Mortality of North Island tomtits (*Petroica macrocephala toitoi*) caused by aerial 1080 possum control operations, 1997-98, Pureora Forest Park

R. G. Powlesland, J. W. Knegtmans[1] and A. Styche[2]
Science and Research Unit, Department of Conservation, P.O. Box 10-420, Wellington, New Zealand
[1]Present address: 1 Trent Street, Taradale, Napier, New Zealand
[2]Present address: 5 Newcombe Crescent, Karori, Wellington, New Zealand

Abstract: Aerial poisoning operations with carrot or cereal baits are used to control brushtail possum (*Trichosurus vulpecula*) populations in New Zealand forests for ecosystem conservation and to stop the spread of bovine tuberculosis to cattle and deer herds on adjacent farmland. Although various measures have been implemented to reduce the incidence of bird kills, dead birds continue to be found after poison operations. Colour-banded North Island tomtits (*Petroica macrocephala toitoi*) were monitored in treatment and non-treatment areas in Pureora Forest Park to determine the costs and benefits of aerial 1080 possum poisoning operations to tomtit populations. The August 1997 operation (carrot baits with very little chaff, 0.08% w/w 1080, 10 kg ha^{-1}), resulted in 11 (79%) of 14 tomtits disappearing, but none of nine from the non-treatment area. Whether the birds died of primary or secondary poisoning is unknown. No tomtits in either treatment or non-treatment areas disappeared following the August 1998 operation (cereal baits, 0.08% w/w 1080, 5 kg ha^{-1}). The carrot bait operation resulted in almost all possums and rodents being killed, but a few possums and rodents survived the cereal bait operation, apparently because of a gap in bait distribution. During the 1997/98 nesting season, tomtit pairs in the 1997 treatment area had high nesting success (80% of nests fledged chicks, mean of four fledglings per nest). Even so, by the following spring it seemed that the population had not recovered to its pre-poison level. Further research on this topic is warranted, the priority being to monitor tomtit mortality during more aerial 1080-cereal bait operations in order to assess the likely risks of using those baits.

Keywords: North Island tomtit; *Petroica macrocephala toitoi*; 1080; sodium monofluoroacetate; carrot baits; cereal baits; colour bands; mortality; nesting success; Pureora Forest Park.

Introduction

Over the past 30 years there have been increasing attempts to reduce brushtail possum (*Trichosurus vulpecula* Kerr) populations in New Zealand because of the damage they cause to indigenous forest ecosystems (Atkinson *et al*., 1995), and because they are a vector of bovine tuberculosis (Tb) to cattle and deer (Livingstone, 1994). Currently, one method of reducing possum densities involves aerial broadcasting of carrot or cereal baits containing sodium monofluoroacetate (Compound 1080), which on average achieves a population reduction of greater than 90% (Eason *et al*., 1994; Morgan *et al*., 1997).

As well as possums, rodent populations, particularly those of the ship rat (*Rattus rattus* L.), are known to suffer high mortality (87-100%) during aerial 1080 possum poisoning operations (Innes *et al*., 1995). As ship rats eat seeds, invertebrates, lizards, and birds and their eggs (Innes, 1990), including the eggs and young of North Island tomtits (*Petroica macrocephala toitoi* Lesson) (Brown, 1997), the major reduction in rat densities, albeit temporary, is a beneficial by-product of aerial possum control operations for forest ecosystem conservation.

Birds, including native and endemic species, have been found dead after aerial possum control operations (Spurr and Powlesland, 1997). Various procedures have been implemented to reduce the number of birds killed during aerial 1080 operations. These include the sieving out of small fragments of bait or 'chaff' that birds are more capable of swallowing, dying baits green so that they are less attractive to birds, adding cinnamon which acts as a repellent to birds but not possums, and reducing application rates on the assumption that it will reduce bird-bait encounters

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

North Island tomtits have been found dead after 1080 possum poisoning operations, whether carrot or cereal baits were used. This was particularly so in the 1970s when the poison was applied to unscreened carrot baits (Harrison, 1978a,b; Spurr, 1981, 1991). In one such operation (30 kg ha^{-1}, 0.06% w/w 1080) in Cone State Forest, Southland in September 1977, no tomtits were seen or heard two weeks afterwards (Spurr, 1981). In spite of removing chaff and adding cinnamon in an attempt to repel birds, dead tomtits are still found after aerial 1080 possum poisoning operations using carrot or cereal baits. For example, dead tomtits (number unknown) were found after an application of Wanganui No. 7 cereal baits (5 kg ha^{-1}, 0.15% w/w 1080) in the Hunua Ranges in June 1994 (J. Fanning *in* Spurr and Powlesland, 1997). Landcare Research staff working in the Waihaha forest block, Pureora Forest Park, in August 1994 immediately after an aerial application of screened carrot baits (15 kg ha^{-1}, 0.08% w/w 1080) did not see or hear any live tomtits (Nugent *et al.*, 1996). At Tahae, Pureora Forest Park, five tomtits, two of which were colour-banded, would regularly approach to be fed mealworm (*Tenebrio molitor* L.) larvae in early September 1996 (Powlesland *et al.*, 1998). Following an aerial carrot bait operation (15 kg ha^{-1}, 0.08% w/w 1080) during 17-18 September, apparently containing much chaff (Lorigan, 1996), none of these tomtits approached for mealworms. Between 19 and 26 September, no tomtits were seen or heard in the treatment area, but they were evident beyond it. Two recently-dead tomtits were found in the treatment area following the poison operation; both tested positive for 1080 in muscle samples (Powlesland *et al.*, 1998).

