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Varied success from the landscape-scale management of kiwi *Apteryx* spp. in five sanctuaries in New Zealand

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Summary

In late 2000, five sanctuaries were established on the mainland of New Zealand for the express purpose of protecting populations of five kiwi *Apteryx* spp. taxa belonging to three species. Conservation management was undertaken at a landscape scale (10,000–20,000 ha) in each sanctuary to improve recruitment of kiwi. This was done by controlling introduced mammalian predators (especially stoats *Mustela erminea*), and/or by removing eggs and chicks from predation risk, and returning subadults when they were big enough to cope with stoats. Population modelling of the first five years of the sanctuary programme indicated that kiwi numbers in all five sanctuaries would increase as a result of the management. Calculated population increases varied from 0.6% per year at Okarito to 11.3% per year at Moehau, even though predator trapping was more intense at Okarito. The variation from site to site was explained by the widely different inherent productivity of the various kiwi taxa; widely different rates of adult mortality due to the presence or absence of dogs *Canis familiaris* and ferrets *M. furo*, the main predators of long-lived adult kiwi; and, local forest conditions affecting predator-prey cycles, and the density of stoats. As a result of this analysis, the management in four of the five sanctuaries has since been modified to try to achieve better overall gains for kiwi within the same operating budget.

Introduction

Kiwi are a family of flightless, mainly nocturnal, ratite birds endemic to New Zealand. Four out of the five species (Brown Kiwi *Apteryx mantelli*, Rowi *A. rowi*, Tokoeka *A. australis* and Great Spotted Kiwi *A. haastii*) are classified as 'Threatened' (Miskelly *et al.* 2008, BirdLife International 2011) following huge reductions in both their range and numbers on the mainland of New Zealand over the past 100 years (Heather and Robertson 2005). The fifth species, Little Spotted Kiwi *A. owenii*, has been recently downgraded to 'At risk: Recovering' (Miskelly *et al.* 2008) or 'Near Threatened' (Birdlife International 2011) following successful transfers to predator-free islands and sanctuaries. The main threat to kiwi populations on the mainland is predation by introduced mammals, especially stoats, *Mustela erminea*, cats *Felis catus*, ferrets *M. furo* and dogs *Canis familiaris* (McLennan *et al.* 1996, Robertson *et al.* 2011). Without control of predators, only about 6% of kiwi chicks survive to reach adulthood (Robertson *et al.* 2011). Once kiwi reach about 1 kg at 6–8 months old, stoats and cats no longer pose a serious risk to them, but dogs and ferrets kill many subadult and adult birds (McLennan *et al.* 1996) and are the critical predators in some parts of New Zealand, driving populations to local extinction (Robertson *et al.* 2011). Experimental work has shown that intensive control of predators or the temporary removal of eggs and young chicks from risk in the wild (Bank of New Zealand Operation Nest

Egg™ [BNZONE]; see Colbourne *et al.* 2005, Robertson *et al.* 2006), can significantly reduce the impact of predation and allow kiwi populations to stabilise or recover (Robertson *et al.* 2011).

In 1999, the Royal Forest & Bird Protection Society of New Zealand, the New Zealand partner of BirdLife International, mounted a campaign calling for the establishment of 11 kiwi sanctuaries because of the alarming decline in the numbers and range of kiwi on the mainland. Five kiwi sanctuaries of 10,000–20,000 ha were established by the New Zealand government in 2000 as part of its Biodiversity Strategy (Robertson 2004), with a combined annual operating budget of $NZ2 million (=£1 million or $US 1.6 million). The Department of Conservation's (DOC's) Kiwi Recovery Group recommended the five populations to manage in order to recover the most critically endangered taxa, to slow the decline of those taxa declining at the greatest rate, and to maintain the genetic diversity of kiwi (Robertson 2004). These included key populations of three of the four genetically distinct taxa of Brown Kiwi ('Northland', 'Coromandel' and 'Western', the entire range of the critically endangered Rowi, and a large part of the range of the 'Haast' taxon of Tokoeka (Figure 1).

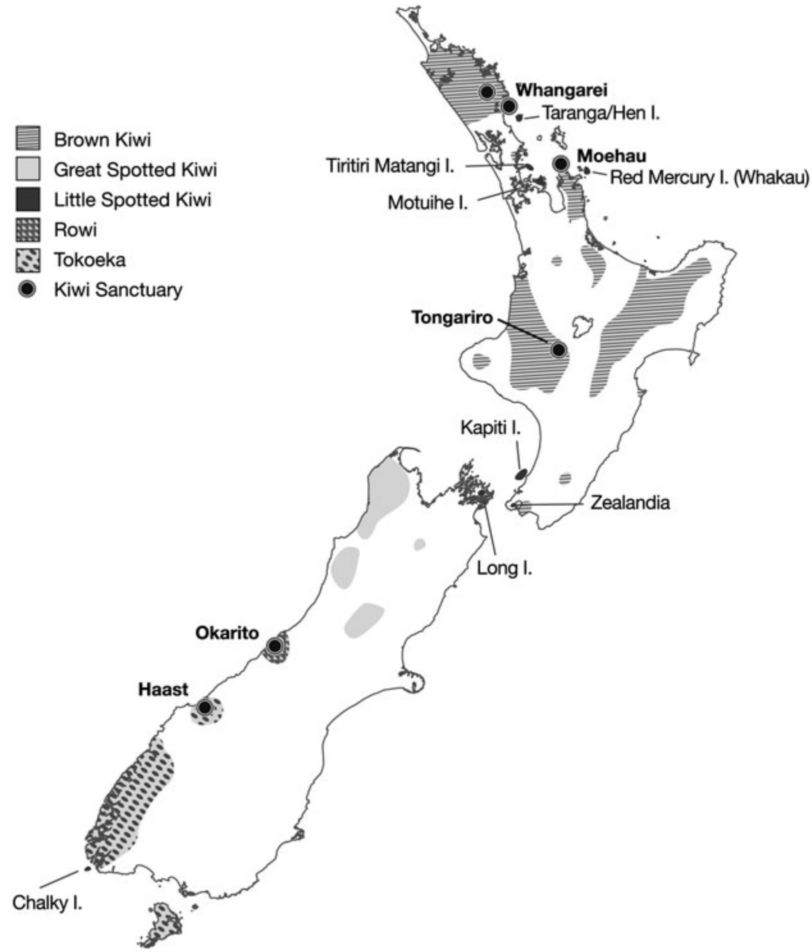

Figure 1. Distribution of the five species of kiwi *Apteryx* spp. in New Zealand and the location of the five Kiwi Sanctuaries (bold circles). Note that the Whangarei Kiwi Sanctuary has two separate blocks.

