Rowley Taylor pers. comm.
Otata	15	?	Capt. Wainhouse	?	Shooting	1945	B P Neureuter pers.comm.
Stewart (Part)	174 600	1942	Dept Agriculture	c1948	Traps & shooting	1950	Rowley Taylor pers. comm.
Takangaroa	6	<1930	T.Clarkson	?	Shooting	<1950	Taylor 1989
Tiritiri Matangi	196	<1894	Everard Hobbs	c1900	?	c1920	Anon 1987
Whale	173	1968	Paul Jansen	1985	Poison & traps	1987	Paul Jansen pers. comm
<u>MOUSE</u> (*Mus musculus*)							
Allports	16	c1900	Derek Brown	1989	Poison	1989	Brown 1990
Motutapu (by Allports)	2	?	Derek Brown	1989	Poison	1989	Brown 1990
Whenuakura	3	?	Ian McFadden	1983	Poison	1984	Ian McFadden pers. comm
<u>SHIP RAT</u> (*Rattus rattus*)							
Awaiti	2	?	David Taylor	1982	Poison	1982	Taylor 1984
Kauwahaia	0.7		Graeme Taylor	1989	Poison	1989	Graeme Taylor pers. comm
Mokopuna (Leper)	<1	c1961	Rod Sutherland	1988	Poison	1990	Ian McFadden pers. comm
Somes	32	c1961	Rod Sutherland	1988	Poison	1990	Ian McFadden pers. comm.
Tawhitinui	21	?	David Taylor	1983	Poison	1983	Taylor 1984
<u>NORWAY RAT</u> (*Rattus norvegicus*)							
Breaksea	170	1800s	R Taylor, B Thomas	1988	Poison	1988	Taylor & Thomas 1989
David Rocks	0.3	<1960	Don Merton	1960	Poison	1960	Moors 1985
David Rocks B	0.2	<1960	Don Merton	1960	Poison	1960	Moors 1985
David Rocks C	0.2	<1960	Don Merton	1960	Poison	1960	Moors 1985
Hawea	9	1800s	R Taylor, B Thomas	1986	Poison	1986	Taylor & Thomas 1989
Maria	1	<1960	Don Merton	1960	Poison	1960	Moors 1985
Mokoia	133	?	Paul Jansen	1989	Poison	1989	Paul Jansen pers. comm.
Motuhoropapa	8	<1962	Phil Moors	1979	Trap & poison	1987	Moors 1985
Motuhoropapa A	0.2	<1962	Phil Moors	1979	Trap & poison	1987	Moors 1985
Otata	15	c1956	Phil Moors	1979	Trap & poison	1987	Moors 1985
Otata A	0.2	c1956	Phil Moors	1979	Trap & poison	1987	Moors 1985
Takangaroa	6	Unk	T Clarkson	Unk	Unk	Unk	Taylor 1989
Te Haupa (Saddle)	6	?	Rex Gilfillan	1989	Poison	1989	Rex Gilfillan pers. comm.
Titi	32	?	Brian Bell, Don Merton	1970	Poison	1975	Gaze 1983
Whale	173	?	Paul Jansen	1986	Poison	1986	Paul Jansen pers. comm.
Whenuakura	3	c1982	I McFadden, M Wilke	1983	Poison	1984	Ian McFadden pers. comm
<u>KIORE</u> (*Rattus exulans*)							
Double	32	?	Ian McFadden	1989	Poison	1989	Ian McFadden pers. comm
Korapuki	17	?	Ian McFadden	1986	Poison	1987	Towns 1988
Lizard (Mokohinau)	1	1977	Dick Veitch	1978	Poison	1978	McCallum 1986
Rurima	7	?	Ian McFadden	1983	Poison	1984	Towns 1988
<u>STOAT</u> (*Mustela erminea*)							
Maud	309	c1980	Bill Cash	1980	Trapping	1983	Brian Bell
Otata	22	?	Capt. Wainhouse	?	Shooting	1955	B P Neureuter pers.comm.

CAT (*Felis catus*)

Cuvier	170	c1889	Don Merton	1960	Traps & shooting	1964	Merton 1970
Herekopare	28	c1925	Dick Veitch	1970	Traps & dogs	1970	Fitzgerald & Veitch 1985
Kapiti	2023	?	Dick Fletcher	?		1934	Wilkinson 1952
Little Barrier	3083	<1870	Dick Veitch	1977	Traps, poison,dogs	1980	Veitch 1983
Motuihe	195	?	Steve Boyle	?	Shooting	c1981[1]	John Allen pers. comm.
Stephens	180	c1892	Lighthouse keepers	c1910	Not known	1925	Veitch 1985

PIG (*Sus scrofa*)

