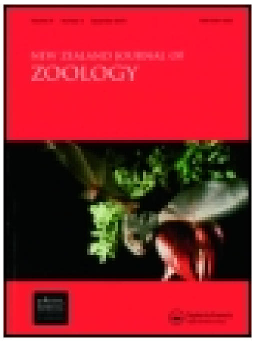

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RESEARCH ARTICLE

Short pulse of 1080 improves the survival of brown kiwi chicks in an area subjected to long-term stoat trapping

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ABSTRACT
Many mainland populations of kiwi are declining because stoats (*Mustela erminea*) kill most of their chicks. Stoats are often trapped during conservation programmes, but the long-term effectiveness of trapping has not been measured. During continuous trapping of mammalian predators in the 9800 ha Whangarei Kiwi Sanctuary, the survival of brown kiwi (*Apteryx mantelli*) chicks declined over time. Following the use of sodium fluoroacetate (1080) to kill rats (*Rattus* spp.) and possums (*Trichosurus vulpecula*) and likely secondary poisoning of stoats, chick survival at Riponui increased from 5% to 56%, and the 62% chick survival at Rarewarewa was better than the 20% recorded in a trapped-only area nearby. We suggest that untrappable stoats accumulate in areas subjected to continuous predator trapping. Conservation managers should build into their long-term pest control programmes a periodic pulse of an alternative tool to kill pests that, for whatever reason, actively avoid the primary control tool.

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Apteryx mantelli; *Mustela erminea*; trappability; secondary poisoning; sodium fluoroacetate; invasive species; integrated pest control; New Zealand

Introduction

Kiwi are flightless, mainly nocturnal, ratite birds endemic to New Zealand. Four of the five species—brown kiwi (*Apteryx mantelli*), rowi (*A. rowi*), tokoeka (*A. australis*) and great spotted kiwi (*A. haastii*)—are classified as 'Threatened' (Robertson et al. 2013) following huge reductions in both their range and numbers on the mainland of New Zealand over the past 100 years (Heather & Robertson 2015). The main threat to kiwi populations is predation by introduced mammals, especially stoats (*Mustela erminea*), cats (*Felis catus*), ferrets (*Mustela furo*) and dogs (*Canis familiaris*) (McLennan et al. 1996; Robertson et al. 2011). Research has shown that, without control of predators, only about 6% of brown kiwi chicks in Northland survive to reach adulthood (Robertson et al. 2011). Once they 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 and are the critical predators in Northland (Robertson et al. 2011).

It has been shown that predator trapping can allow kiwi populations to stabilise or recover. In a review of the first 5 years of kiwi conservation efforts in five sanctuaries, Robertson & de Monchy (2012) found that 62% of brown kiwi chicks survived to 6

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months old in an area of Northland subjected to landscape-scale predator trapping in 2001–2006 and, despite poor adult survival (92.7%/hectare) compared with other kiwi sanctuaries, population growth was modelled to be 8.6%/hectare. Further monitoring has revealed a progressive decline in the Kaplan-Meier survival estimate of kiwi chicks in the main study blocks of the Whangarei Kiwi Sanctuary from 67% in 2003 ($n = 31$) to 24% in 2008 ($n = 43$) (H Robertson, DOC, unpubl. data). If predation pressure was stable, the probability of a run of 5 years with a successive decline in chick survivorship was very low (Binomial test, $P = 0.03$). Data from Moehau Kiwi Sanctuary, another site with landscape-scale predator control designed to protect kiwi (Robertson & de Monchy 2012), showed a remarkably similar gradual decline in chick survival from 95% in 2002 to 38% in 2007, when kiwi chick monitoring ceased (P de Monchy, DOC, unpubl. data).

