Comparing methods for assessing mortality impacts of an aerial 1080 pest control operation on tomtits (*Petroica macrocephala toitoi*) in Tongariro Forest

Ian M. Westbrooke[1], Nicola D. Etheridge[2] and Ralph G. Powlesland[3]
[1]Science and Research Unit, Department of Conservation, P.O. Box 13 049, Christchurch, New Zealand (E-mail: iwestbrooke@doc.govt.nz)
[2]Tongariro/Taupo Conservancy, Department of Conservation, Private Bag, Turangi, New Zealand
[3]Science and Research Unit, Department of Conservation, P.O. Box 10 420, Wellington, New Zealand

Abstract: This study aimed to estimate the level of mortality of North Island tomtits (*Petroica macrocephala toitoi*) during an aerial 1080 possum poisoning operation in Tongariro Forest, New Zealand, and to evaluate transect-based alternatives to banding for monitoring tomtit populations. The operation used 12 g toxic (1080 at 0.15% weight/weight) cereal baits sown at 3 kg/ha. Transects were established at three neighbouring sites; two within the 1080 poison area, and one outside. The re-sighting of 14 out of 15 banded male tomtits at one site within the 1080 operation indicated that mortality was low. This was backed up by results from a before-after-control-impact (BACI) design to analyse density estimates from distance sampling along transects. We analysed the change in counts of territorial males before and after the operation based on the same transect surveys. This also showed little impact of poisoning on tomtits, and indicated that loss rates greater than 8.4% due to 1080 were incompatible with the data (95% one-sided confidence bound). Counts of territorial males gave a much tighter confidence bound than the banding or distance sampling results. Of the techniques applied, the counting of territorial males appears to have the most promise for providing high-precision estimates of short-term impacts, by taking full advantage of the territorial habits of male tomtits in spring. However, distance sampling shows potential for providing the basis for longer-term monitoring of tomtit populations. The transect-based approaches involved substantially fewer resources than banding for estimating short-term impacts, and offer a considerably less-intensive means of longer-term monitoring of tomtits.

Keywords: aerial distribution; cereal baits; compound 1080; impact assessment methods; mortality; North Island tomtit; sodium monofluoroacetate.

Introduction

The introduced brushtail possum (*Trichosurus vulpecula*) is a serious pest throughout New Zealand because of its detrimental impacts on indigenous forest ecosystems (Department of Conservation, 1994; Atkinson *et al*., 1995; Cowan, 2001), and on agriculture through the spread of bovine tuberculosis to cattle and deer (Livingstone, 1994; Cowan, 2001). The possum's impacts as a folivore on native plants have been well documented, including changes to the composition of some forest communities (Nugent *et al*., 2000; Payton, 2000; Cowan, 2001). It is now also recognised that possums negatively affect some native bird populations (Sadleir, 2000), following evidence that possums eat eggs, nestlings and adult birds (Brown *et al*., 1993; Innes, 1995). Over the past 30 years one method used to reduce possum densities has involved aerial broadcasting of carrot or cereal baits containing sodium monofluoroacetate (compound 1080). This method can achieve a population reduction of greater than 90% (Eason *et al*., 1994; Morgan *et al*., 1997; Veltman and Pinder, 2001).

Native birds, including tomtits (*Petroica macrocephala*), have been found poisoned after aerial possum control operations (Spurr and Powlesland, 1997; Powlesland *et al*., 2000). The tomtit, a small (10–13 g) passerine, is one of three endemic species of the family Eopsaltriidae, the Australasian robins. The North Island tomtit (*P. m. toitoi*) occurs throughout the North Island and on a few of the larger offshore islands (Bull *et al*., 1985). It inhabits a variety of forest habitat types, including mature native forests [(podocarp-hardwood and beech (*Nothofagus* spp.)], second-growth manuka (*Leptospermum scoparium*)/kanuka (*Kunzea ericoides*) scrub, and older stands of exotic plantations (Heather and Robertson, 1996). Tomtits are territorial all year; they forage from ground level to the top of the canopy (Brockie, 1992), and their diet is mainly invertebrates, plus small fruits in autumn and winter (Brockie, 1992; Heather and Robertson, 1996).

Procedures to minimise the number of birds killed during aerial 1080 operations 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, increasing bait size, and reducing application rates on the assumption that it will reduce bird-bait encounters (Harrison, 1978a, b; Morgan *et al*., 1986; Spurr, 1991). Despite these procedures, dead tomtits have been found after aerial 1080 possum poisoning operations. At Tahae, Pureora Forest Park, none of five tomtits (two of which were colour-banded) that had been trained to approach observers to be fed mealworm (*Tenebrio molitor*) larvae was found following an aerial carrot bait poisoning operation (15 kg/ha, 0.08% w/w 1080, apparently much chaff) in September 1996 (Powlesland *et al*., 2000). Similarly, an aerial carrot bait operation (10 kg/ha, 0.08% w/w 1080, very little chaff) at Waimanoa, Pureora Forest Park, resulted in 11 of 14 (79%) colour-banded and trained tomtits disappearing, whereas all nine in the non-treatment area survived (Powlesland *et al*., 2000).