Management in the five sanctuaries varied in some aspects, but all aimed primarily to trap predators (especially stoats), or to remove young kiwi from the threat of stoat predation, so that enough young kiwi survived to more than balance adult mortality, and thus allow populations to recover. The Kiwi Sanctuary Programme offered DOC an opportunity to expand the scale of predator control by at least an order of magnitude, from hundreds of hectares in the 1990s, to tens of thousands of hectares. No previous attempt had been made to trap predators on such a landscape scale in New Zealand, and it required close working relationships between DOC, iwi (the indigenous Maori people), community groups, and private landowners for it to operate successfully.

It was anticipated that at the 10,000+ ha scale, management aimed at recovering kiwi populations may have costs and benefits to other protected wildlife and unwanted pests living in each sanctuary. The population dynamics of kiwi in each sanctuary was measured, indices of stoat and rodent (mostly ship rat *Rattus rattus*) abundance were collected using tracking tunnels (King and Edgar 1977) set following standard DOC protocols (Craig Gillies and Dale Williams unpubl.), and populations of other birds were monitored through 5-minute bird counts (Dawson and Bull 1975) and by recording the breeding success of Grey Fantails *Rhipidura fuliginosa*, a common native passerine in all five sanctuaries. In this paper, we assess the effect of management in each sanctuary on its kiwi population, and describe how these results have shaped the current conservation management at the five sites.

Methods

Kiwi sanctuary management

Whangarei Kiwi Sanctuary

The Whangarei Kiwi Sanctuary was established in central Northland to protect the rapidly declining population of the Northland taxon of the Brown Kiwi. Landscape-scale predator trapping was carried out over 13,400 ha in two discrete blocks. One, a 9,800 ha area of farmland, native kauri *Agathis australis* -podocarp-broadleaf forest patches, and some exotic pine *Pinus* spp. plantations centred on 35°35′S 174°05′E, and ranging from 100 to 575 m asl, was about 30 km north-west of Whangarei. The other 3,600 ha block of coastal broadleaf forest, manuka *Leptospermum scoparium* scrub, and farmland ran from Whangarei Heads (35°50′S, 174°33′E) to Taranui (35°43′S, 174°27′E), south-east of Whangarei (Figure 1). The larger block incorporated small reserves and private forest patches near Purua that had been used for an adaptive management study of kiwi (Robertson *et al.* 1999a,b, 2011). The smaller coastal block was a network of reserves in and around Bream Head (905 ha), Mt Mangaia (1,102 ha), Taranui (686 ha) and Pataua (233 ha).

Throughout both management blocks, a total of about 1,140 'Fenn Mark VI' or 'DOC 200' traps were set to catch stoats, the main target of trapping operations, and about 170 'Steve Allan' Conibear-style traps were set to catch ferrets, cats and possums *Trichosurus vulpecula*. Traps (one stoat trap/11 ha and one 'Steve Allan' trap/80 ha) were checked, re-set and re-baited fortnightly. The density of traps was much lower in open farmland than in the forest patches where kiwi lived.

Between July 2001 and June 2005, a total of 361 stoats, 352 possums, 301 cats, 198 weasels *M. nivalis* and 41 ferrets were trapped. In addition, 1,229 hedgehogs *Erinaceus europaeus* and 943 rats *Rattus* spp. were trapped as non-target species. Stoat captures peaked in January, but remained moderately high until June; cat captures peaked in late summer and autumn, while weasel and ferret captures were spread evenly through the year.

Sanctuary staff talked to local residents to try to ensure that farm dogs and pet dogs were kept under close control, and not allowed to roam freely, and a kiwi-aversion training programme was run for local dogs. This used electric collars that were activated when the dogs approached kiwi-related lures, to try to deter the dogs from attacking kiwi in the future. Hunting access to forests with a population of feral pigs *Sus scrofa*, was restricted to those hunters whose dogs had attended a kiwi aversion training course.

In addition to the predator control and kiwi aversion programmes, a BNZONE programme was also used. A total of 120 eggs and 32 young chicks were collected from 87 (25%) of 350 nests, mainly from the Purua area. They were hatched in captivity at Auckland Zoo or at Whangarei Bird Rescue Centre, and then raised on predator-free Motuora Island (36°30′S, 174°48′E) or Matakohe/Limestone Island (35°47′S, 174°22′E) until they were over 8 months old, at which stage they weighed > 1,200 g and were therefore more capable of defending themselves against stoat and cat attacks. These subadult birds were used to restock the severely depleted kiwi population in the Whangarei Heads part of the sanctuary, and some were later used to help establish a new population at Tawharanui Peninsula (36°17′S, 174°50′E) in 2006 and 2007, an area with a predator-proof fence, about 100 km south of the sanctuary.

Moehau Kiwi Sanctuary

The Moehau Kiwi Sanctuary was established near the northern tip of the Coromandel Peninsula (36°32′S 175°24′E) to protect and enable recovery of the rare Coromandel taxon of Brown Kiwi (Figure 1). Landscape-scale stoat control was carried out, using 1,723 'Fenn Mark VI' or 'DOC 200' traps set in 18,500 ha (one trap/11 ha) of mainly native kauri-podocarp-hardwood forest and regenerating kanuka *Kunzea ericoides* and manuka scrubland north of the road between Colville Bay and Waikawau Bay. The area was steep, and ranged in altitude from near sea level to 892m. A total of 7,107 ha of the land is administered by DOC, with the remaining land being owned privately. Traps were checked and re-set 18 times a year in 2001–2002, 15 times a year from 2002 to 2004, and then 12 times a year to 2006.

Between April 2001 and June 2005, a total of 7,890 rats, 887 stoats, 303 weasels, 85 cats and no ferrets were trapped. Stoat captures peaked in December and January; however, the numbers caught in these two months diminished over time: 113 in 2001/2002, 134 in 2002/2003, 33 in 2003/2004 and 32 in 2004/2005.

The forests at Moehau have internationally significant ecological values, including the presence of threatened endemic invertebrates, frogs and plants. Management for Brown Kiwi at Moehau was established in parallel with an existing intensive possum trapping and poisoning programme that had run since 1987 in response to a deterioration in forest canopy condition following colonisation of the area by possums in the late 1970s (Leigh 1995). The continuing possum control programme used toxic baits in bait stations. Some experimental rat trapping and poisoning was done in a small (c.600 ha) part of the sanctuary since 2005. Pigs and goats *Capra hircus* were present throughout the Moehau Kiwi Sanctuary, but because they had only minor direct impacts on Brown Kiwi, they were not specifically targeted for control. However, they were a target for hunters with dogs, and so a kiwi-aversion training programme was run to try to deter dogs from attacking kiwi, and hunting access to DOC land in the sanctuary was limited to those people whose dogs were certified as having attended kiwi aversion training.