Aorangi	110	c1820	Major Yerex	1936	Shooting & dogs	1936	Challies 1976
Blumine	377	<1957	Mike Finch	1988	Shooting & dogs	1989	Clarke & Dzieciolowski in press
Inner Chetwode	194	c1900	Unknown	?	Shooting	1926	Internal Affairs Files
Inner Chetwode	194	c1954	D Cummings	1959	Shooting & dogs	1963	Internal Affairs Files
Motuara	59	?	?	>1950	?	?	Clarke & Dzieciolowski in press
Outer Chetwode	81	c1948	Unknown	1953	Shooting	1953	Internal Affairs Files
Outer Chetwode	81	c1955	D Cummings	1964	Shooting	1964	Internal Affairs Files
Pickersgill	96	?	?	>1950	?	?	Clarke & Dzieciolowski in press
Stewart (Part)	174 600	?	K.Purdon, H.Vipond	1948	Shooting & dogs	1948	Holden 1982
Tuputupungahau	13	1950s	Owners	?	Not known	c1966	Wright 1977

GOAT (*Capra hircus*)

Burgess	62	?	Dick Veitch	1973	Shooting	1973	Veitch 1973
Cuvier	170	1890s	Brian Bell	1959	Shooting	1961	Merton 1970
East	13	1906	George Goldsmith	1959	Shooting	1960	Hal Hovell pers. comm.
Ernest (Masons Bay)	25	<1948	Muttonbirders	1980s	?	c1980	Parkes 1990
Great (Three Kings)	407	1889	Logan Bell	1946	Shooting & dogs	1946	Turbott 1948
Herekopare	28	1973	Muttonbirders	1975	Shooting	1976	Ron Tindall pers. comm.
Kapiti	2023	c1830	A.S.Wilkinson	1928	Shooting	1928	Wilkinson 1952
Macauley	236	<1836	Brian Bell	1966	Shooting	1970	Williams & Rudge 1969
Maud	309	c1965	Brian Bell	c1970	Shooting	c1976	Brian Bell
Mokoia	133	1987	Phil Alley	1989	Shooting & dogs	1989	Paul Jansen pers. comm.
Nukutaunga (Cavalli)	13	?	Chris Smuts-Kennedy	1972	Shooting	1972	C Smuts-Kennedy pers.comm.
Ocean (Auckland)	8	1865	CAPE Expedition	1941	Shooting	1942	Rudge & Campbell 1977
Raoul	2941	<1836	NZ Forest Service	1972	Shooting & dogs	1984	Parkes 1990
South East	218	<1900	Mr McLurg	1914	Unknown	1916	Ritchie 1970
Whale	173	c1890	Wildlife Service	1964	Shooting	1977	Ogle in press

CATTLE (*Bos taurus*)

Campbell (Part)	11 400	1902	Ron Peacock	1984	Shooting	1984	Lands & Survey files
Kapiti	2023	c1837	J.L.Bennett	1916	Shooting	1917	Wilkinson 1952
Stewart (Part)	174 600	?	Dept Internal Affairs	1940s	Shooting	1940s	Taylor 1976

SHEEP (*Ovis aries*)

Kapiti	2023	<1896	Peter Rodda	c1930	Shooting	1969	Peter Daniel pers. comm.
Mangere	130	c1900	Brian Bell	1968	Shooting	1968	Brian Bell
South East	218	1915	Brian Bell	1956	Shooting	1961	Ritchie 1970

BIRDS

WEKA (*Gallirallus spp*)

Awaiti	2	?	David Taylor	1982	Poison	1982	Taylor 1984
Codfish	1336	<1850	Andy Cox, Euan Kennedy	1980	Poison, trap & shoot	1985	Andy Cox pers. comm.
Herekopare	28	c1920	Muttonbirders	1940s	Not known	<1968[1]	Fitzgerald & Veitch 1985
Kundy	19	c1937	Ron Nilsson, E Kennedy	1981	Poison, trap, dog	1985	Internal Affairs Files
Rabbit (French Pass)	5	c1974	Aston Family	c1975	Shooting	c1975	Brian Bell
Tawhitinui	21	?	David Taylor	1983	Poison	1983	Taylor 1984
Middle Trio	17	c1950	Logan Bell *et al.*	1951	Shoot & trap	1964	Campbell 1967

[1] Subsequently re-introduced.

Table 2 Incomplete or failed eradications.