Studies of the impact on tomtits of aerial 1080 operations using cereal baits have yielded varied results. Dead tomtits (number unknown) were found after an application of Wanganui No. 7 baits (5 kg/ha, 0.15% w/w 1080) in the Hunua Ranges in June 1994 (J. Fanning *in* Spurr and Powlesland, 1997). No tomtits in either the treatment (n =14) or non-treatment areas (n=16) disappeared following an application of Wanganui No. 7 baits (5 kg/ha, 0.10% w/w 1080) in Pureora Forest Park in August 1998. All of these tomtits had been colour-banded and trained to approach observers for mealworm larvae.

Given the above results, one objective of this study was to obtain further information about the level of mortality of North Island tomtits during an aerial 1080 cereal bait possum poisoning operation. In addition, because of the high cost of capturing and banding tomtits, a second objective was to determine the suitability of distance sampling (Buckland *et al*., 2001) and territorial male counts as alternative, and possibly more efficient, methods of monitoring tomtit populations.

Study areas

Three study areas, two treatment and one non-treatment, were established on the western side of Mt Ngauruhoe within the Tongariro Forest Conservation Area (Fig. 1). They were located near the edge of a planned 1080 operation, in areas with relatively high tomtit numbers, and ready access. All three study areas have an average annual rainfall of *c*. 1500 ml, and their ambient temperatures range from –10 to 28°C.

Kapoors Road, treatment site 1, was at 830 m a.s.l. (Fig. 1). The vegetation was heavily logged from 1930 to 1950, and the area is now covered by a regenerating mixed broadleaf forest containing occasional emergent Hall's totara (*Podocarpus hallii*), matai (*Prumnopitys taxifolia*), black maire (*Nestegis cunninghamii*), kamahi (*Weinmannia racemosa*) and pokaka (*Elaeocarpus hookerianus*). Interspersed through the forest are relatively open areas of toetoe (*Cortaderia fulvida*), manuka, and five-finger (*Pseudopanax arboreus*). Taurewa Loop, treatment site 2, was at 790 m a.s.l. (Fig. 1). The vegetation at this site is of mature matai and Hall's totara forest that was selectively logged during the 1930s. This forest patch abuts pine (*Pinus radiata*) forest at one end and farmland at the other. Access Road No. 3 was the one non-treatment site (Fig. 1), and was at 718 m a.s.l. The vegetation is similar to that at Taurewa Loop, having been logged during the 1940s, but also includes extensive open patches containing cabbage trees (*Cordyline australis*). It is bordered by pine forest and native forest.

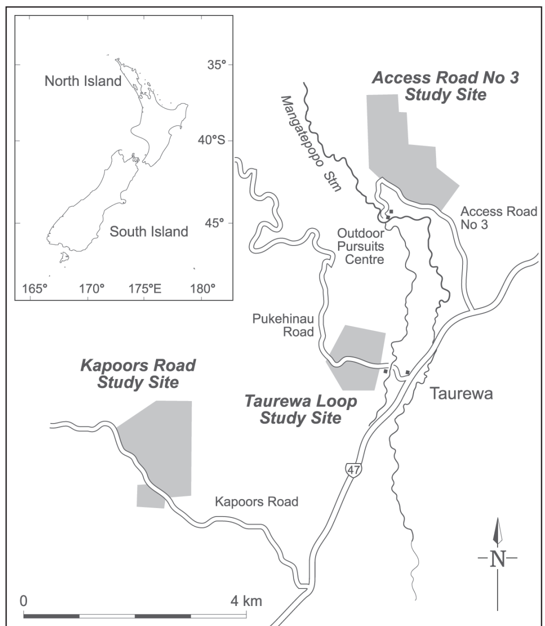

Figure 1. Location of study sites in central North Island, New Zealand.