The finding of dead poisoned birds gives no indication of the effect of possum control operations on bird populations. Poisoning may replace other causes of mortality, such as winter starvation, or may be additional to them (Spurr, 1991). If poisoning represents an additional source of mortality, it may have considerable impact on the species' population dynamics. This would be particularly true in forests where bovine tuberculosis is endemic in possums, as control operations will be carried out regularly, often at two- to five-year intervals.

The objective of this study was to determine the costs (tomtit mortality during poison operations) and benefits (improved nesting success and recruitment following poisoning of introduced mammalian predators) of aerial possum control operations using 1080 baits, carrot in 1997 and cereal in 1998, to North Island tomtits in Pureora Forest Park. As well as monitoring tomtit mortality after each operation, and breeding success following the 1997 operation, possum and rat populations were monitored before and after each poison operation.

Methods

Study areas

The study areas (treatment and non-treatment for each poison operation) were selected because they contained sufficient numbers of tomtits and were reasonably close to Pureora village (Fig. 1). The Tahae study area (non-treatment area in 1997 and 1998), part of the Waipapa Ecological Area, is bounded by Fletcher's Road, the Waipapa River and an extensive area of scrub known as Taparoa Clearing (Leathwick, 1987) (Fig. 1). The site is approximately 100 ha in area, relatively flat at 520-540 m a.s.l., and has not been logged. A description of the forest cover of the study area is given in Powlesland *et al.* (1999). An aerial possum poison operation, using 1080-carrot baits (15 kg ha^{-1}, 0.08% w/w 1080) was carried out here in September 1996 for Tb vector control. Possum density was low prior to the October 1995 poison operation, with 6.2 possums captured 100 trap-nights^{-1} (Powlesland *et al.*, 1999).

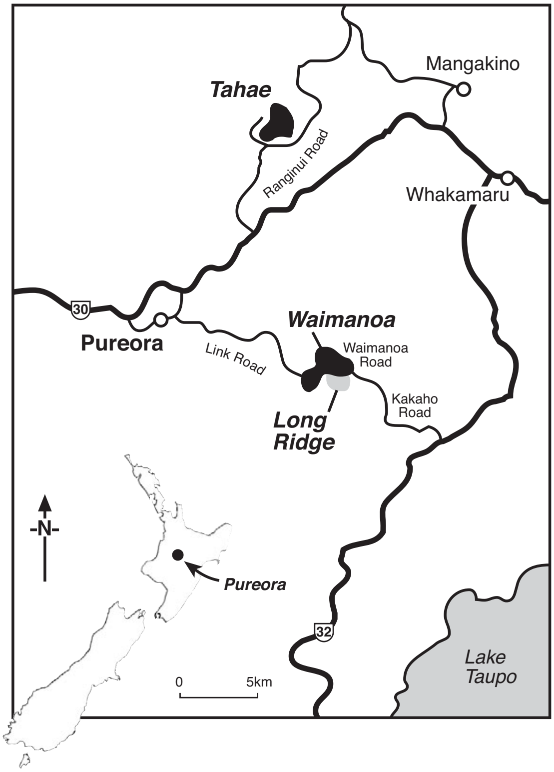

Figure 1. Location of the Tahae, Waimanoa and Long Ridge study areas, Pureora Forest Park.

The Waimanoa study area (treatment area in 1997, non-treatment area in 1998) is bordered by Waimanoa and Link Roads (Fig. 1). Although the study area is approximately 300 ha, only about 100 ha was regularly searched for tomtits. The topography is rolling, with the altitude varying from 700 to 740 m a.s.l. For a description of the forest cover of this study area, see Powlesland *et al.* (1999). There had been no possum control in the study area during the 10 years prior to the operation in August 1997, but 1080 carrot baits were spread over the forest to the north of Waimanoa Road in winter 1993 (aerial 1080-carrot operation, but further details are unknown), and south of Link Road in winter 1994 (non-toxic carrot baits were spread at 10 kg ha^{-1} during late June and early July, and toxic carrot baits (1080 at 0.08% w/w) at 15 kg ha^{-1} during 21 July to 12 August of that year) (Greene, 1998). Possum density was moderate in this study area prior to the poison operation in August 1997, with 23.7 possums captured 100 trap-nights^{-1} in July 1997.