In addition to the stoat control and dog aversion programmes, a very small BNZONE programme was run, usually for chicks and eggs left when nests were abandoned following our disturbance. The resultant chicks were returned from captivity at Kiwi Encounter in Rotorua at about 1 month old (i.e. at an age when they become completely independent (Heather and Robertson 2005), but at a weight that meant that they were vulnerable to stoats and cats), and released near their natal areas.

Tongariro Kiwi Sanctuary

The Tongariro Kiwi Sanctuary (39°05′S, 175°28′E) protected the easternmost population of the Western taxon of the Brown Kiwi (Figure 1). It was developed from an existing BNZONE

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programme at Tongariro Forest, which had followed on from a research project on part of that population (Miles 1995). The 20,000- ha cut-over podocarp-hardwood forest had been subject to periodic landscape-scale aerial poisoning operations to control possums which are a key vector of bovine tuberculosis *Mycobacterium bovis*, an economically important pathogen of livestock. The Animal Health Board, DOC and Horizons (Manawatu-Wanganui) Regional Council jointly applied Compound 1080 (sodium fluoroacetate) in carrot or pollard baits spread by helicopters at about 5-yearly intervals.

In September 2001, an area of 19,380 ha was treated with an aerial application of 1080 in pollard baits, and the remaining 600 ha, in the Owhango Water Supply catchment, was treated with hand-laid 1080 baits placed away from water courses. The survival of a small sample of Brown Kiwi chicks was monitored in the wild through the 2001/2002 breeding season.

For the rest of the 5-year period, BNZONE was the sole management tool. All accessible eggs of a sample of adult birds were collected and taken to be hatched at Kiwi Encounter in Rotorua. The resultant chicks were raised there or in a predator-proof crèche site at Warrenheip (37°55′S, 175°30′E) until they were 4–12 months old, when they were returned to Tongariro Forest.

Okarito Kiwi Sanctuary

The Okarito Kiwi Sanctuary (43°17′S, 170°10′E) aimed to protect and recover the single population of the critically endangered Rowi (Figure 1). Part of Westland National Park, the 10,000-ha sanctuary contains podocarp (especially rimu *Dacrydium dacrydioides*)-hardwood forest, with some areas of swamp, lying on old glacial moraine deposits, ranging from sea-level to 450 m. The Rowi population was already under active management, with a successful BNZONE programme having returned 62 subadults to the population since 1994, which had boosted the population of this critically endangered species to about 200 birds by the end of 2000 (Chris Rickard pers. comm.).

For five years, from May 2001 to May 2006, landscape-scale stoat trapping was undertaken by setting two Mark VI Fenn traps in each of 1,426 tunnels throughout 10,000 ha of South Okarito Forest and in about 2,000 ha of neighbouring buffer zones (1 trap/4 ha). The buffer zones were likely routes for re-invasion (e.g. along beaches and on road verges) and trapping there aimed to intercept stoats before they reached the Sanctuary. All traps in the Sanctuary and in buffer zones were checked and re-set 20 times a year, twice a month from September to April and once a month for the rest of the year.

Over the five years from May 2001 to May 2006, a total of 2,144 stoats, 11,331 rats, no weasels and no ferrets were trapped in the 10,000 ha sanctuary and about 2,000 ha of buffer zones. Apart from the very beginning of the trapping, when resident stoats were caught throughout the winter, stoat captures peaked every December–January. There were exceptional numbers of stoats trapped in December 2002–January 2003 (315 stoats) and again in December 2003–January 2004 (464) following spring seasons when rats were superabundant, i.e. (> 1,400 caught in September–October 2002, and > 3,100 in September–October 2003).

Over the study period, various toxic baits were laid in and around parts of the sanctuary by the West Coast Regional Council to control possums, but the location and intensity of this work were not recorded by them. The use of toxins may have influenced some of the results for the Rowi population, with an improvement of survival rates of Rowi chicks the most likely effect based on results of toxic bait application elsewhere (Robertson *et al.* 2011).

BNZONE was re-introduced late in the 2002/2003 breeding season to protect the last two chicks that hatched that season, after all the other chicks had been killed by stoats. BNZONE was used in 2003 to protect as many chicks as possible, because rat and stoat indices showed that their numbers were even higher than they had been in 2002/2003. In subsequent years, five designated Rowi pairs were used for BNZONE to ensure at least some recruitment each year, while the majority of chicks from monitored pairs were left in the forest to test the effectiveness of the stoat trapping programme. The young BNZONE chicks were taken to a crèche site on mammal-free Motuara

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Island, Marlborough Sounds (41°05′S, 174°17′E), and then returned to Okarito Kiwi Sanctuary when they were about 1 year old.

Haast Kiwi Sanctuary

The Haast Kiwi Sanctuary (44°03′S, 168°50′E) was established to reverse the decline of the critically endangered Haast taxon of Tokoeka (Figure 1). The Sanctuary covered about 11,400 ha of rimu-hardwood-silver beech *Nothofagus menziesii* forest and near-pure silver beech forest at the northern end of the Haast Range, between the Waiatoto and Arawhata Rivers. At the start of the study, the sanctuary held about 200 of the total population of about 300 birds (Rogan Colbourne pers. comm.).

Kiwi management at the sanctuary built on some earlier research work on the ecology and genetics of the Haast Tokoeka but, unlike at the other sanctuaries, no specific kiwi management had been attempted at the site beforehand.

In May 2001, during the establishment of the sanctuary, an aerial Compound 1080 operation was conducted over 5,300 ha of the sanctuary and a further 4,000 ha was treated with hand-laid 1080 baits for possum control. For five years, from 2001/2002 to 2005/2006, landscape-scale stoat trapping was undertaken by setting 1,510 Mark VI Fenn traps (two traps in each of 755 tunnels) throughout the 11,400-ha sanctuary (one trap/8 ha), with most trap lines running up selected ridges from near sea level to the mountain tops at up to 1,643 m. A further 150 traps were set in ‘buffer zones’ outside the sanctuary to intercept stoats before they reached it.