ISLAND	AREA (ha)	DATE INTRODUCED	ERADICATION LEADER	START ERADICATION	METHODS	STATUS AS AT 1/6/90	REFERENCE
POSSUM							
Allports	16	<1980	Trevor Neal	1982	Poison & traps	Failed	Derek Brown pers. com.
Allports	16	<1980	Derek Brown	1989	Poison	Incomplete[1]	Brown 1990
RABBIT							
Browns (Hauraki Gulf)	57	c1975	Fred David	1985	Trap dog shoot poison	Incomplete[2]	C Roberts pers. comm.
Quail	81	c1855	John Trotter	1989	Poison	Incomplete[1]	John Trotter pers. comm.
MOUSE							
Mana	217	1800s	Phil Todd	1989	Poison	Incomplete[1]	Hutton 1990
Rimariki	22	?	Chris Smuts-Kennedy	1989	Poison	Incomplete[1]	C Smuts-Kennedy pers.comm.
SHIP RAT							
Duffers Reef	2	<1983	David Taylor	1983	Trap & poison	Failed[3]	D Brown pers. comm.
Moturako (GBI)	0.8	?	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. cor.
Opakau (GBI)	4	?	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. com.
Oyster (GBI)	0.3	?	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. comm.
Saddle (GBI)	2	1961	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. comm.
Wood (GBI)	1	?	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. comm.
Wood Stack A (GBI)	0.3	?	Graeme Taylor	1990	Poison	Incomplete	Graeme Taylor pers. comm.
KIORE							
Motuopao	30	?	McKenzie & Parrish	1989	Poison	Incomplete[1]	R Parrish pers. comm.
STOAT							
Adele	87	<1977	Rowley Taylor	1980	Trap	Failed[3]	Taylor & Tilley 1984
CAT							
Raoul	2941	c1850	Dick Veitch	1972	Traps	Stopped	Dick Veitch
PIG							
Mayor	1131	?	Pat Burstall	1963	Shooting dogs poison	Failed	Paul Jansen pers. comm.
RED DEER (*Cervus elaphus scoticus*)							
Secretary	8000	<1965	John von Tunzelman	1975	Shooting & poison	Failed[3]	Mark & Baylis 1982
GOAT							
Auckland (Part)	45 975	1865	Kingsley Timpson	1989	Shooting & poison	Incomplete[1]	K Timpson pers. comm.
SHEEP							
Campbell	11400	1895	Brian Bell	1970	Shooting	Incomplete[4]	Brian Bell
WEKA							
Allports	16	1974	Warwick Brown	1976	Trap & shoot	Failed	Derek Brown pers. com.
Allports	16	1974	Derek Brown	1989	Poison	Incomplete[1]	Derek Brown pers. comm.
Motutapu (by Allports)	2	c1974	Derek Brown	1989	Poison	Incomplete[1]	Derek Brown pers. comm.
Blumine	377	1972	Bill Cash & Allan Munn	1982	Trap & shoot	Failed	Bill Cash pers. comm.
Inner Chetwode	194	1928	Wildlife Service	1970	Trap & shoot	Stopped	Brian Bell
Maud	309	1950s	Warwick Brown, Bill Cash	1974	Trap & shoot	Failed[3,5]	Buck Bucknell pers. comm.

[1] All animals may be gone - checks continuing.

[2] Few animals remain.

[3] Re-invaded by swimming.

[4] Remaining animals are within a fenced area.

[5] Re-introduced by humans is likely

Conservation and ecological restoration in New Zealand

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The introduction of alien species to New Zealand's terrestrial ecosystems has caused rapid loss of native biodiversity since human settlement. Faced with this crisis, conservation managers and scientists have responded by developing innovative techniques such as translocation of native animals and the eradication of introduced mammals from islands. We review recent progress with conservation of New Zealand's terrestrial flora and fauna (especially birds) and consider future prospects for ecological restoration of islands and mainland areas. We stress the value of linking species and ecosystem approaches to conservation and we reinforce the importance of maintaining a dynamic partnership between researchers and conservation managers in the development of conservation initiatives.

Keywords: Translocation, Eradication, Conservation Planning, Island Restoration, Ecosystem Conservation, Mainland Restoration, Keystone Species.

INTRODUCTION

NEW ZEALAND'S terrestrial ecosystems have suffered massive and rapid change since Polynesian settlement of the archipelago less than 1 000 years ago. Clearance by fire and felling progressively reduced native forest cover from the original 78% of the land area to 53% by 1840 and 23% by the 1980s (King 1990). Fertile lowland habitats were severely modified, with most natural forests and wetlands being cleared or drained for farmland in the past 150 years. Large-scale habitat loss has virtually ceased in the past decade, with the introduction of laws controlling the clearance of native forests, but the landscape is irrevocably changed, with native vegetation greatly diminished and fragmented. Only some parts of the mountainous high country and a few remote islands remain relatively untouched.

Habitat destruction and direct human predation may have caused the extinction of some large wildlife species, most notably the Moas *Dinornithidae* (Anderson 1989), but the most severe impacts on New Zealand's native flora and fauna have been caused by introduced species. In their original state, New Zealand ecosystems contained no land mammals apart from some small bats. Flightless birds and insects evolved to occupy niches normally filled by mammals, plants evolved features protecting them from browsing birds rather than mammals (Greenwood and Atkinson 1977), and birds evolved behaviour to avoid primarily diurnal avian predators rather than nocturnal mammals. Polynesian settlers introduced Polynesian Rats, or Kiore, *Rattus exulans*, which seem to have eliminated several species of small birds, flightless insects, and some reptiles (Atkinson and Moller 1990). Overall, at least 35 bird species became extinct following Polynesian settlement. From 1769, Europeans introduced and established over 80 species of vertebrates, including 32 mammals. Among these were three further species of rodents, three mustelids, six marsupials, and seven deer. Predatory mammals (e.g., Ship Rats *R. rattus*, Stoats *Mustela erminea*, and Cats *Felis catus*) have caused extinctions of a further 10 bird species and threaten several more. Herbivorous mammals (e.g., Brushtail Possums *Trichosurus vulpecula*, Red Deer *Cervus elaphus*, and Goats *Capra hircus*) have altered the structure and composition of native plant communities through their selective browsing (King 1990). At least three endemic plants have become extinct since 1840 and a further 45 are highly threatened (Cameron *et al.* 1993). Recent research has shown that possums not only damage vegetation and compete with birds for fruit, but also prey on eggs and chicks (Brown *et al.* 1993).