The Long Ridge study area (treatment area in 1998), adjacent to Waimanoa (Fig. 1), is bordered by Long Ridge and Link Roads along the western and northern boundaries respectively, and the headwater streams of Kakaho stream along the eastern and southern boundaries. It is about 200 ha in area, but only about 100 ha were visited regularly to locate tomtits. The topography is rolling, with altitude varying from 650 to 730 m a.s.l. The vegetation of this study area is much the same as that in the Waimanoa study area, with logging in the 1970s having removed some emergent podocarps and created open areas now covered mainly by toetoe (*Cortaderia fulvida* Zotov), wineberry (*Aristotelia serrata* W.R.B. Oliver), bush lawyer (*Rubus* spp.) and tree ferns, such as *Dicksonia squarrosa* Forst. f. and *Cyathea smithii* Hook. f. 1080-carrot baits were distributed over the area in winter 1994. Non-toxic carrot baits were spread at 10 kg ha^{-1} during late June and early July 1994, and toxic carrot baits (1080 at 0.08% w/w) at 15 kg ha^{-1} during 21 July to 12 August 1994 (Greene, 1998).

Aerial possum poisoning operations

The August 1997 poison operation that included the Waimanoa study area encompassed 8,577 ha (the Waimanoa study area was part of the 5077 ha second stage of the operation). Non-toxic pre-feed carrot baits were spread during 5-7 August 1997 at a rate of 5 kg ha^{-1}. The toxic baits (carrot baits, nominally 0.08% w/w 1080) were distributed at 10 kg ha^{-1} on 29-30 August for Tb vector control.

Prior to sowing, bait quality was checked by Department of Conservation staff. Chaff was considered to include any particle able to pass through a sieve of 5-mm square mesh. All 10 samples of bait checked contained less than 0.2% of chaff by weight of the processed carrots, and so were well within the Department of Conservation guideline of 2.5% (J. Mason, Department of Conservation, Pureora, N.Z., *pers. comm.*). There was 9.5 mm of rain during 2-3 September and a further 22 mm on 11-12 September. By the 23 September over 100 mm of rain had fallen since the poison baits had been distributed.

The Long Ridge study area (c. 200 ha) was treated in August 1998 to compare the impacts of a cereal bait possum poisoning operation on tomtits with those of the 1996 and 1997 carrot bait operations. There was no pre-feeding with non-toxic baits; the toxic cereal baits (Wanganui No. 7 baits, nominally 0.08% w/w 1080) being distributed at 5 kg ha^{-1} on 4 August. Two samples of bait were submitted to the National Chemical Residue Laboratory, Upper Hutt with the analyses indicating the toxin level at 0.095 and 0.106%. J.W. Knegtmans (Department of Conservation, Pureora, N.Z.) assisted with the loading of the baits into the hopper slung under the helicopter. He observed that the baits were in excellent condition, appearing to be freshly made, and the bags of baits seemed to contain little dust and fragments. The first two nights after the baits were spread were frosty, followed by a few showers during 7-9 August. On 10 August, 58 mm of rain fell, and by 16 August 200 mm had fallen and the remaining baits on the ground were saturated and disintegrating.

Capture and banding tomtits

Prior to capture attempts, North Island tomtits in all three study areas were fed mealworm larvae in conjunction with tapping the lid against the mealworm container. This noise was made so that the tomtits associated it with being fed, and would learn to approach us for food, rather than us having to search for them. Each tomtit was captured only after it regularly approached us for mealworms. The birds were fed near a mist net and then startled into it. Once captured, each tomtit was fitted with an individual combination of a numbered metal leg band and two or three colour bands (size A, butt bands).

Monitoring tomtits

The survival of each banded tomtit was monitored at least once a week during the study, and every day or second day for a fortnight immediately after each poison operation. In order to find nests to monitor breeding success during the 1997/98 season, if the female of a pair was attracted she was subsequently followed back to the nest. If the male was attracted, often he would go to the vicinity of the nest with mealworms to feed his mate, and we could then follow her back to the nest. Once found, the nest location was marked nearby with track tape, and the nest visited at least every third day to monitor its fate.