Initially, the decline in chick survival in the two kiwi sanctuaries was attributed to a reduction in trapping frequency. In the Whangarei Kiwi Sanctuary, re-baiting of traps was changed from fortnightly to monthly in 2005, and the trapping frequency at Moehau also declined gradually from 15 times a year in 2002 to eight times a year in 2007. In 2008, when baiting frequency at the Whangarei Kiwi Sanctuary was increased to 3-weekly during the peak period of kiwi chick exposure to stoats (November to March), the survival rate of kiwi chicks continued to decline. At Riponui Reserve, one of the four main study blocks in our study, the Kaplan-Meier estimate of chick survival to 6 months old declined from 77% ($n = 12$) in the 2 years 2001–2003 to 5% ($n = 20$) in the 5 years 2004–2009. In the 2008–2009 breeding season, all seven radio-tagged kiwi chicks were killed by stoats before they had reached 63 days old. At the same time, we monitored the survival of seven radio-tagged kiwi chicks at Bream Head Scenic Reserve, 60 km away, in a separate part of the Whangarei Kiwi Sanctuary; none of them were killed by stoats—at least five reached 3 months old, and at least two reached 6 months old. That year, the 584 ha Bream Head Scenic Reserve had been treated with 1080 in bait stations to reduce rat densities, in addition to the ongoing mustelid and cat trapping programme run in the reserve by the Department of Conservation (DOC) and in nearby forest patches by the Whangarei Heads Landcare Forum. The contrasting results made us suspect that the poor survival of kiwi chicks in some of the western portion of the Whangarei Kiwi Sanctuary was due to the presence of an unknown number of untrappable stoats.

Stoats were introduced to New Zealand in 1884 in a vain attempt to control rabbits (*Oryctolagus cuniculus*) and have spread throughout both main islands (King & Murphy 2005). Female stoats often appear to be less trappable than males (King & Edgar 1977), but because females have smaller home ranges than males in both forests and farmland in New Zealand (Miller et al. 2001; King & Murphy 2005) they are likely to encounter fewer traps.

Unpublished evidence suggests that continuous predator trapping in the five kiwi sanctuaries led to an increase in peak tracking rates of rats (*Rattus* spp.), the main prey species of stoats, compared with nearby non-treatment areas (I Flux and C Gillies, DOC, unpubl. data; although see Blackwell et al. 2003 and Ruscoe et al. 2011). An increased prey supply, and lack of other territorial stoats, could create an opportunity to establish a home range for any stoat that actively avoided trapping tunnels (i.e. encountered them, but did not enter them), either through a near-miss in a previous encounter with a trap, or by being naturally averse to artificial objects (such as traps or tracking tunnels) or averse to human scent associated with traps. Indeed, King et al. (2003) postulated that variation in the probability of first capture among stoats would mean that ongoing removal campaigns, such as that in the Whangarei Kiwi Sanctuary, will select for the survival of animals that tend not to enter traps.

Video-recordings and observations of captive stoats suggest that a portion of the population will not enter tunnels, or will only look in the entrance or enter part way before departing. Dilks & Lawrence (2000) found that on eight of 45 (18%) occasions, a stoat approached a tunnel containing a poisoned egg, but did not enter it, and Brown (2001) found that two of 16 (12%) captive stoats did not enter tunnels placed in their pen. Murphy & Dowding (1995) ringed a stoat den with traps but failed to catch the female or any of the four young seen playing outside the den. Female stoats that reached Maud and Kapiti islands, and Orokonui Ecosanctuary, proved either impossible or very difficult to trap despite high trap densities (Crouchley 1994; P Jansen, DOC, pers. comm. 12 October 2015; E Smith, Orokonui Ecosanctuary, pers. comm. 15 January 2016). King et al. (2003) modelled capture and recapture probabilities of stoats in Fiordland, and found considerable individual differences in the probability of first capture in live traps. Adult females had an especially low recapture probability. Stoats are less attracted to artificial baits in tunnels when prey is superabundant (Alterio et al. 1999; King & White 2004), but this reduction in trappability, through disinterest in additional food, or through smaller territories not overlapping with traps, is a different phenomenon to a stoat living in an area with many traps, but being untrappable.