A total of 2,237 stoats, no weasels, no ferrets and 6,931 rats were caught between June 2001 and February 2006. The catch rate of both stoats and rats was highly variable from year to year. Rats were caught most frequently in summer, but stoats did not show the clear summer peak observed in the other sanctuaries. Instead, there were extended periods with extremely high monthly captures (> 150/month between April 2003 and January 2004), and then relatively low monthly captures (< 60/month from November 2004 to September 2005).

After BNZONE was re-introduced at the Okarito Kiwi Sanctuary following the predation of all monitored Rowi chicks in the 2002/2003 season, a small-scale BNZONE programme was also introduced at the Haast Kiwi Sanctuary in 2003 to ensure that some chicks survived there each year. Eggs were collected from four designated pairs, and were incubated at Kiwi Bird Park, Queenstown, or at Willowbank, Christchurch. The resultant chicks were reared on Centre Island in Lake Te Anau (45°14′S, 167°46′E) and then returned to the Haast Kiwi Sanctuary when they were 6–12 months old, i.e. at or above their target weight of 1,200 g. The scattered population beyond the Sanctuary boundaries, mainly on the western side of the Arawhata River, was not managed, and is assumed to have declined during this study period.

Kiwi capture and monitoring

Kiwi were caught at night by hand or in hand-nets after they were lured to a catching site by playing recorded calls, or were caught in the daytime when specially trained kiwi-finding dogs (see Robertson and Fraser 2009) found their daytime dens. The birds were measured and permanently marked with a uniquely numbered leg band or with a transponder injected subcutaneously above the ribcage. Adult birds had a 20–25 g Sirtrack® or Kiwitrack® transmitter attached to their tibiotarsus with a hospital identification bracelet (Miles and McLennan 1998), so that all breeding attempts could be monitored at about 1-month intervals. Resultant chicks were marked with transponders, and the majority had an 8–10 g Sirtrack, Kiwitrack, or Holohil® transmitter attached to their tibiotarsus with a cut-down hospital identification bracelet. The transmitters were changed to more powerful c.15-g transmitters at about 6–9 months old, once they had reached about 1,000 g in weight. After they had reached 1,500–1,600 g, they were fitted with an adult kiwi transmitter (25 g) and checked 3-monthly to ensure that the leg attachment was not getting too tight.

Population modelling

Population matrix models were developed in PopTools, a Microsoft Excel™ add-in, for each sanctuary. For some parameters, such as adult mortality, which is the key factor in kiwi population dynamics (Robertson *et al.* 2011), estimates were pooled over a number of years before and after the sanctuary management described above in order to achieve adequate sample sizes and reduce the influence of stochastic events. Management over the five-year period reported on here has primarily aimed at improving chick survival to 6 months old, rather than subadult or adult survival rates.

Adult survival

Annual survival of adults in each sanctuary was calculated using the Mayfield method, assuming that mortality rates remained constant over time (Robertson and Westbrooke 2005). However, there is some evidence that there are pulses of mortality in adult kiwi, resulting from sporadic attacks by dogs or ferrets at particular locations (e.g. Taborsky 1988). To improve sample size and reduce the influence of these stochastic events, data were pooled for each of the five sanctuaries by incorporating radio-transmitter data from those sites before and/or after this study.

Productivity

For each sanctuary, the number of eggs laid per radio-tagged pair (including non-breeding pairs) was recorded, along with hatching success. Based on a range of behavioural observations, it was assumed that all kiwi were monogamous, and capture records indicated that sex ratios were close to even in all five sanctuaries.

Chick survival

Survival rate of chicks from hatching to 6 months old (at which time they weighed about 1 kg and were generally safe from stoat and cat predation) was obtained from the product of the percentage of chicks surviving from hatching to radio-tagging at about 10 days old and the Kaplan-Meier estimate of survival (Robertson and Westbrooke 2005) from 10 to 183 days (6 months) old. For life table analysis, survival during the first year was the product of chick survival to 183 days old and the Kaplan-Meier estimate for subadult survival from 6 months to 1 year old.

Subadult survival

Using a staggered entry design (Pollock *et al.* 1989) based on known ages of chicks followed since they were nestlings, or estimated ages from bill length and weight of wild-hatched subadults found by trained kiwi-finding dogs, we obtained Kaplan-Meier estimates of subadult survival from 6 months old to 4 years old. To improve the sample size, estimates were supplemented with data collected in years before and after to the study period. Where little information existed from wild-hatched subadults, the survival rate was smoothed over age classes, or survival was estimated at a rate intermediate between the survival rates of yearlings and adults.

Age at first breeding

In life table analysis, the size of the Leslie matrix depends on the number of years to maturity (Robertson and Westbrooke 2005). Based on long-term research on Brown Kiwi in Northland (Robertson *et al.* 2011) and from observations in the sanctuaries, we assumed that age of first breeding was 4 years old for all populations. This parameter affects the size of the matrix, but not the final population growth rates.

Immigration and emigration

We did not include corrections for immigration or emigration in the models, because very few data were available for either parameter. We assumed, from the $< 10\%$ survival of chicks to 1 year old in unmanaged mainland areas (McLennan *et al.* 1996, Robertson *et al.* 2011), that there would have been very little immigration into the sanctuaries from nearby unmanaged areas, and for Rowi, the entire range of the species was managed. During the study, no adults and only between 0 and 9% of subadults left the managed areas of the sanctuaries; however, transmitter disappearance caused by long-distance dispersal well beyond the sanctuary boundaries would have been hard to identify, despite regular searches for missing birds from aircraft with strut-mounted Yagi aerials. Transmitter failure, the alternative explanation for transmitter disappearance, was often proven by the subsequent discovery of birds carrying a dead transmitter or birds otherwise marked without a transmitter, and so it appeared that emigration beyond the sanctuary boundaries was minimal.

Leslie matrices and sensitivity analysis

Population data (Table 1) were calculated for each of the main forms of management undertaken in each sanctuary and then analysed in life tables (Leslie matrices) in PopTools (Table 2). The size of each matrix was 5×5 on the assumption that first breeding was at 4 years old. PopTools calculated the intrinsic rate of population growth, λ, which was then converted to a percentage annual change, r. A sensitivity matrix is presented for each life table (Table 2), which shows the contribution that a small change to each matrix element makes to the overall population growth, and this allowed the key factor to be identified.