A recent estimate concludes that there are 606 New Zealand taxa (species, subspecies and forms) classed as endangered, vulnerable, rare or regionally threatened, according to previous IUCN criteria (Veitch 1992). Most of these now persist only on islands which are largely free of introduced mammals, or in dwindling mainland populations. The situation is dire, but there is hope in the development of new techniques to enhance the productivity of threatened species and to remove (or reduce the impacts) of threatening factors. The continuing impacts of introduced pests are the most significant remaining threats to New Zealand's biodiversity, given that deliberate habitat destruction has largely ceased and public attitudes generally support conservation. The challenges facing those concerned with the conservation of New Zealand's biodiversity are no longer merely the legal protection of native species and preservation of their remaining habitats, but the active management of persistent threats such as introduced mammals and the restoration of natural communities and processes.

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In this paper we review recent progress with conservation of New Zealand's terrestrial flora and fauna (especially birds) and consider future prospects for ecological restoration of islands and mainland areas. We stress the value of linking species and ecosystem approaches to conservation and we reinforce the importance of maintaining a dynamic partnership between researchers and conservation managers in the development of conservation initiatives.

TRANSLOCATIONS AND ERADICATIONS: OPENING THE DOOR FOR ECOLOGICAL RESTORATION

For the most of the past 100 years nature conservation in New Zealand has mainly involved the legal protection of native wildlife and the establishment of National Parks and reserves, within which natural areas are shielded to some extent from direct human impacts. The underlying philosophy, based on the northern hemisphere experience of conservation on continental areas, was that by reserving natural areas (chosen mostly for scenic rather than biological values), the key attributes of plant and animal communities would be protected. Active management was largely confined to the attempted control of introduced browsing mammals on the mainland by shooting and trapping. It is doubtful if this did more than temporarily slow the degradation of natural forests and grasslands, and it failed to halt the spread of deer and possums throughout New Zealand. Native animals vulnerable to introduced predators continued to decline towards extinction or persisted only on islands free of these threats.

The inadequacy of conventional protection measures has become increasingly apparent for vulnerable species which evolved on a mammal-free archipelago. The response of New Zealand wildlife managers, faced with a series of critically endangered species, has been to take advantage of the presence of over 700 islands within the archipelago, firstly by translocating endangered species to islands free of threatening mammals, and more recently by creating mammal-free islands through eradication programmes.

Translocation — the intentional release of plants and animals to the wild in an attempt to establish, re-establish, or augment a population (Griffith *et al.* 1989) — has in fact been used as a conservation technique in New Zealand for over 100 years. Early (but ultimately unsuccessful) translocations included those of Kakapo *Strigops habroptilus* and Kiwi *Apteryx* spp. by Richard Henry late last century (Williams 1956). A major advance came in the early 1960s when North Island Saddlebacks *Philesturnus carunculatus rufusater* were successfully translocated from their sole remaining habitat on Hen Island to nearby predator-free islands (Merton 1975). Following the Saddleback translocations, the methods used were adapted and successfully used during the 1970s and 1980s for other birds, including Chatham Island Black Robin *Petroica traversi*, Kakapo, and Kokako *Callaeas cinerea wilsoni*. Although records are incomplete, over 400 translocations of at least 52 New Zealand taxa (comprising 43 birds, five reptiles, and four invertebrates) have been undertaken (Veitch 1992; C. R. Veitch, pers. comm.). Provided appropriate transfer techniques are used and threatening factors in the release habitats are controlled, translocation success rates now approach 95% (Lovegrove and Veitch 1994). Many species recovery plans now being prepared and implemented include translocation proposals: a reflection of the perceived value of translocation as a conservation management tool.

Other techniques of intensive species management have also been developed in New Zealand in recent years. These include the cross-fostering of eggs and chicks, which was used (together with translocation) in the recovery of the Black Robin population from five individuals to over 140 (Butler and Merton 1992) and has since been applied to other species. Supplementary feeding of wild birds is another technique which has been developed to increase productivity. It is currently being applied to translocated Kakapo to increase their frequency of breeding and is a good example of a management technique which has grown directly from research findings (on Kakapo diet and breeding (Powlesland *et al.* 1992)), through collaboration between scientists and conservation managers.

Eradication of introduced mammals from islands has been the other major advance in New Zealand conservation practice in recent years. Given the potential of mammal-free islands for conservation of threatened species in New Zealand, conservation managers have increasingly attempted to eradicate introduced mammals where there is little prospect of their unaided recolonization. Research has helped to define re-invasion risks through work on mammal dispersal and distribution patterns on New Zealand islands (Taylor 1984; Taylor and Tilley 1984).