Given that stoats are highly vulnerable to secondary poisoning following pest control operations using 1080 or brodifacoum (e.g. Alterio 1996; Brown et al. 1998; Gillies & Pierce 1999; Murphy et al. 1999; Alterio 2000; Alterio & Moller 2000), we decided to use a short pulse of 1080 to control brush-tailed possums (*Trichosurus vulpecula*) and rats to determine whether the poor survival of kiwi chicks at Riponui Reserve was due to the presence of one or more untrappable stoats. We expected that any resident stoats that did not enter trapping tunnels would still be susceptible to secondary poisoning in their normal use of the treatment area. This is the first trial we know of that attempted to determine if untrappable stoats were resident in a site, and if they could be removed by a short pulse of toxin.

Materials and methods

Study area

The kiwi productivity study (Robertson et al. 2011; Robertson & de Monchy 2012) was carried out in four forest patches of remnant broadleaf-podocarp forest within 5 km of Rarewarewa Scenic Reserve (35°37′ S, 174°08′ E) in central Northland, New Zealand (Figure 1). The forest patches range in size between 35 ha and 110 ha, though kiwi also reside in some adjacent patches of exotic woodlots or scattered native forest fragments in nearby farmland. The vegetation and topography of the four study blocks have been described by Robertson et al. (1999a, 2011).

The breeding ecology and demography of endangered brown kiwi have been studied in these four study blocks for 17–18 years (Robertson et al. 1999a, 1999b, 2011; Robertson & de Monchy 2012). Over this period, a variety of conservation management techniques have been tested to try to increase their populations (Robertson et al. 1999a, 1999b; Colbourne et al. 2005; Robertson et al. 2011; Robertson & de Monchy 2012).

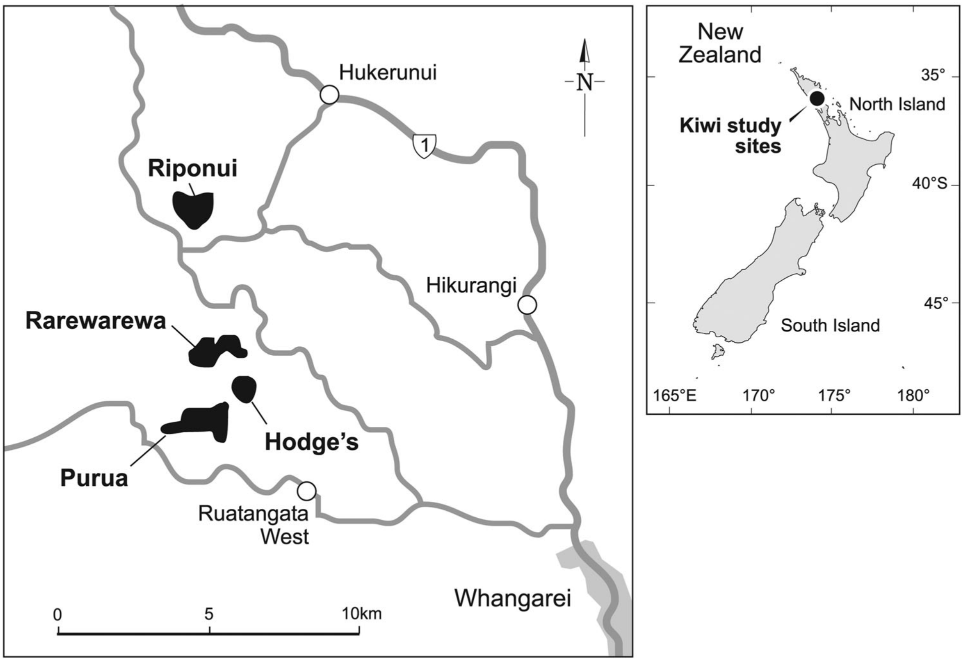

Figure 1. Map of the four kiwi study sites in central Northland, to the northwest of Whangarei.