Results

Whangarei Kiwi Sanctuary

Annual survival rate of adult Brown Kiwi in the Whangarei Kiwi Sanctuary during 1994–2008 was 92.7% (Table 1), which equated to a life expectancy of 13.8 years – only 30–50% of the potential life expectancy, judging from adult survival rates observed in the other sanctuaries. A total of 64 adult deaths were recorded between 1994 and 2008, and in 44 cases where a specific cause of death could be attributed from scene or necropsy evidence, dog predation (22) and ferret predation (9) were the leading causes of death (Robertson *et al.* 2011). This high adult mortality was balanced by very high productivity, with 90% of adults attempting to breed each year, and many pairs had two 2-egg clutches. Hatching success from 2001 to 2005 was moderately high at 53% (Table 1). Overall annual chick production was very high at 0.60 chicks per adult, as was chick survival to 6 months old at 62.4% (Table 1). Despite the extensive trapping network, stoat predation remained the main cause of chick mortality.

Population modelling showed that the kiwi population grew at an average rate of 8.6% per year; however, with the use of BNZONE on 25% of the nests, a technique that resulted in a 12.5% per annum increase (Robertson *et al.* 2011), the overall rate of population increase from this mixed trapping and BNZONE management was estimated to be 9.6% per annum.

Moehau Kiwi Sanctuary

Observed annual survival of adults in the Moehau Kiwi Sanctuary from 2000 to 2008 was 97.5%, which equated to a life expectancy of 39.8 years (Table 1). Based on site evidence or necropsy analysis, dog predation was identified as the cause of death for seven of the 12 adults killed over the eight years. Overall chick production, at 0.38 hatched chicks per adult, was only about two-thirds of that observed at Whangarei Kiwi Sanctuary because only about 67% of adults attempted to breed each year, and hatching success (43%) was also much lower than at Whangarei

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Table 1. Life history parameters and population growth rates for the five kiwi sanctuaries; data for BNZONE are shown separately to those from the other management. Data shown in bold type refer to data obtained solely during 2001–2006, those in normal type have been measured or calculated using data obtained from the sanctuaries before and after the first five years of sanctuary management in order to improve sample size and reduce the impact of stochastic events, while those data in italics have been estimated due to limited available field data. The BNZONE data for Whangarei Kiwi Sanctuary was from Robertson *et al.* (2011). At Moehau and Haast, the average figure for annual subadult survival is given, hence the same values appear in several rows. These data were used to populate the Leslie matrices given in Table 2.

	Whangarei	Moehau	Tongariro	Okarito	Haast
Annual adult survival (%)	92.7	97.5	96.7	97.9	97.8
No. bird years	880	239	276	627	358
Life expectancy (years)	13.8	39.8	30.7	48.3	44.7
Non-BNZONE data only					
No. transmitter years	**119**	**136**	**98**	**191**	**127**
No. eggs	**271**	**240**	**174**	**184**	**88**
Eggs per adult	**1.14**	**0.88**	**0.89**	**0.48**	**0.35**
% eggs hatched	**53**	**43**	**47**	**48**	**62**
Chicks per adult	**0.60**	**0.38**	**0.41**	**0.23**	**0.22**
Chick survival (0–183 days)	**0.624**	**0.671**	0.155*	**0.151**	**0.322**
Survival (0–1 y)	**0.512**	0.659	0.148*	**0.145**	0.278
Subadult survival (1–2 y)	0.886	0.966	0.844	*0.920*	0.974
Subadult survival (2–3 y)	0.881	0.966	0.800	*0.940*	0.974
Subadult survival (3–4 y)	0.958	0.966	1.000	*0.960*	0.974
Leslie matrix, λ	**1.090**	**1.120**	**1.007**	**1.006**	**1.030**
Annual population growth, r (%)	**8.6**	**11.3**	**0.7**	**0.6**	**2.9**
BNZONE data only					
No. transmitter years			**54**		**12**
No. eggs			**111**		**10**
Eggs per adult			**1.09**		**0.42**
% eggs hatched			**64**		**50**
Chicks per adult			**0.68**		**0.21**
Chick survival (0–183 days)	0.831		**0.828**	**0.917**	**0.667**
Survival (0–1 y)	0.713		**0.768**	**0.917**	**0.667**
Subadult survival (1–2 y)	0.746		**0.770**	0.870	*0.974*
Subadult survival (2–3 y)	0.908		**0.961**	0.955	*0.974*
Subadult survival (3–4 y)	0.805		**1.000**	0.973	*0.974*
Leslie matrix, λ	**1.133**		**1.171**	**1.098**	**1.074**
Annual population growth, r (%)	**12.5**		**15.8**	**9.4**	**7.1**

*averaged over 4 non-treatment years and 1 year with a 1080 operation

(Table 1). Chick survival to 6 months old was very high at 67% (Table 1). Despite the extensive trapping network, stoat predation remained the main cause of chick mortality at Moehau. Population modelling showed that with the trapping regime employed at Moehau, the kiwi population grew at an average rate of 11.3% per year.

Tongariro Kiwi Sanctuary

Annual adult survival at Tongariro between 1992 and 2008 was moderately high at 96.7%, giving a life expectancy of 30.7 years (Table 1). Chick production from the BNZONE sample was high at 0.68 hatched chicks per adult, partly because the BNZONE programme allowed more adults to re-nest within a season, but also because hatching success was high at 64%. Survival of BNZONE chicks to 6 months old in captivity, at Warrenheip crèche, or after return to Tongariro Forest at > 4 months old, was a very high 83% (Table 1).

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Table 2. Leslie matrix and its corresponding sensitivity matrix for each of the five sanctuaries and the main management treatments within them. In the Leslie Matrix, the top right-hand figure is the number of chicks hatched per adult, the sub-diagonal figures from left to right represent annual survival of birds aged 0–1, 1–2, 2–3, and 3–4 years, and the bottom right figure is annual survival of adults. In the corresponding sensitivity matrix, the magnitude of each number reflects the importance that a set small change to each variable makes to the overall population growth rate. In all nine matrices, adult survival is clearly the key factor (shown in bold) in controlling rate of growth of kiwi populations.