Rat population indices

The proportion of baited tracking tunnels containing rat foot-prints was used to provide an index of rat abundance (King and Edgar, 1977; Innes *et al.*, 1995). We assumed that there was a linear relationship between these indices and the actual population densities (Innes *et al.*, 1995; Brown *et al.*, 1996). One hundred tracking tunnels were placed at 50 m along a circuit route through the Tahae study area, and along lines spaced 150 m apart in the Waimanoa and Long Ridge study areas. Each tunnel was baited with peanut butter at both ends and 'set' for one night. Data are expressed as percent 'available' tunnels with rat tracks; those tipped over were deleted from analyses. Foot-print tracking indices in the treatment and non-treatment study areas were taken on the same night to minimise differences due to weather and other variables on rat activity.

Possum population indices

The capture rate of possums in leg-hold traps was used to provide an index of possum abundance (Warburton, 1996). Two trap lines were set in each treatment and non-treatment area, each line consisting of 20 traps spaced at 20 m intervals along a tape line. Lure (a mixture of 5 kg of white flour and 1 kg of icing sugar, no essence), was smeared on the tree above each trap, and re-applied daily if necessary. The trap lines in both areas were operated simultaneously for three dry nights. All trapped possums were killed and disposed of at least 10 m from the traps. The index of abundance (captures 100 trap-nights^{-1}) is corrected for traps sprung but without a captive, and non-target captures (rats) (Cunningham and Moors, 1996).

1080 analysis

A muscle sample from each dead tomtit found was submitted to the National Chemical Residue Laboratory (Ministry of Agriculture & Forestry, Wallaceville

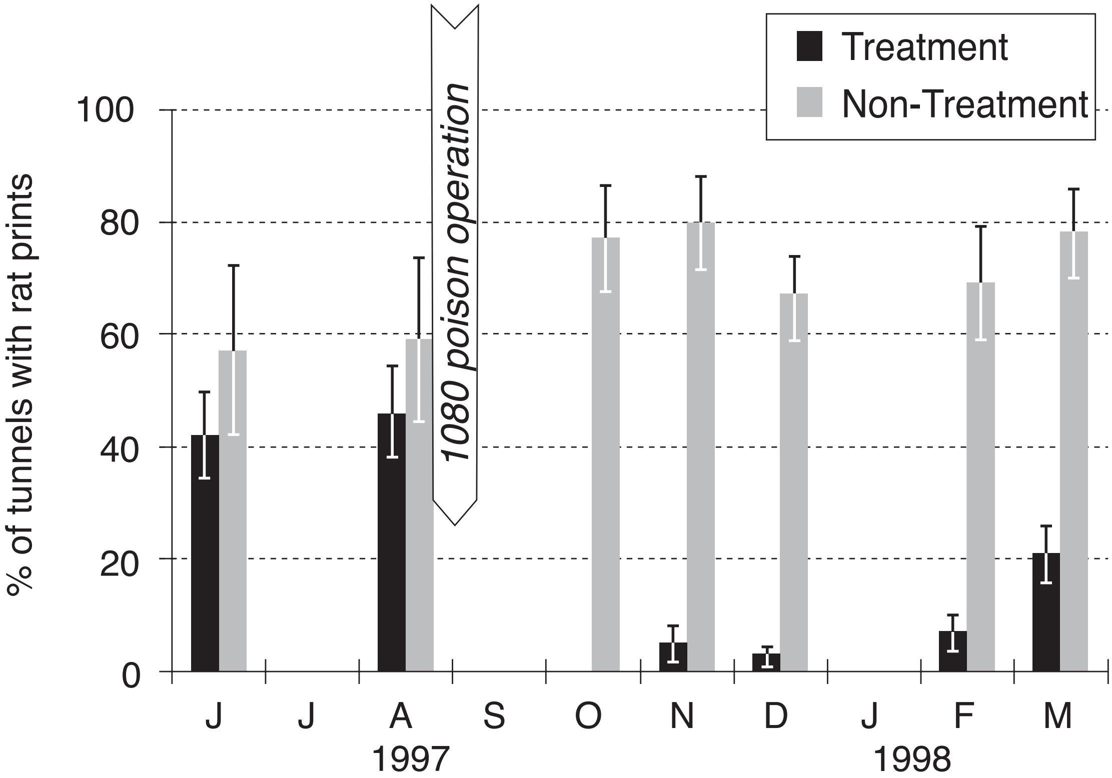

Figure 2. Tracking indices for rat abundance (% of tunnels with foot-prints) in the treatment (Waimanoa) and non-treatment (Tahae) study areas before and after the August 1997 1080 possum poisoning operation, Pureora Forest Park. Bars are standard errors.

Animal Research Centre, Upper Hutt, N.Z.) for 1080 residue analysis. The determination of 1080 presence in the samples was by gas chromatography (1080ToxV2.GC FID) (Hoogenboon and Rammell, 1987), with a detection limit of 0.1 mg kg^{-1}.