Stoat control

In 2001, the original adaptive management study areas (Robertson et al. 2011) became subsumed within the Whangarei Kiwi Sanctuary (Robertson 2003), and from 2002 landscape-scale (9800 ha) predator trapping has been carried out in the western part of the sanctuary to protect kiwi and their chicks. Approximately 225 trap-sets were established in the area, each with two Fenn Mark VI or DOC 200 traps per box, to catch stoats—the main target of trapping operations—and weasels (*Mustela nivalis*). Approximately 95 'Steve Allan' Conibear-style traps, set on sloping boards or on raised platforms out of kiwi reach, were also established to catch ferrets, cats and possums.

The density of traps was much lower in open farmland and in a 2300 ha tract of continuous forest (Marlow–Motatau) than in and around the four original forest patches where the majority of kiwi lived. The overall density has been one stoat trap-set per 43 ha and one 'Steve Allan' trap per 102 ha, but has averaged one stoat trap-set per 10 ha and one cat trap per 13 ha in and several hundred metres around the four study blocks. The traps were checked, re-set and re-baited fortnightly, with a variety of baits, but mainly eggs and dried rabbit, from June 2002 to June 2005, monthly from July 2005 to June 2008, and thereafter at 3-weekly intervals during the peak of stoat abundance and kiwi chick vulnerability (November–March), monthly on the shoulder seasons (April–May and September–October) and 6-weekly in winter (June–August). This landscape-scale trapping regime continued throughout the experiments described here, and so the treatment area was trapped and had a pulse of toxin, whereas the non-treatment area was only trapped.

Kiwi research

In the four study blocks, an annual average of 55 (44–73) adult male kiwi were marked with a 25 g two-stage Sirtrack radio-transmitter strapped to their tibia with a plastic hospital identification bracelet (Miles & McLennan 1998) so that we could find their nests. Brown kiwi lay one to two clutches of one to two eggs each year, which the male alone incubates (Heather & Robertson 2015). Eggs hatch 5–15 days apart after 75–85 days. The chick first emerges from the nest to feed at night at 5–7 days old, but returns each day to share the nest burrow with its father and any sibling until 15–50 days old. Chicks were radio-tagged in the nest at 1–40 days old, but generally when < 10 days old. A few chicks (from unmonitored adults) found by our trained kiwi dogs were added to the sample at up to 95 days old; their age was estimated from sex-specific linear bill length growth, once gender had been determined from DNA analysis (Huynen et al. 2003). All chicks were monitored fortnightly and cause of death was determined by inspecting the scene and necropsy evidence.

To boost, or even out, sample sizes across the study blocks, we released Bank of New Zealand Operation Nest Egg (ONE) chicks that had been hatched in Auckland Zoo from eggs collected in the study blocks (for methodology see Colbourne 2002; Colbourne et al. 2005; Robertson et al. 2011). These captive-raised chicks were released at 17–29 days old, once they had regained their original hatching weight, and at an age when most wild-hatched chicks become independent.

Survivorship analysis

A Kaplan-Meier estimate of chick survival to 6 months old was calculated using a staggered entry design (Pollock et al. 1989; Robertson & Westbrooke 2005). The Kaplan-Meier estimate is superior to the simple percentage of marked chicks that survive to 6 months old as it takes into account the probability that censored birds (e.g. those whose transmitter or attachment fails) would have survived to 6 months old, given that they were of a certain age when lost from the study. The comparison of survival rates between treatments or years used the Mantel-Haenszel log-rank statistic Z, according to the methods described by Robertson & Westbrooke (2005).

Riponui trial

Riponui Scenic Reserve (35°34′ S, 174°08′ E) was chosen as the first site to test whether a pulse of toxin could kill untrappable stoats that had apparently become resident there, based on the very poor survival of radio-tagged kiwi chicks over the previous five breeding seasons—14 (70%) of 20 chicks were killed by stoats, including all seven tagged in 2008.

We used certified kiwi-locating dogs to find an extra eight adult male kiwi to be radio-tagged in order to locate nests and increase the potential sample of chicks in the Riponui study block.