In the past decade, in particular, there has been a series of successful eradications of introduced mammals from New Zealand islands (Veitch and Bell 1990). Successes on large islands include eradication of cattle and sheep from Campbell Island (11 400 ha), goats from Raoul Island (2 941 ha), possums from Kapiti Island (1 978 ha), Norway Rats from Whale Island (173 ha) and mice from Mana Island (217 ha). These and other successes have resulted from the synergy of technical developments and increasing confidence in their use. Of particular significance have been the availability of single-dose anticoagulant poisons such as brodifacoum in special bait formulations, and the development of bait stations

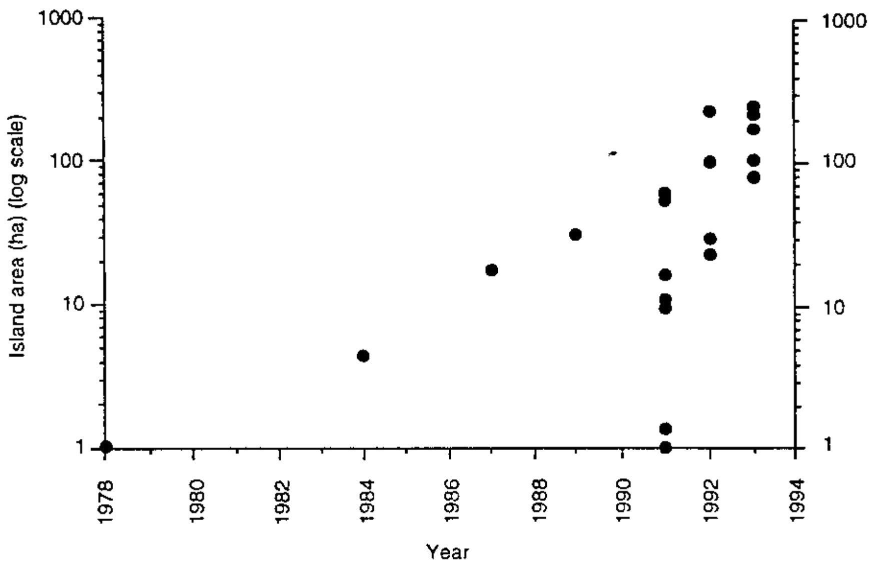

Fig. 1. Sizes of New Zealand offshore islands from which Kiore have been eradicated. (Source: Veitch and Bell 1990; I. G. McFadden, pers. comm.)

and aerial application methods for eradicating rodents from islands (Taylor and Thomas 1989; I. G. McFadden, pers. comm.).

A measure of recent progress in mammal eradications from New Zealand islands is that in the four years since Veitch and Bell (1990) listed all known eradication attempts to that time, the number of successful eradications of rodents has risen from 28 to 49. A further 18 rodent eradications (on islands up to 259 ha) have been conducted since 1992 and remain to be formally classed as successes or failures (C. R. Veitch, pers. comm.). The rate of progress in the technical capacity for rodent eradications is graphically illustrated by the rapid recent rise not only in the number of eradications, but also the size of islands now being cleared of these pests (Fig. 1).

Only 15 years ago the eradication of rodents from islands was thought to be impossible (Dingwall *et al.* 1978), but now their removal from islands of up to 250 ha is almost routine (Fig. 1). A strategy being developed by the New Zealand Department of Conservation plans for the eradication of rodents from a series of islands up to 3 000 ha within the next four years, taking advantage of eradications on smaller islands in the interim to further develop and refine techniques (I. G. McFadden, pers. comm.). If this strategy proceeds to fruition, more than 10 000 ha of island reserves, spanning latitudes from 29° to 50°S, will be freed from the effects of introduced mammals. This will provide immense opportunities for ecological restoration in the future. Given the urgency of threatened species programmes and the evident benefits for ecological restoration, these opportunities for permanently ridding large islands of rodents should be actively pursued. The lessons learned in undertaking these eradications will have great significance not only for New Zealand conservation, but also for other islands which have been invaded by introduced rodents elsewhere in the world.

PLANNING AND CO-ORDINATION

In addition to practical developments, the critical situation facing conservation managers in New Zealand has also encouraged the rapid evolution of procedures for setting priorities and planning recovery programmes. So far these procedures have been focused at the taxonomic level rather than on communities or ecosystems; hence there is a priority ranking system for species (Molloy and Davis 1992) and recovery programmes for individual species or groups of species. Species recovery planning was initiated by the Department of Conservation in 1989 and involves the establishment of consultative groups of conservation practititioners, scientists and others with interests in the species concerned. These groups provide advice on goals and objectives for species recovery. The process has helped to co-ordinate increasingly complex management and research activities and has served as a focus for dialogue between the Department of Conservation and landowners, conservation organizations, universities and other interest groups. To date over 40 recovery plans have been initiated. Although the successes already achieved demonstrate the value of programmes directed at individual taxa in urgent need of specific management, a trend is now emerging for the preparation of multi-taxa plans focusing action at key sites.

An important result of the recovery planning process, (whether this be at taxonomic or community levels), is that it encourages co-operation between scientists and conservation managers and requires both to take part in planned experimentation and learn from successes and failures. Both research and management benefit from this co-operation and conservation outcomes are generally enhanced as a result.