Leslie Matrix for Whangarei (trapping)					Sensitivity matrix				
0	0	0	0	0.6008	0	0	0	0	0.1696
0.5120	0	0	0	0	0.1990	0	0	0	0
0	0.8863	0	0	0	0	0.1150	0	0	0
0	0	0.8802	0	0	0	0	0.1158	0	0
0	0	0	0.9576	0.9273	0	0	0	0.1064	**0.6261**

(b)

Leslie Matrix for Whangarei (BNZONE); data from Robertson *et al.* 2011					Sensitivity matrix				
0	0	0	0	0.8750	0	0	0	0	0.1363
0.7128	0	0	0	0	0.1673	0	0	0	0
0	0.7456	0	0	0	0	0.1600	0	0	0
0	0	0.9048	0	0	0	0	0.1313	0	0
0	0	0	0.8046	0.9273	0	0	0	0.1483	**0.5790**

(c)

Leslie Matrix for Moehau (trapping)					Sensitivity matrix				
0	0	0	0	0.3824	0	0	0	0	0.2494
0.6591	0	0	0	0	0.1447	0	0	0	0
0	0.9661	0	0	0	0	0.0987	0	0	0
0	0	0.9661	0	0	0	0	0.0987	0	0
0	0	0	1.9661	0.9748	0	0	0	0.0987	**0.6592**

(d)

Leslie Matrix for Tongariro (1 year of 1080 and 4 years of non-treatment)					Sensitivity matrix				
0	0	0	0	0.4133	0	0	0	0	0.0837
0.1480	0	0	0	0	0.2336	0	0	0	0
0	0.8438	0	0	0	0	0.0410	0	0	0
0	0	0.8000	0	0	0	0	0.0432	0	0
0	0	0	1.0000	0.9674	0	0	0	0.0346	**0.8627**

(e)

Leslie Matrix for Tongariro (BNZONE)					Sensitivity matrix				
0	0	0	0	0.6759	0	0	0	0	0.1779
0.7680	0	0	0	0	0.1565	0	0	0	0
0	0.7695	0	0	0	0	0.1562	0	0	0
0	0	0.9611	0	0	0	0	0.1251	0	0
0	0	0	1.0000	0.9674	0	0	0	0.1202	**0.5895**

(f)

Leslie Matrix for Okarito (trapping)					Sensitivity matrix				
0	0	0	0	0.2230	0	0	0	0	0.1055
0.1446	0	0	0	0	0.1700	0	0	0	0
0	0.9200	0	0	0	0	0.0267	0	0	0
0	0	0.9400	0	0	0	0	0.0262	0	0
0	0	0	0.9600	0.9793	0	0	0	0.0256	**0.9023**

(g)

Leslie Matrix for Okarito (BNZONE)					Sensitivity matrix				
0	0	0	0	0.2230	0	0	0	0	0.3558
0.9170	0	0	0	0	0.0904	0	0	0	0
0	0.8695	0	0	0	0	0.0953	0	0	0
0	0	0.9550	0	0	0	0	0.0868	0	0
0	0	0	0.9731	0.9793	0	0	0	0.0852	**0.6980**

(h)

Leslie Matrix for Haast (trapping)					Sensitivity matrix				
0	0	0	0	0.2168	0	0	0	0	0.2003
0.2937	0	0	0	0	0.1479	0	0	0	0
0	0.9737	0	0	0	0	0.0446	0	0	0
0	0	0.9737	0	0	0	0	0.0446	0	0
0	0	0	0.9737	0.9776	0	0	0	0.0446	**0.8313**

(i)

Leslie Matrix for Haast (BNZONE)					Sensitivity matrix				
0	0	0	0	0.2083	0	0	0	0	0.3405
0.6670	0	0	0	0	0.1063	0	0	0	0
0	0.9737	0	0	0	0	0.0728	0	0	0
0	0	0.9737	0	0	0	0	0.0728	0	0
0	0	0	0.9737	0.9776	0	0	0	0.0728	**0.7358**

The BNZONE programme resulted in an extremely good projected annual increase of 15.8% from the sample of birds that were managed in this way.

Because an average of only 69% of adult males bred each year, and hatching success in the wild was 47%, the observed chick productivity in the unmanaged population at Tongariro was only 0.41 chicks per year, again about two-thirds of that observed at Whangarei Kiwi Sanctuary (Table 1). Each year, about 80% of the population was left unmanaged, except for the landscape-scale aerial poisoning of pests with 1080 in spring 2001. In the 2001 breeding season, 37% of chicks survived to 6 months old, resulting in a projected population gain of 5.1% that year (Table 1). For the purposes of our model, we assumed that survival of chicks in other non-treatment years was similar to the 10% survival to 6 months old observed in unmanaged parts of Northland (Robertson *et al.* 2011) and so we estimated that the unmanaged population declined at 0.6% per year. The estimated net gain in the non-BNZONE part of the population over the whole 5-year period was 0.7% per annum, mainly due to the very good survival of chicks in the season following the 1080 operation.

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With a 1080 operation in 2001 and no management in other years, the population would have grown by 0.7% per annum; however, with BNZONE undertaken on about 20% of the population in 2000 and in 2002–2005, the overall population was estimated to have increased at an average rate of 3.1% per annum.

Okarito Kiwi Sanctuary

The five years of landscape-scale trapping of stoats from 2001 to 2006 was largely ineffective in increasing the population of Rowi, the rarest species of kiwi. Annual survival of Rowi from 1991 to 2008 was very high at 97.9%, giving a life expectancy of 48.3 years (Table 1); however, productivity in this species was naturally low at 0.23 hatched chicks per bird. Rowi lay only 1-egg clutches, each year about one-third of birds did not attempt to breed, and hatching success was moderate at about 48% (Table 1). Despite the extensive trapping network, only 15% of chicks survived to 6 months old, with stoat predation the main cause of chick mortality. In 2002, when there were very high numbers of rats following mast fruiting of rimu in the area, stoats killed all 14 radio-tagged chicks. In 2003, all 14 chicks seen were collected for BNZONE because rat and stoat indices were even higher than in 2002. By assuming that this cohort would have had a similar survival profile as the 14 chicks had in 2002, the population matrix model gave an average annual growth rate of 0.6% over the whole five-year period of the stoat trapping programme.

Of the 24 Rowi chicks collected for BNZONE in 2002–2005, 92% survived to 6 months old (Table 1), and using all BNZONE data from Okarito through to 2008 to fill the rest of the Leslie matrix, the modelled rate of increase from BNZONE was 9.4% per annum.

If reliant solely on trapping, the population would have grown by 0.6% per annum. By using BNZONE on an average of 10% of the population each year, with a 9.4% projected increase per annum, the overall population would have grown by 1.5% per annum.

Haast Kiwi Sanctuary

Annual survival of Haast Tokoeka from 1991 to 2008 was very high at 97.8%, giving a life expectancy of 44.7 years. Productivity was low at 0.22 chicks per adult bird. Each year, an average of only 62% of Haast Tokoeka adults attempted to breed, and most of them (87%) laid a single 1-egg clutch. Hatching success was high at about 62%. Despite the extensive trapping network, only 32% of chicks survived to 6 months old because stoats killed most radio-tagged chicks, especially in years when there were high numbers of rodents following heavy fruiting of podocarps or mast seeding of silver beech trees in the area. The population matrix model suggested an average annual growth rate of 2.9% under the stoat trapping regime.