In July 2009, three fills of non-toxic cereal baits were placed in 200 Philproof bait stations in an area of 175 ha in and around Riponui, at an average density of 1.1 bait stations per hectare. On 24 July 2009, 4 days after the third fill of pre-feed, 500 g of 12 g cereal baits containing 0.15% sodium fluoroacetate (1080) were placed in each bait station to control rats and possums. The bait stations were re-filled on 28 July, and remaining toxic baits were retrieved on 8 August, 15 days after toxic baits were first deployed.

In the 2009 breeding season, 23 kiwi chicks were radio-tagged at Riponui—17 wild-hatched chicks aged 4–25 days old and six ONE chicks that were released at 17–27 days old. In the other three study blocks, a total of 20 wild-hatched chicks were radio-tagged at 1–27 days old. The survival of chicks at Riponui was compared with that of 20 wild-hatched chicks radio-tagged at 3–32 days old at Riponui over the preceding five breeding seasons (2004 to 2008).

Rarewarewa trial

Following the Riponui trial in 2009, we carried out the same procedure in 2010 at Rarewarewa Scenic Reserve, and compared the survival of chicks in the 2010 breeding season with that observed there in previous years; with chick survival at Riponui in 2010 and with Purua Reserve as a trapped-only site. Rarewarewa was used as the treatment site in 2010 because Purua was not completely fenced, and so farm livestock would have had access to toxic baits. Because a fourth block, Hodges Bush, was separated by only 1 km of farmland from the nearest parts of Rarewarewa and Purua, management there could not be considered independent from that in the neighbouring blocks, and so we harvested most eggs from the block for ONE, and distributed the resultant chicks between the other blocks to boost and even out sample sizes.

Part of the agreement with the neighbouring landowners at Rarewarewa required us to first reduce the possum population with cyanide in order to reduce the risk of farm dogs encountering dead possums containing 1080 in the surrounding farmland. A total of 95 possums were killed on 25 and 26 July 2010. Between 27 July and 12 August, four fills of non-toxic cereal baits were placed in 96 Philproof bait stations in and around the 76 ha of Rarewarewa Reserve and adjoining private forest, at an average density of 1.3 bait stations per hectare. On 16 August 2010, 4 days after the last fill of pre-feed, 500 g of 10 g RS5 cereal baits containing 0.15% 1080 were placed in each bait station to control rats and remaining possums. Of the 48 kg of baits used, 37 kg of uneaten toxic baits were retrieved from bait stations 7 days later. Rat density was monitored by recording the percentage of tracking tunnels (Gillies & Williams 2015) baited with peanut butter that showed inked footprints of rats on one night each before and after the 1080 operation in Rarewarewa ($n = 25$ tunnels) and 6 km away at Marlow (35°33′ S, 174°06′ E) ($n = 50$ tunnels) to verify that rat density was reduced during the poison operation.

In the 2010 breeding season, 21 kiwi chicks were radio-tagged at Rarewarewa. One chick dropped its transmitter when about 66 days old, but was re-found by a trained kiwi dog 19 days later and returned to the sample as an 85 day old chick, thus giving a total of 22 tracking periods. Of the 21 chicks, 13 wild-hatched chicks were tagged at 2–85 days of age, and eight ONE chicks were released at 14–19 days of age. At Riponui, 18 wild-hatched chicks were radio-tagged at 4–95 days old and six ONE chicks were released at 16–22 days old. At Purua, the non-treatment site, we radio-tagged 10 wild-hatched chicks at 3–82 days old and released 11 ONE chicks at 17–26 days old. Survival of chicks in Rarewarewa in 2010 was also compared with that of 66 chicks radio-tagged at the site over the preceding five breeding seasons (2005 to 2009).

Results

Riponui trial

Although there was no direct monitoring of the effect of the 1080 operation on rats or possums, many were found dead; a feral cat was found dead close to a partially eaten possum carcass and two freshly dead stoats were found during kiwi monitoring immediately after the operation. All three predators were presumed to have died from secondary poisoning, but were not tested for pesticide residues.