Results

1997 poison operation

Impact on possums and rats

The determination of possum indices prior to the poison operation was carried out during July 1997. The two trap lines in the treatment area resulted in 18.5 and 28.8 possums captured 100 trap-$nights^{-1}$, with a mean of 23.7. By comparison, the two lines in the non-treatment area, which had been subjected to an aerial 1080 poison operation in September 1996, together caught one possum; a mean of 0.8 possums captured 100 trap-$nights^{-1}$.

The impact of the August 1997 poison operation on possums was determined by MAF Quality Management staff throughout the 8,577 ha block that baits were distributed over. Fifteen lines were operated in the standard Department of Conservation manner (Warburton, 1996), and two possums were caught, giving a mean of 0.2 captures 100 trap-$nights^{-1}$ (G. Cochrane, MAF Quality Management, Taumarunui, N.Z., *pers. comm.*). No post-operation monitoring for possums was carried out in the non-treatment area.

Rat tracking indices for the treatment area (Waimanoa) were at about 44% during June-August 1997, and at about 58% for the non-treatment area (Tahae) (Fig. 2). Following the poison operation no rats were detected in the treatment area during September and October 1997, and the indices rose to 7% by February 1998, late in the tomtit nesting season. By comparison, rat tracking indices for the non-treatment area during October 1997 to February 1998 remained high (67-80%; Fig. 2).

Tomtit mortality

In the non-treatment study area (Tahae), none of the nine banded tomtits (6 males, 3 females) that were approaching us for a food reward disappeared during the fortnight following the poison drop. However, of the 14 tomtits (10 males and 4 females) in the treatment study area (Waimanoa), 11 (9 males, 2 females) or 78.6% disappeared during the same period. No dead banded tomtits were found, but three dead unbanded tomtits were. Muscle samples (wing and leg combined) from each of the birds tested positive for 1080 (1.9, 1.5 and 1.3 mg kg^{-1}). The oesophagi of the three birds were empty; one of the gizzards contained a seed, another contained invertebrate remains, and the third was empty.

Tomtit nesting success

Eleven nests were found during the 1997-98 nesting season, six in the non-treatment study area (Tahae) and five in the treatment area (Waimanoa). Four (67%) of the non-treatment nests were successful, one was abandoned for no obvious reason, and the other failed due to predation. By comparison, four (80%) of the five nests found in the treatment study area were successful, the unsuccessful nest failing due to predation. The difference in nesting success between the two study areas was not significant (Fisher exact test, P=1.00).

Status of population one year later

Because fewer than 50% of the Waimanoa tomtits seemed to be banded at any time during the study it was not possible to accurately map the territories of each male tomtit along the rodent tracking tunnel lines and determine density. However, our impression, based on observations made during work along the tracking tunnel lines, was that there were fewer tomtits present in July-August 1998 than there had been prior to the poison operation in July-August 1997. Over the same period, our observations suggested there was no marked change in density of the tomtit population in the non-treatment area (Tahae).

1998 poison operation

Impact on possums and rats

Possum indices prior to the poison operation were measured during 16-19 July (traps closed because of rain for one night) simultaneously in the non-treatment (beyond the boundaries of the Long Ridge study area) and treatment areas. The two trap lines in the treatment area resulted in 8.8 and 10.7 possums captured 100 trap-$nights^{-1}$, with a mean of 9.7. The two lines in the non-treatment area caught 13.9 and 12.4 possums 100 trap-$nights^{-1}$, with a mean of 13.2.

The possum indices after the poison operation were determined during 18-20 August. The two trap lines in the treatment area resulted in zero and 5.0 possums captured 100 trap-$nights^{-1}$, with a mean of 2.5. By comparison, the two lines in the non-treatment area caught 3.5 and 13.7 possums 100 trap-$nights^{-1}$, with a mean of 8.6.

The rat tracking index for the treatment area (Long Ridge) was at 46% on 21 July 1998, and at 45% for the non-treatment area (Waimanoa) on the same date. On 16 August, when the post-operation rat monitoring was carried out, the index for the treatment area was 9%, and 41% for the non-treatment area.

Tomtit mortality

Banded tomtits that would approach us for a food reward were monitored in two non-treatment study areas in order to increase the number monitored; nine at Waimanoa (6 males, 3 females) and seven at Tahae (4 males, 3 females). None of these birds disappeared during the fortnight following the poison operation. Likewise, none of 14 tomtits (11 males, 3 females) in the treatment area (Long Ridge) disappeared during the same period.