Recent conservation successes and the growing array of techniques have led to growing confidence in prospects for species recovery. In order to capitalize on the opportunities which now exist for conservation gains in New Zealand there is a pressing need to develop policies, strategies and plans which reflect these opportunities and provide a philosophy and framework to guide them. This need for a guiding philosophy was stressed by Towns and Williams (1993) in relation to single species conservation, but also applies in the broader context of ecological restoration.

As the impetus for ecological restoration on islands grows, it is likely that conflicts will arise between individual species recovery objectives and between these and the goals of ecosystem restoration. Translocations of threatened species to pest-free islands may, for example, compromise ecological restoration goals — particularly where the threatened species concerned was not among the original biota of the island. Current programmes to establish Takahe *Porphyrio mantelli* on islands such as Mana and Tiritiri Matangi, and Kakapo on Maud and Little Barrier Islands illustrate the need to evaluate carefully the potential costs and benefits of such actions, in order to minimize conflicts. Groups established to advise on the recovery of a particular species are typically concerned only with the future of that species, but a set of formal "translocation guidelines" has now been produced by the New Zealand Department of Conservation, requiring those proposing translocations to consider impacts on other species. The use of predator-free islands as temporary refuges for endangered species whilst their populations recover and their natural habitats are restored is usually justified, provided that risks to other biota are properly assessed and the ultimate goals are clear.

It is perhaps not surprising that the rapid advances in conservation management which have been made in New Zealand in the past few decades have led to some actions which, in retrospect, appear unwise. The significant recent increase in the number of species translocations has led to questions being asked not only about the overall wisdom of some translocations in relation to restoration goals, but also about the timing of some transfers. Recent successes in eradicating rodents mean that eradications can now be contemplated for islands previously considered too large for this, including some to which various threatened species have been translocated in the past. For example, a recent operation to eradicate Kiore from Tiritiri Matangi (220 ha), was made more difficult by the presence of threatened birds which had been translocated to the island only a few years previously. Although all of the Takahe and most of the Brown Teal *Anas chlorotica* on the island were captured and penned during the poisoning operation, two Brown Teal were not caught and died as a result of ingesting poison baits intended for Kiore. In hindsight, it would have been more prudent to have refrained from translocating these threatened species to Tiritiri Matangi until rodent eradication had been completed.

An important challenge facing conservation planners is to develop restoration strategies and plans which allow for management to be appropriately prioritized and scheduled, whilst permitting new opportunities resulting from technological advances to be incorporated. A national policy is required to embrace the principles of biodiversity conservation, within which species and ecosystem conservation goals can be defined and integrated. Such a policy would allow for the ordered development of ecological restoration strategies for islands and selected mainland sites and would serve to reduce the potential for conflict as further conservation opportunities arise.

Taken together, the translocation of threatened species and eradication of introduced ones have proved to be powerful tools for the conservation and management of species on islands. The next challenge is to use these and other tools to restore ecological communities not only on islands, but also the mainland of New Zealand.

ECOLOGICAL RESTORATION AT MAINLAND SITES

Whilst islands offer significant opportunities for conservation, they are limited both in number and in the variety of potential habitats they contain. Conservation managers are therefore starting to apply the techniques learned with islands to the restoration of mainland ecosystems in New Zealand (Clout 1989). The potential benefits from managing mainland ecosystems are enormous, including enhanced possibilities for direct public involvement. Mainland restoration is, however, more difficult than that on islands because permanent eradication of pests is not possible, and ecological interactions are generally more complex. Control programmes aimed at ecological restoration may therefore have unforeseen consequences. One example is the outcome of the control of Ship Rats by aerial poisoning with 1080 at Mapara reserve (1 400 ha) for protection of Kokako. Murphy and Bradfield (1992) found that, following the temporary elimination of rats, Stoats switched their main diet from rats to birds. The rat control, aimed at bird protection, may have had the opposite effect through changes it caused in the behaviour of Stoats. Another recent example is the unexpected increase in mouse *Mus musculus* numbers following poisoning of Ship Rats for protection of New Zealand Pigeons *Hemiphaga novaeseelandiae* in a 55 ha forest patch near Auckland (M. N. Clout *et al.*, unpubl. data). These and other examples are cautionary tales for conservation managers, and highlight the need for an understanding of ecological interactions when planning restoration programmes.

The cost-benefit balance of using poisons to manage mammal pests may be less favourable in mainland habitats than on islands because of the need for perpetual control rather than short-term, once only, eradication programmes. Because New Zealand has no native land mammals (apart from bats), poisons and traps designed to kill mammals can generally be used without significant adverse effects on "non-target" native animals. However, the potential for development of poison resistance by target mammals, and the possibility of environmental accumulation of toxins at sites where they are regularly used may preclude the routine use of some poisons on the mainland in future. Conservation managers need to be aware of these issues when planning sustained mammal control on the mainland for ecological restoration. At mainland sites where intensive, ongoing management is proposed, a dynamic spectrum of control techniques will be needed to maintain key pests at minimum levels.