The Kaplan-Meier estimate of 56% survival of chicks to 6 months old (Table 1) was significantly better than the 5% survival observed over the previous five breeding seasons (Mantel-Haenszel log rank statistic $Z = 11.1$, $P = 0.001$). The survival at Riponui in 2009 was, however, not significantly different from the 34% ($n = 20$) observed in the three non-treatment (trapped-only) blocks (Mantel-Haenszel log rank statistic $Z = 1.6$, $P = 0.21$). Even though the pulse of toxin provided improved protection for kiwi chicks, six (26%) of the 23 chicks at Riponui were killed by stoats between 19 November 2009 and 24 May 2010. The ongoing predator trapping in and around Riponui killed only one stoat in the year after the pulse of toxin (in March 2010).

Rarewarewa trial

At Rarewarewa, the rat tracking index dropped from 18% of tunnels before the 1080 operation to 4% afterwards, but remained similar at Marlow over the identical 'before and after' sampling nights (44% cf. 48%). This indicated that a good proportion of the rat population had been killed during the 1080 operation, even though bait station density of 1.3 per hectare was lower than would be needed to achieve a very good knockdown of rats, and a total of only 11 kg of toxic bait was eaten.

The 62% survival of chicks to 6 months old at Rarewarewa (Table 1) was the highest recorded since 2004, but was not significantly different from that recorded (45%, $n =$ 66) over the preceding 5-year period (Mantel-Haenszel log rank statistic $Z = 0.6$, $P =$ 0.43). In this treatment block, we lost just two of 22 (9%) chicks to stoat predation during the breeding season (in January and March 2011) following use of 1080. In 2010, the 20% survival of chicks in the non-treatment (trapped-only) site 3 km away at

Table 1. Annual Kaplan-Meier estimates of % kiwi chick survival to 6 months old (and sample size) for three forest patches used in this study.

Breeding season	Riponui	Rarewarewa	Purua
2002	100 (6)	34 (11)	– (0)
2003	60 (6)	60 (14)	– (3)[a]
2004	20 (5)	79 (17)	– (11)[a]
2005	0 (3)	49 (12)	42 (12)
2006	0 (2)	33 (19)	30 (11)
2007	0 (3)	45 (15)	0 (1)
2008	0 (7)	48 (13)	32 (12)
2009	56 (23)	43 (7)	50 (6)
2010	33 (24)	62 (22)	20 (21)

Predators were trapped in all areas every year, but a short pulse of 1080 was additionally used at Riponui in 2009 and at Rarewarewa in 2010 (shaded cells).

[a]Survival estimates could not be obtained from Purua in 2003 or 2004 because all chicks were removed to pest-free island crèches for later reintroduction to the mainland.

Purua (Table 1) was significantly worse than at Rarewarewa (Mantel-Haenszel log rank statistic $Z = 5.8$, $P = 0.016$). At this non-treatment site, 11 of 21 (52%) chicks were killed by stoats and this was significantly worse than the stoat predation losses observed at Rarewarewa (Fisher exact test, $P = 0.003$). Over the preceding five breeding seasons (2005 to 2009) there had been no significant difference in chick survival at Rarewarewa (45% of 66) and Purua (35% of 42) (Mantel-Haenszel log rank statistic $Z = 1.7$, $P = 0.19$).

The Kaplan-Meier estimate of 33% chick survival at Riponui in 2010 (Table 1), one year after 1080 use, was intermediate between and not significantly different from the treatment (Rarewarewa) or non-treatment (Purua) sites. The outcome in 2010 was also intermediate between the results from the previous year (56%, Mantel-Haenszel log rank statistic $Z = 2.6$, $P = 0.11$), and from the years 2004–2008 (5%, Mantel-Haenszel log rank statistic $Z = 2.5$, $P = 0.11$). Although the 2010 result was lower than hoped for, when the 2 years after the 1080 operation are combined, the overall survival to 6 months old (45% of 47) was very much better than the 5% survival observed during the preceding five breeding seasons (Mantel-Haenszel log rank statistic $Z = 8.2$, $P = 0.004$).