The first 5 years of landscape-scale trapping of stoats from 2001 to 2006 were more effective at increasing the population of Haast Tokoeka than it had been for Rowi 140 km away, thanks mainly to very good chick survival (78%, $n = 10$) in 2004/2005 when stoats were scarce.

Productivity from the small-scale BNZONE programme introduced at the Haast Kiwi Sanctuary in 2003 was low at 0.21 chicks per adult because of the relatively poor (50%) hatching success of the small number of eggs involved. However, chick survival to 6 months old in captivity or on crèche islands was very high (67%), and so this method was modelled to result in an annual population increase of 7.1% (Table 1).

Population modelling showed that the introduction of BNZONE to about 5% of the population in 2003, led to the annual population growth increasing from 2.9% per annum to 3.2% per annum

Discussion

The results of the landscape-scale management in the five sanctuaries were mixed. Extremely good rates of population growth were observed at Whangarei and Moehau Kiwi Sanctuaries using predator trapping over 13,400 and 18,500 ha respectively; however, a trapping programme at a similar scale, but with a higher density of traps, and similar or greater frequency of trap visits, failed to result in any effective population growth at Okarito Kiwi Sanctuary, and only modest population growth at the Haast Kiwi Sanctuary. Similar modest population growth was observed at the Tongariro Kiwi Sanctuary which was managed with a different approach of periodic landscape-scale application of toxic baits and then intensive BNZONE over a small part of the population in intervening years.

Part of the relatively poor performance of the Okarito and Haast sanctuaries was due to the naturally low productivity of Rowi and Haast Tokoeka, which lay 1-egg clutches, compared with the usual 2-egg clutches of Brown Kiwi (Heather and Robertson 2005). Compounding this, a high proportion of birds did not attempt to breed, or if they did, they failed at a very early stage before their nesting attempt was detected. Hatching success was about normal for kiwi at 48–62% but, in spite of the extensive trapping networks, chick survival to 6 months old was very poor in these sanctuaries compared with those in the North Island. The main redeeming feature for Rowi and Haast Tokoeka, and probably the reason why they are not already extinct, was their extremely high annual adult survival, the key factor in sensitivity analyses of kiwi life history parameters (Table 2). These mean life expectancies of over 40 years were more than three times that recorded in the Whangarei Kiwi Sanctuary, where dog and ferret predation were the two leading causes of adult mortality. Fortunately, dogs and ferrets are very scarce at both the Okarito and Haast Sanctuaries, and ongoing management for these populations need to ensure that this status quo remains.

Despite intensive trapping efforts, stoats remained the main cause of chick mortality in all sanctuaries. The capture rate of stoats in the Okarito and Haast Sanctuaries was far higher than that recorded in either the Whangarei or Moehau Sanctuary, with total captures over a single month at Okarito (335 stoats caught in 2,852 traps over 12,000 ha in December 2003) almost equal to that over 4 years at Whangarei Kiwi Sanctuary (361 Stoats in 1,140 traps over 13,400 ha). At both the Okarito and Haast Kiwi Sanctuaries, stoat abundance was probably driven by rat abundance which, in turn, was most likely to have been driven by mast fruiting of rimu, the dominant emergent tree in both sanctuaries, and also by mast seeding of silver beech at Haast only. In some years, rats were superabundant following heavy fruiting or seeding, and these rats provided an important food supply for stoats. It is possible that the superabundance of rats at Okarito in spring 2002 and spring 2003 may have been influenced by the ongoing removal of stoats, their main predator. Monitoring of stoats and rats in nearby non-treatment areas showed that although the seasonal and yearly pattern of abundance were similar to that in the sanctuaries, the magnitude of the peaks was much less than in the trapped areas (Ian Flux and Craig Gillies unpublished data).

Even though large numbers of stoats were killed at Okarito and Haast Sanctuaries, immigrating or residue resident stoats found and killed most kiwi chicks. The consistently better survival of chicks in the North Island and at Haast compared with Okarito may have been related to differences in their social behaviour. Brown Kiwi and Haast Tokoeka chicks became independent of their parents and the natal burrow at 2–7 weeks old (Heather and Robertson 2005, Chrissy Wickes pers. comm.) whereas Rowi chicks remained with their parents, often in their natal burrow, for several years (Chris Rickard pers. comm.). This may mean that scent trails of Rowi leading to and from the natal burrow were easy for stoats to detect, making Rowi chicks and juveniles (before they reach a safe size at about 6 months old) especially vulnerable to predation when out foraging.

Use of these data

The preliminary analysis of the data that appear in this paper led to some dramatic changes to the management of the five kiwi sanctuaries from 2006 onwards. The results of the new management in each sanctuary will be reported elsewhere.

At Whangarei Kiwi Sanctuary, where population growth was very strong, the frequency of trap visits was halved to monthly checks, and the time saved was directed towards protecting kiwi in a new 4,000-ha area along the eastern coast of Northland between Whangaruru (35°10′S, 174°16′E) and

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Ngunguru (35°38′S, 174°30′E), to supplement an existing trapping programme to protect the endangered Brown Teal *Anas aucklandica*.

At Moehau Kiwi Sanctuary, trapping continued at the reduced frequency of 12 trap visits a year, but the monitoring of kiwi has been gradually reduced and the funds redirected to the management of the other four sanctuaries, especially at Okarito and Haast. Encouragement has been given to nearby community groups to develop their own stoat trapping projects, providing a buffer right across the Coromandel Peninsula on the southern boundary of the sanctuary. This has led to a doubling of the area of stoat control at the northern tip of the peninsula.

Another large-scale application of 1080 was carried out at Tongariro Forest in September 2006 and most chicks were left in the wild in following years to assess whether there is a benefit from landscape-scale control of mammalian predators, and how long that benefit might last. Some BNZONE management of eggs and chicks has been carried out to help establish a new Brown Kiwi population in a c.3,400 ha area behind a predator-proof fence at Maungatautari (38°01′S, 175°34′E).

Stoat trapping at Okarito was abandoned in May 2006, and management reverted to the successful BNZONE programme that ran before 2001, and again during the later stages of the 2001–2006 sanctuary programme. Landscape-scale application of 1080 for possum and rat control, with anticipated incidental flow-on stoat control through secondary poisoning (Murphy *et al.* 1999) has been planned but then postponed for two years in a row, due, ironically, to a lack of rats to act as suitable vectors to pass the toxin on to the stoats.