Discussion

Possum and rat mortality during poison operations

The objective of this study was to determine the costs and benefits of aerial possum control operations to North Island tomtits in Pureora Forest Park. There is no point in carrying out an aerial 1080 possum control operation if it results in little or no tomtit mortality but does not kill most possums and rodents. Ideally, for ecosystem conservation in areas inhabited by tomtits, the operation should result in a residual possum trap-catch rate of ≤ 3 possums per 100 trap-nights (Saunders, 1999), a rat tracking rate of ≤ 5% (Powlesland *et al.*, 1999) and insignificant tomtit mortality. Although minimal monitoring was carried out after the 1996 poison operation, indications were that both it and the 1997 operation killed almost all possums. By comparison, three possums were caught along one of the lines operated in the treatment area following the 1998 operation, and none along the other. Based on observations during our movements through the study area monitoring tomtits, we suspect that these possums survived the poison operation because they occupied a small area that did not receive baits, rather than because there were too many possums for the density of baits or that the baits were unpalatable.

Ship rats are competitors with (for invertebrates and fruit) and predators of (taking eggs, chicks and adults) forest birds (Innes, 1990). This species is a major cause of tomtit nesting failure (Brown, 1997). As a beneficial by-product of controlling possum populations for ecosystem conservation, aerial 1080 operations also kill most rats (Innes *et al.*, 1995). Indices of rat populations using foot-print tracking tunnels indicated that the aerial carrot 1080 possum poisoning operations at Pureora in 1996 and 1997 (Fig. 2) reduced rat populations markedly (< 5% tracking rate). As a result of the 1998 operation, the rat tracking index in the treatment area declined to only nine percent. As with possums, rat foot prints were present in tracking tunnels in an area over which baits apparently were not spread, and in a few tunnels at the edges of the study area because baits had to be at least 50 m from roads. Aerial 1080 cereal bait operations can be expected to reduce ship rat populations to an index of less than five percent (Innes *et al.*, 1995).

Tomtit mortality during poison operations

The present study is the first attempt to monitor the mortality of individually colour-banded tomtits during aerial 1080 possum control operations. It was expected that some of the tomtits would disappear immediately after the toxic carrot baits had been distributed because of the findings from two other poison operations on the species (Spurr, 1981; Nugent *et al.*, 1996). However, the apparent magnitude of the mortality in 1996, and the measured mortality in 1997 (79%), were surprising.

Dead tomtits have also been found after aerial 1080 possum poisoning operations using cereal baits. For example, dead tomtits were found after Wanganui No. 7 cereal baits (5 kg/ha, 0.15% w/w 1080) were distributed in the Hunua Ranges, Auckland, in June 1994 (J. Fanning *in* Spurr and Powlesland, 1997). Therefore, the survival of all 14 colour-banded tomtits at Long Ridge, Pureora, in August 1998 following the aerial application of Wanganui No. 7 cereal baits (5 kg/ha, 0.08% w/w 1080) was pleasing. The only obvious difference between this operation and that in the Hunua Ranges was the concentration of the toxin.

Whether the tomtits died of primary or secondary poisoning during the 1080 operations at Pureora is unknown. None of three tomtits necropsied after being found dead following the 1997 operation contained carrot fragments, and neither did two dead tomtits found after the aerial 1080-carrot operation in the Waihaha block, Pureora Forest Park, during August 1994 (P.J. Sweetapple, Landcare Research, Lincoln, N.Z., *pers. comm.*). This does not necessarily mean that they did not die of primary poisoning because tomtits regularly regurgitate pellets of indigestible portions of food (R.G. Powlesland, Department of Conservation, Wellington, N.Z., *pers. obs.*). Therefore, they may regurgitate toxic foods from the crop and/or gizzard during the period between eating them and dying.

Tomtit nesting success

The poison operations during this study at Pureora were planned to be carried out in July-August, just prior to the start of nesting by tomtits. The expectation was that ship rat populations would not recover to former levels before and during the following tomtit nesting season from September to February inclusive (Knegtmans and Powlesland, 1999), and so allow the birds to nest more successfully than if the poison operation was carried out in autumn, as is more usual. During the 1996 and 1997 nesting seasons, rat tracking indices remained below 10% compared with pre-poison levels of 94% in June 1996 and 44% in August 1997 (Fig. 2). While frequent rain in July-August can delay aerial poison operations, the use of toxic baits without pre-feeding with non-toxic baits reduces delays. Cereal bait operations without prefeeding are able to achieve just as high possum kills (>80%) as carrot bait operations involving prefeeding (Warburton and Cullen, 1995; Morgan *et al.*, 1997). The difference in nesting success of some forest bird species at 5% or less rat tracking index with that at 10-20% can be quite marked. For example, North Island robins (*Petroica australis longipes* Garnot) nesting in the Waipapa bait station area, Pureora Forest Park, had 70.6% nesting success (n=34) during the 1996-97 season when rat tracking indices averaged 6.5%, but only 47.6% success (n=42) the following season when rat tracking indices averaged 12% (χ^2=3.18 with Yates correction, d.f.=1, P=0.075) (H.J. Speed, Department of Conservation, Pureora, N.Z., *pers. comm.*).