Discussion

Control of untrappable stoats

Trapping grids, or lines that followed suitable contours, roads or forest edges, to control stoats have been established in many government and community conservation programmes in New Zealand. The scale of trapping effort has grown from tens or hundreds of hectares in the 1980s and 1990s (e.g. Dilks et al. 1996; Robertson et al. 2011) to thousands or tens of thousands of hectares (e.g. Hegg et al. 2012; Robertson & de Monchy 2012). King et al. (2003) predicted that variation in the trappability of individual stoats would mean that removal campaigns will select for animals that tend to be trap shy; however, this advice has not been acted upon by many conservation managers in New Zealand.

The significant decline in the survival of kiwi chicks in the four study blocks, from a peak of 67% in 2003 to 24% in 2008, under a trapping regime with a constant density of traps and similar baits and lures, but with a reduction and then increase in frequency in trap checks, indicated a growing problem for kiwi chicks and, hence, kiwi populations in these areas. Leslie matrix analysis, similar to that used by Robertson & de Monchy (2012), showed that chick survival to 6 months old had to exceed 20% in order to maintain the population (H Robertson, DOC, unpubl. data), and so the 24% survival in the seventh year of trapping was dangerously close to this minimum target.

We suspected that one or more untrappable stoats had become established in the area, especially at Riponui, and that these resident stoats were killing most kiwi chicks produced there. Unfortunately, we had no tracking tunnel or camera trap data to support our suspicion, but if stoats were untrappable they may well have been unwilling to enter tracking tunnels. Camera traps could have provided independent data on the presence of resident stoats. With a density of about one trap per 10 ha in the forest patches where the kiwi chicks were resident, there were sufficient traps available to ensure any resident stoat would have access to one or more traps, and so it seemed that the stoats were disinterested in the lures and baits in traps, or were actively avoiding the traps. The results of the first toxic bait trial showed that the resident stoats were efficiently removed, presumably as a result of secondary poisoning after eating rats and possums killed by 1080 used during a very short pulse of baiting. The discovery of a dead feral cat and two dead stoats immediately after this operation was very unusual, because none had been found dead in the other 15 years during which we have worked at least monthly in this block. Only two stoats had been trapped in the block in the preceding 12 months (in February and March 2009).

The results of the second trial indicated that the benefit from the single pulse of 1080 used a year earlier at Riponui was short term, because chick survival dropped from 56% to 33%; however, even this lower rate of chick survival was well above the 20% survival needed to grow the population. In the 2010–2011 season, 11 (46%) of 24 chicks radio-tagged at Riponui were killed by stoats between 7 November 2010 and 15 May 2011. On 7 December 2010, PJG saw a female stoat and at least three young kittens hunting in the heart of the block, yet only four stoats were trapped there between August 2010 and July 2011 (one in each month between November 2010 and February 2011). These observations suggest stoats quickly established a territory at Riponui soon after the poison pulse, and/or that the combined poisoning and trapping had failed to remove all resident stoats even at a density of one trap per 10 ha.

The results of the second trial helped to confirm the observations from the previous year. This time, with improved sample sizes, we were able to show a significant difference in chick survival between the poisoned and nearby unpoisoned block, and stoat predation of kiwi chicks in the poisoned block was virtually eliminated after treatment.

Although we had to infer what was happening with the local stoat population through the survival rate of kiwi chicks, our two trials provided a good conservation outcome for kiwi and the results were consistent with our suspicion that some untrappable stoats had become resident within the area subjected to long-term trapping.