The largest areas currently subject to sustained control of introduced mammals are in the central North Island forest reserves of Mapara (1 400 ha) and Kaharoa (380 ha), both of which are being managed to benefit the endangered Kokako. Goats, feral pigs, possums, rodents, mustelids and feral cats have been shot, poisoned or trapped since 1989 at Mapara, and since 1990 at Kaharoa. The number of Kokako pairs has subsequently risen by 31% at Mapara and 17% at Kaharoa, making them the only mainland Kokako populations known to be increasing. Eleven of 13 (85%) monitored pairs at Kaharoa fledged chicks in the 1992/1993 season; a higher success rate than the Kokako population on Little Barrier Island, which has no introduced mammals except Kiore (J. Innes, pers. comm.).

The "research by management" approach to Kokako conservation at Mapara, Kaharoa, and other mainland sites has involved research on ecological threats as management proceeds, with scientists and managers working in partnership to set objectives and develop effective pest control and monitoring techniques. Further opportunities for public support and community involvement are now being developed at Mapara and elsewhere. Benefits of this increased public participation could include the transfer of some operating funds (currently c. $70 000 per annum at Mapara) to other mainland conservation programmes.

In the short to medium term, conservation of threatened species and ecosystems on the mainland will of necessity be restricted to establishing "holding patterns", whereby further significant declines of key species and processes may be arrested through intensive management at selected mainland sites. Because of the problems associated with effectively managing mainland ecosystems (compared with small islands), there is an urgent need for the development of criteria to identify sites where intensive management is justified and sustainable. These could either be existing foci of native biodiversity or sites containing natural habitats of potentially high quality for re-introduction of native biota. They should be of sufficient size and integrity to support viable native communities, but small enough to be manageable, and should ideally have local geography (e.g., peninsulas, habitat islands) reducing the probability of re-invasion by pests.

In the long term, the best prospects for broad scale restoration on the mainland lie with biological control rather than the perpetual use of traps and toxins. Several agricultural weeds and insect pests are already controlled in this way in New Zealand, but scant attention has been given to the potential for biocontrol of introduced mammals, since the conservation catastrophe of mustelids being released for rabbit *Oryctolagus cuniculus* control last century. The mounting concerns over economic impacts of possums and rabbits have recently focused attention back onto biocontrol of mammals; this time with the prospect of species-specific diseases and the possibility of these being produced by genetic engineering. As with traditional methods of control, the ecological consequences of controlling one part of the small mammal community need to be considered when applying biocontrol. Diet-switching by predators or increases in prey populations may be unwanted side-effects of controlling one species only. Restoration of mainland ecosystems, in particular, will require increased knowledge of the complex ecological interactions within them. Partnerships between researchers and conservation managers are particularly important here, to take advantage of the experimental opportunities presented by management programmes.

Ecological restoration on the New Zealand mainland can involve management action at a range of intensities, from episodic pest control to permit some recruitment of native fauna and flora, to programmes involving continuous local control of weeds and pests, re-establishment of native species, and provision of supplementary food and nest sites to encourage their reproduction. The approach of local, temporary pest control to enhance recruitment has been successfully applied in Stoat control to benefit Yellowheads *Mohua ochrocephala* in the Eglinton Valley, Fiordland (O'Donnell, Dilks and Elliott 1992), in rat control to benefit New Zealand Pigeons at Wenderholm, Auckland (M. N. Clout *et al.*, unpubl. data), and in the control of possums, rats and mustelids to benefit Kokako at Kaharoa and Mapara (Saunders 1990).

Control of mammals on the mainland to enhance recruitment of native wildlife does not necessarily need be continuous. For example, frugivorous birds such as Kokako and New Zealand Pigeons could benefit from episodic mammal control, focused in years when key native trees fruit heavily and the birds are likely to make more breeding attempts (Clout *et al.* 1995).

Some of the most exciting prospects for conservation and ecological restoration in New Zealand relate to the possible re-establishment of locally extinct species on the mainland. This will be difficult and can only be achieved through substantial public participation and support, but the experience of restoration of Tiritiri Matangi Island (Craig 1990) shows that this should be forthcoming. Among native birds, candidate species for local re-establishment at mainland sites include Weka *Gallirallus australis*, Saddleback, Kiwi, Kaka *Nestor meridionalis*, and Stitchbird *Notiomystis cincta* (Clout 1989). In each case, management would involve reducing and holding mammalian predators and competitors to very low densities (or eliminating them within large, secure enclosures). Food supplies could be augmented as necessary by supplementary feeding, and nest sites provided where lacking. Optimal sites for such re-introductions are "habitat islands", especially those partially protected from pest re-invasion by natural barriers to dispersal.

A plan for the establishment of a 200 ha mammal-free enclosure for restoration of a natural area of regenerating forest at Karori (Wellington) has already received support in principle from the Wellington City and Wellington Regional Councils. If it proceeds and is successful, other projects may follow, involving sponsors and the general public in the return of "exiled" native species to managed mainland sites, where they can exist as parts of functioning ecological systems, protected by human intervention.

"SINGLE SPECIES" OR "ECOSYSTEM" CONSERVATION?

There has been much recent discussion (within New Zealand and internationally) of the need for approaches to conservation planning and management which focus less on individual species and more on ecosystems (Fiedler *et al.* 1993; La Roe 1993). In New Zealand, the view that conservation effort should focus more at the ecosystem level has developed partly because of the sheer scale of the task of separately planning and implementing the recovery of over 600 taxa (Veitch 1992), and partly through a growing concern in some quarters that too much attention is focused on high cost programmes for charismatic species, to the detriment of habitat protection and restoration programmes.