Tomtit nesting success at managed and unmanaged mainland sites has differed markedly. At Pureora during the 1997/98 season, nesting success at our Tahae site was 67% (1080 operation in 1996) and at Waimanoa was 80% (1080 operation in 1997). In contrast, at Kaharoa, an unmanaged site, only 8% of 26 tomtit nesting attempts were successful (Brown, 1997). Of 16 attempts that Kearton (1979) monitored on Banks Peninsula, an unmanaged site, during the 1977/78 and 1978/79 seasons, only 31% were successful. Thus, aerial 1080 possum poisoning operations can improve nesting success of forest passerines considerably by the substantial reduction in mammalian predator populations.

Recovery of tomtit population

Too small a proportion of tomtits in the Waimanoa study area was colour banded to accurately monitor the recovery of the population following the species' high mortality immediately after the August 1997 poison operation. However, our impression, based on observations while mapping the presence of males along the tracking tunnel lines in July-August 1998, was that the population had recovered to about 75% of its former level. Spurr (1981) found, using 5-minute counts to monitor tomtits in Cone State Forest, Southland, after a carrot bait operation (30 kg/ha, 0.06% w/w 1080) decimated the population, that it took three years for it to recover to pre-poison levels. By comparison, the robin population in the Tahae study area suffered c. 50% mortality during the 1996 poison operation (Powlesland *et al.*, 1999). A year later this population contained more robins and a greater proportion of females than just before the operation.

Following the 1997 aerial poison operation, tomtit pairs were able to rear two broods in a season, and even three broods occasionally (Knegtmans and Powlesland, 1999). With a mean of four chicks per brood, the likelihood of the population recovering from the losses suffered during an aerial 1080 poison operation within a year or two is good.

The finding of high tomtit mortality during two 1080-carrot bait operations and nil mortality during a 1080-cereal bait operation indicates that further research on this topic is warranted. The priority is to monitor tomtit populations during future 1080-cereal bait operations in order to gain replication given that dead tomtits have been found after previous cereal bait operations (Spurr & Powlesland, 1997). Also, our results (high tomtit mortality during carrot operations and no mortality during a cereal operation) are the opposite of what was expected if the birds die from secondary poisoning. This is because invertebrates are found more often on cereal (23% of 6000 baits observed) than carrot baits (12% of 11000) (Sherley *et al.*, 1999).

The tomtit is a resilient species, being a good coloniser of suitable habitat, and pairs are capable of rearing two to three broods in a season when mammalian predators are reduced to very low densities. Under such circumstances the species can quickly replace the losses suffered after a mortality event. However, if 1080-carrot bait operations occurred at three-yearly intervals or less then such a regime may have a long-term detrimental impact on tomtit populations.

Acknowledgements

Our thanks to Fiona Bancroft, Suzie Bettany, Rhys Burns, Paul Cuming, Rob Field, Bruce Keeley, Ian Marshall, Shinichi Nakagawa, Hazel Speed and Marieke van Dijke for assistance with several facets of this project, particularly the mist-netting of tomtits; to Hazel Speed for mealworms when our supplies ran out; to John Mason, Pureora Field Centre manager, for making various facilities and equipment available to us, to the possum crew, especially Ces Koia and Howard Matthew, for items used for operating the rodent tracking tunnels; and to Graham Hickling, John Innes, Eric Spurr and Clare Veltman for improvements to drafts of the manuscript.

References

Atkinson, I.A.E.; Campbell, D.J.; Fitzgerald, B.M.; Flux, J.E.C.; Meads, M.J. 1995. *Possums and possum control: effects on lowland forest ecosystems. A literature review with specific reference to the use of 1080.* Science for Conservation 1. Department of Conservation, Wellington, N.Z.

Brown, K.P. 1997. Predation at nests of two New Zealand endemic passerines; implications for bird community restoration. *Pacific Conservation Biology 3:* 91-98.

Brown, K.P.; Moller, H.; Innes, J.; Alterio, N. 1996. Calibration of tunnel tracking rates to estimate relative abundance of ship rats (*Rattus rattus*) and mice (*Mus musculus*) in a New Zealand forest. *New Zealand Journal of Ecology 20:* 271-275.

Cunningham, D.M.; Moors, P.J. 1996. *Guide to the identification and collection of New Zealand rodents. Third edition.* Department of Conservation, Wellington, N.Z.

Eason, C.T.; Frampton, C.M.; Henderson, R.; Thomas, M.D.; Morgan, D.R. 1994. Sodium monofluoroacetate and alternative toxins for possum control. *New Zealand Journal of Zoology 20:* 329-334.

Greene, T.C. 1998. *The effects of compound 1080 on populations of specific non-target species, Waihaha Ecological Area, Pureora Forest Park, winter 1994.* Science for Conservation No. 69. Department of Conservation, Wellington, N.Z.