At Haast, the trap density was doubled by placing new traps halfway between existing trap boxes. At the same time, the BNZONE programme was expanded from four pairs in 2003–2006 to as many pairs as possible, recognising that many pairs are not monitored, some monitored pairs nest in remote and mountainous sites where BNZONE would be impractical, and that some nest burrows are too deep to collect eggs from. In 2009/2010, the BNZONE programme was further expanded to include some egg collection from the portion of the population that resides outside the sanctuary boundaries.

Synopsis

The kiwi sanctuary programme allowed some bold conservation management to take place; in particular, the management of kiwi on a landscape-scale not previously possible, allied with good monitoring of the outcomes. Success was highly variable from site to site, partly due to inherent differences in the biology of the kiwi taxa, and partly due to local conditions affecting predator-prey relationships. The landscape-scale trapping of stoats worked to the benefit of kiwi chicks at some sites, but in others appeared to lead to an explosion of the rat population and ultimately produced no significant benefit to kiwi chicks. The lessons learned have been applied within an adaptive management framework, with new management approaches in four of the five sanctuaries aimed at maximising population gains within the same overall budget. At the Moehau Sanctuary, where management has remained the same, the outcome monitoring has been reduced to periodic call count surveys, and this has freed up resources for more intensive management elsewhere. Sensitivity analyses have shown that in long-lived species such as kiwi, adult survival is consistently the key factor in population persistence, even though chick predation is the most commonly observed mortality event. Conservation managers need to be aware not only of the biology of the particular species being protected, but also the local predator-prey drivers and possible consequences stemming from targeted management of one key predator.

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predators, or to monitor kiwi in the sanctuaries. Others have managed staff, budgets and resources in what has been one of the biggest biodiversity projects undertaken by DOC. Staff at Auckland Zoo, Kiwi Encounter, Whangarei Bird Rescue Centre, Willowbank and Queenstown Bird Park assisted with the BNZONE programme. Ian Westbrooke provided statistical advice. Lynette Clelland, Rogan Colbourne, Craig Gillies, Avi Holzapfel and an anonymous referee provided useful improvements to the manuscript. All of our procedures were approved by the DOC Animal Ethics Committee, and had the support of the local iwi.

References

BirdLife International (2011) BirdLife International's Data Zone. [http://www.birdlife.org/datazone/species/index.html, accessed on 5/5/2011]

Colbourne, R., Bassett, S., Billing, A., McCormack, H., McLennan, J., Nelson, A. and Robertson, H. (2005) *The development of Operation Nest Egg as a tool in the conservation management of kiwi*. Wellington, New Zealand: Department of Conservation. (Science for Conservation 259).

Dawson, D. G. and Bull, P. C. (1975) Counting birds in New Zealand forests. *Notornis* 22: 101–109.

Heather, B. D. and Robertson, H. A. (2005) *The field guide to the birds of New Zealand*. Revised edition. Auckland, New Zealand: Penguin.

King, C. M. and Edgar, R. L. (1977) Techniques for trapping and tracking stoats (*Mustela erminea*); a review, and a new system. *N. Z. J. Zool.* 4: 193–212.

Leigh, A. H. (1995) *Possum control, Moehau Range, 1987-1994*. Hamilton, New Zealand: Department of Conservation.

McLennan, J. A., Potter, M. A., Robertson, H. A., Wake, G. C., Colbourne, R., Dew, L., Joyce, L., McCann, A. J., Miles, J., Miller, P. J. and Reid, J. (1996) Role of predation in the decline of kiwi *Apteryx* spp., in New Zealand. *N. Z. J. Ecol.* 20: 27–35.

Miles, J. E. C. (1995) *Comparative ecology of Northern Brown Kiwi (Apteryx australis mantelli) in Tongariro National Park and Tongariro Forest Park, central North Island*. MSc thesis, Massey University, Palmerston North, New Zealand.

Miles, J. and McLennan, J. (1998) A new technique for radio-tagging immature kiwi (*Apteryx* spp.). *Notornis* 45: 44–48.

Miskelly, C. M., Dowding, J. E., Elliott, G. P., Hitchmough, R. A., Powlesland, R. G., Robertson, H. A., Sagar, P. M., Scofield, R. P. and Taylor, G. A. (2008) Conservation status of New Zealand birds, 2008. *Notornis* 55: 117–135.

Murphy, E. C., Robbins, L., Young, J. B. and Dowding, J. E. (1999) Secondary poisoning of stoats after an aerial 1080 poison operation in Pureora Forest, New Zealand. *N. Z. J. Ecol.* 23: 175–182.

Pollock, K. H., Winterstein, S. R., Bunck, C. M. and Curtis, P. D. (1989) Survival analysis in telemetry studies: the staggered entry design. *J. Wildl. Manage.* 53: 7–15.

Robertson, H. A. (2004) *Research and monitoring plan for the kiwi sanctuaries*. Wellington, New Zealand: Department of Conservation. (Science for Conservation 241).

Robertson, H. A. and Fraser, J. R. (2009) Use of trained dogs to determine the age structure and conservation status of kiwi (*Apteryx* spp.) populations. *Bird Conserv. Internatn.* 19: 121–129.

Robertson, H. A. and Westbrooke, I. M. (2005) *A practical guide to the management and analysis of survivorship data from radio-tracking studies*. Wellington, New Zealand: Department of Conservation. (Department of Conservation Technical Series 31).

Robertson, H. A., Colbourne, R. M., Graham, P., Miller, P. J. and Pierce, R. J. (1999a) Survival of Brown Kiwi (*Apteryx mantelli*) exposed to brodifacoum poison in Northland, New Zealand. *N. Z. J. Ecol.* 23: 225–231.

Robertson, H. A., Colbourne, R. M., Graham, P., Miller, P. J. and Pierce, R. J. (1999b) Survival of Brown Kiwi exposed to 1080 poison used for control of Brushtail Possums in Northland, New Zealand. *Wildl. Res.* 26: 209–214.

Robertson, H. A., Colbourne, R. M., Graham, P. J., Miller, P. J. and Pierce, R. J. (2011) Experimental management of Brown Kiwi (*Apteryx mantelli*) in central Northland, New Zealand. *Bird Conserv. Internatn.* 21: 207–220.

Robertson, H. A., Colbourne, R. M., Nelson, A. and Westbrooke, I. M. (2006) At what age should Brown Kiwi (*Apteryx mantelli*) eggs be collected for artificial incubation? *Notornis* 53: 229–232.

Taborsky, M. (1988) Kiwis and dog predation: observations in Waitangi State Forest. *Notornis* 35: 197–202.

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