Management implications

Managers of conservation or game bird programmes that rely solely on long-term trapping to control stoats or other cautious and intelligent predators should be aware that the probability of an animal entering a trap or bait station is highly variable (King et al. 2003, 2009). Some animals are naturally wary of traps or other artificial structures or have learned to actively avoid them (i.e. they find but do not enter traps or bait stations), perhaps because of a near-miss or seeing/hearing another animal being caught, or are wary of objects with human scent on them. These wary animals will not be killed in traps or by toxic baits in bait stations and, if they are actively avoiding artificial objects or human scent, they may not even show up in standard monitoring or indicator techniques such as inked footprint tracking papers placed in tunnels.

Without ongoing conservation outcome monitoring of the kiwi we were trying to protect beyond the first 3–4 years of landscape-scale trapping, we would have assumed that the ongoing trapping programme was still highly successful. It was only because we wanted to measure the effect of decreasing the frequency of re-baiting that we continued to monitor the survival of kiwi chicks. Had we ceased our chick monitoring programme, as was done at Moehau Kiwi Sanctuary, we would have been oblivious to the developing problem in our study blocks. The lack of improvement in the survival rate of kiwi chicks when trapping frequency increased to 3-weekly rather than monthly led us to try an alternative (secondary poisoning) approach.

We recommend that managers of all long-term trapping programmes consider using a periodic pulse of a completely different pest control method that does not rely on the same behaviour of the target species to reach a kill trap (which, in our case, was by entering a wooden tunnel) or by eating a toxic bait. Here, we suggest that survival of kiwi chicks improved because some or all resident stoats were secondarily poisoned after toxic baits were made available to rats and possums for a very short period.

Both 1080 and brodifacoum are two commonly-used toxins that very effectively control rat and possum populations, and also secondarily poison animals that kill and eat intoxicated rats or scavenge rat and possum carcasses. Some other rodenticides and possum poisons (such as diphacinone and cyanide) are very effective in controlling their target pests, but have a low to medium risk to scavengers and so are unlikely to have a secondary poisoning benefit by controlling other pests, particularly stoats (Fisher et al. 2004). Compound 1080 can be used by only licensed handlers and requires very strict conditions for its use, mainly due to its high toxicity to dogs and threat to livestock. Brodifacoum and its derivatives, in its various trade names, is widely available from supermarkets and agricultural stores, and has no particular conditions attached to its use except that the DOC will generally not allow it to be used in mainland reserves because it is a very persistent toxin that can bioaccumulate in the tissue of non-target wildlife and hence pose a risk to human health through consumption of contaminated game meat (Eason et al. 1999). If brodifacoum is used on private land, it is best presented in very short pulses rather than in sustained programmes where secondary poisoning of native wildlife, or contamination of game animal products, could be an issue.

Research is needed to determine how current trapping practices may induce stoats to actively avoid traps in tunnels. It is possible that other designs of predator traps (such as the A24 trap, www.goodnature.co.nz), that rely on the target species reaching upwards for a bait rather than entering a horizontal tunnel, may be an effective alternative to pulsed toxin use in areas where toxins are deemed unacceptable (e.g. where threatened wildlife or livestock may be at risk of primary or secondary poisoning).

The 2011 registration of para-aminopropiophenone (PAPP), a vertebrate pesticide for the control of stoats and feral cats in New Zealand (Eason et al. 2014), offers considerable promise for kiwi conservation for the future because these two introduced predators can be targeted specifically rather than relying on trapping or secondary poisoning. Delivery mechanisms that work at a landscape scale and are safe to non-target species have yet to be fully established. If delivered only in tunnels or bait stations, as the current registration allows, some pests may still avoid being poisoned if they are naturally averse to entering artificial structures.

The key message from our work is that conservation managers should periodically vary their pest control methods to reduce the possibility that they are selecting for individuals that are not able to be trapped or directly poisoned because they are disinterested in the lures or baits, or are actively avoiding lures, baits or traps. The worst scenario would be if active avoidance by stoats has a genetic component, meaning that control activities may be inadvertently selecting for 'super pests' that are behaviourally resistant to trapping and/or primary poisoning. Another important message is that wildlife managers need to monitor their pest control programmes at least periodically to ensure that they are still achieving the same conservation outcomes they may have achieved initially.

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Disclosure statement

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