Harrison, M. 1978a. The use of poisons and their effect on birdlife. *In: Proceedings of the seminar on the takahe and its habitat,* pp. 203-211. Fiordland National Park Board, Invercargill, N.Z.

Harrison, M. 1978b. 1080. *Wildlife - a Review 9:* 48-53.

Hoogenboom, J.J.L.; Rammell, C.G. 1987. Determination of sodium monofluoroacetate in tissues and baits as its benzyl ester by reacting capillary gas chromatography. *Journal of Analytical Toxicology 11:* 140-143.

Innes, J.G. 1990. Ship rat. *In:* King, C.M. (Editor), *The handbook of New Zealand mammals,* pp 206-225. Oxford University Press, Auckland, N.Z.

Innes, J.; Warburton, B.; Williams, D.; Speed, H.; Bradfield, P. 1995. Large-scale poisoning of ship rats (*Rattus rattus*) in indigenous forest of the North Island, New Zealand. *New Zealand Journal of Ecology 19:* 5-17.

Kearton, P.M. 1979. *The breeding biology and behaviour of the yellow-breasted tit* (*Petroica macrocephala macrocephala*). M.Sc. thesis, University of Canterbury, Christchurch, N.Z.

King, C.M.; Edgar, R.L. 1977. Techniques for trapping and tracking stoats (*Mustela erminea*): a review and a new system. *New Zealand Journal of Zoology 4:* 193-212.

Knegtmans, J.W.; Powlesland, R.G. 1999. Breeding biology of the North Island tomtit (*Petroica macrocephala toitoi*) at Pureora Forest Park. *Notornis 46:* 446-456.

Leathwick, J.R. 1987. *Waipapa Ecological Area: a study of vegetation pattern in a scientific reserve.* Forest Research Institute Bulletin No. 130. Ministry of Forestry, Rotorua, N.Z.

Livingstone, P.G. 1994. The use of 1080 in New Zealand. *In:* Seawright, A.A. and Eason, C.T. (Editors). *Proceedings of the science workshop on 1080*, pp. 1-9. The Royal Society of New Zealand, Wellington, N.Z.

Lorigan, R.D.A. 1996. *Rangitoto Range Tb possum control operation audit report.* Environment Waikato, Taupo, N.Z.

Morgan, D.R.; Batcheler, C.L.; Peters, J.A. 1986. Why do possums survive aerial poisoning operations? *Proceedings Vertebrate Pest Conference 12:* 210-214.

Morgan, D.R.; Thomas, M.D.; Meeken, D.; Nelson, P.C. 1997. Less 1080 bait usage in aerial operations to control possums. *Proceedings of the 50th New Zealand Plant Protection Society Conference:* 391-396.

Nugent, G.; Sweetapple, P.; Whitford, J. 1996. Waihaha after poisoning - what can you see? *Maniapoto Hunters' Newsletter 10:* 5-6.

Powlesland, R.; Knegtmans, J.; Marshall, I. 1998. *Evaluating the impacts of 1080 possum control operations on North Island robins, North Island tomtits and moreporks at Pureora – preliminary results.* Science for Conservation No. 74. Department of Conservation, Wellington, N.Z.

Powlesland, R.G.; Knegtmans, J.W.; Marshall, I.S.J. 1999. Costs and benefits of aerial 1080 possum control operations using carrot baits to North Island robins (*Petroica australis longipes*), Pureora Forest Park. *New Zealand Journal of Ecology 23:* 149-159.

Saunders, A. 1999. *Mainland Islands - a review.* Department of Conservation, Wellington, N.Z.

Sherley, G.; Wakelin, M.; McCartney, J. 1999. Forest invertebrates found on baits used in pest mammal control and the impact of sodium monofluoroacetate ("1080") on their numbers at Ohakune, North Island, New Zealand. *New Zealand Journal of Zoology 26:* 279-302.

Spurr, E.B. 1981. *The effect of 1080-poisoning operations on non-target bird populations.* What's New in Forest Research No. 94. Forest Research Institute, Rotorua, N.Z.

Spurr, E.B. 1991. Effects of brushtail possum control operations on non-target bird populations. *Acta XX Congressus Internationalis Ornithologici:* 2534-2545.

Spurr, E.B.; Powlesland, R.G. 1997. *Impacts of aerial application of 1080 on non-target native fauna: review and priorities for research.* Science for Conservation No. 62. Department of Conservation, Wellington, N.Z.

Warburton, B. 1996. *Trap-catch for monitoring possum populations, version 3.0.* Waikato Conservancy, Department of Conservation, Hamilton, N.Z.

Warburton, B.; Cullen, R. 1995. *Cost-effectiveness of different possum control methods.* Science for Conservation No. 4. Department of Conservation, Wellington, N.Z.