One of the difficulties in dealing with the concept of ecosystem conservation "versus" species conservation is defining the difference between the two. Single species conservation is readily understood as a management process which aims to restore a particular taxon to a particular level of abundance within a given time-frame. However, there is usually another (stated or unstated) aim of ultimately restoring that taxon to its natural environment as part of a functioning ecological system. Towns and Williams (1993) have suggested that this could be encapsulated in the goal (based on New Zealand conservation statutes) to "preserve species as functioning members of a system of interacting organisms and their environment, in which their essential nature is maintained". The distinction between species and ecosystem conservation is therefore blurred, and possibly unhelpful. The collective conservation of groups of species, which may be united by common threats or habitats, is even less easily distinguished from ecosystem conservation.

Ecosystem conservation itself implies an ability to define and understand what constitutes a particular ecosystem and how it functions, as a precursor to management. It involves the maintenance of natural processes as well as biodiversity. In practice, the management of ecosystems consists of habitat maintenance and species management. The latter may include both the enhancement (or re-establishment) of native species and the control or eradication of introduced ones.

The concepts of "keystone" and "umbrella" species are relevant here since they are both categories of species whose management is significant at the ecosystem level.

"Keystone" species either affect or support large numbers of other species in the community. Some of them are apparent through their pivotal roles as important food sources (e.g., the native Beech Scale Insect *Ultracoelostoma assimile* which produces honeydew on *Nothofagus* trees), or as agents of regeneration (e.g., seed-dispersing birds). Others are apparent through their adverse impacts on native flora and fauna (e.g., introduced possums and vespulid wasps). Conserving or controlling known keystone species is effectively a form of ecosystem management. In New Zealand, this has normally taken the form of pest or weed control, where target species are reduced by poisoning, trapping, or spraying.

"Umbrella" species are generally animals which require large areas of habitat and are sensitive to ecosystem modification. They are often species higher up the food chain and their conservation involves maintenance of large areas of habitat relatively free of modifying influences. A result is that ecological management to retain healthy populations of such species creates an "umbrella", protecting other natural elements of the ecosystem. Thus, by managing an area for a particularly vulnerable and sensitive species, other species (and the ecosystem as a whole) benefit. An example in New Zealand is the Kokako, a bird threatened by forest fragmentation, predation and competition from introduced mammals (Rasch 1992). Management of mainland forest areas for Kokako involves control of rats, possums, cats and mustelids. This in turn should improve habitat quality for other native fauna and flora which are adversely affected (either directly or indirectly) by these introduced mammals.

An example of a potential restoration programme where both species and ecosystem conservation goals could be met by a single action would be the re-establishment of New Zealand Pigeons on Raoul Island (2 941 ha) in the Kermadec Group. This, or a very similar species of fruit pigeon, was exterminated from Raoul Island last century by hunting. Since then, local large-fruited plants such as *Corynocarpus laevigatus* and *Rhopalostylis baueri* have had no natural seed disperser. The pigeon is now declining in abundance in northern parts of the North Island of New Zealand (Pierce 1993). Re-establishment of a population on Raoul would therefore not only provide a natural dispersal agent for large-fruited plants on this island, but also increase the population base of the pigeon. The timing of this and other translocations in relation to other planned management is critical. On Raoul Island, it is important that the eradication of fruiting woody weeds such as guava and olive is complete before pigeons (potential dispersers) are released. It may also be wise to await the planned eradication of cats (a possible predator of pigeons) and rats before transferring any birds.

We conclude that, although there are philosophical distinctions between approaches to species management and ecosystem management, in practice they involve similar actions and generally complement one another. We therefore suggest that they be viewed not as alternatives, but as part of the same spectrum of conservation action for ecological restoration.

CONCLUSIONS

The recent experiences in conservation planning and practice in New Zealand reviewed here contain useful lessons for the future restoration of island biotas and ecosystems both in New Zealand and elsewhere. The techniques of translocation, intensive species management and eradication of mammals have potentially widespread applications in the archipelagos of the South Pacific region in particular, where vulnerable biotas and ecosystems face very similar threats to those encountered in New Zealand. In addition to species rescue and recovery operations, conservation in the future is likely to increasingly involve the management of processes. In New Zealand the key threatening processes for natural ecosystems are predation and competition from introduced species. These threats are manageable (especially on islands) but mitigating their effect has to be done carefully, in the right sequence, and in the light of knowledge of the ecological interactions within the system being managed. Close co-operation between scientists and conservation managers is vital in this context.

Technical advances in the control of ecological pests and increased public involvement in conservation have raised the potential for ecological restoration at sites on the New Zealand mainland, applying the knowledge gained on islands. Whilst islands free of introduced mammals will continue to be the primary locations for conserving critically endangered species for the foreseeable future, ecological restoration programmes on the mainland will make increasingly significant contributions to the conservation of biodiversity in New Zealand in the 21st century.

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