Methods

1080 operation

Two kg/ha of non-toxic cereal baits (12 g baits) were aerially broadcast on 13 and 14 September 2001 over the 19980 ha operational area of Tongariro Forest, including our Kapoors Road and Taurewa Loop study areas, to train the possums to consume a novel food. Toxic (1080 at 0.15% w/w) cereal baits at 3 kg/ha were applied over the same area on 19 September 2001. This compares with sowing rates of 5–10 kg/ha of cereal baits in the early 1990s (Morgan, 1994). Baits were delivered by aircraft using differential GPS (global positioning system) to ensure that baits were evenly spread over the operational area, that baits were not dropped beyond the operational boundaries, and that sensitive areas within the operational area were excluded (e.g., the Owhango water supply catchment area). There were nine nights without rain after the drop which ensured baits retained their toxicity. During 19–30 September, 32 mm of rain fell, and 100 mm was reached on 6 October (climate data from National Institute of Water and Atmospheric Research Ltd.). At this point, baits were considered non-toxic.

Residual trap-catch of possums

The capture rate of possums in leg-hold traps (number caught per 100 trap-nights) was used to provide an index of possum abundance using the methods set out in the National Possum Control Agencies' national trap-catch protocol (National Possum Control Agencies, 2001). The reported pre-operational trap-catch result (± nominal 95 percent confidence interval half-width) was 6% ± 1.5% (*n* = 1080 trap-nights). The post-operational result was 0.1% ± 0.3% (*n* = 1080 trap-nights). The result for 18 trap lines in the aerial operational area was 0%: no possums were caught in the aerially treated area, but there was one sprung empty trap.

Banding and monitoring of tomtits

Male tomtits were captured at the Kapoors Road treatment study area, and the non-treatment study area, Access Road, during April–August 2001. They were caught with mist-nets set up along or near the transect lines used for the distance sampling and counts of territorial males. Tomtits were attracted into mist-nets by playing calls and full song of their local dialect. An attempt was made to capture every second territorial male along each transect. Once captured, each tomtit was fitted with an individual combination of a numbered metal leg band and three colour bands (two bands per leg, size A butt bands).

The birds were banded over several months prior to the possum poisoning operation, so during the three weeks before the distribution of the toxic baits, we searched for each banded male to determine whether he was still alive. The post-operational monitoring of these males to determine survival began a fortnight after the poison drop, and lasted for 25 days. In order to see some of the males during the pre- and post-operational monitoring it was necessary to play taped calls and song to attract them to the observer. Banding searches took place separately from the distance sampling.

Distance sampling

Distance sampling is a method of estimating the absolute density of a population, based on accurate distance measurements of all individuals near a line or at a point. For a detailed description of the theory pertaining to distance sampling, as well as field design and methods, see Buckland *et al*. (2001). We used the line transect method of distance sampling, each transect being set up along a compass bearing, and its length measured using a hip-chain. Each transect was 250 m long, with a gap of 100 m between transects along the same compass bearing. The start, finish and 50 m intervals along transects were marked with flagging tape, and the markers numbered. Based on observations of banded males, tomtit territories were estimated to be less than 100 m wide. Therefore, parallel lines of transects were 200 m apart to ensure that no territory was crossed by more than one transect. To obtain the required minimum of 50 tomtit detections (birds seen or heard) per sampling effort (Buckland *et al*., 2001), 20 transects were established at each study site (Fig. 1). Observations were made when the weather was dry, when there was little or no wind, and between 0800 and 1300 hours (few calls or song were heard in the afternoon in winter). While walking along a transect, we recorded any tomtit seen or heard within 50 m of the transect, its perpendicular distance to the line (an estimate) and, where possible, its sex. Prior to and during a pilot study, the two people who did the field observations learnt to recognise tomtit calls and song, and to accurately estimate the distance of birds from the line by measuring distances using a hip chain.

The pre-operation distance sampling at each of the three study sites was carried out during 27 August–6 September 2001. Post-operation sampling took place during 3–27 October 2001, beginning two weeks after the toxic baits were broadcast on 19 September. Distance sampling was carried out twice along each transect during both the pre- and post-operation sampling periods. In addition, distance sampling was carried out three times at each of the Kapoors Road and Access Road sites during a pilot phase of the study, between 28 May and 6 June. The layout of the transects was adjusted slightly after the pilot phase to avoid the 50 m margins on either side of roads where no bait was dropped.

Territorial male counts

To estimate the number of territorial males along each transect, locations of all males seen or heard giving full-song were noted relative to transect markers. This estimate was done while carrying out the distance sampling and while searching for banded males during the pre-operational period of the study (27 August– 7 September). These counts were made in all three study areas. The same procedure was followed during the post-operational monitoring period (3–27 October 2001). During both periods, each transect was walked 3–5 times. Based on these sets of information, we made a single estimate of the number of territorial males adjacent to each transect for the pre-operational period, and another separate estimate for the post-operational period.

Statistics

This study was designed primarily to assess the techniques — with limited replication, selection of sites constrained by a planned poisoning operation, and no control over the application of treatment to the sites. Therefore the results of the study refer only to the specific study sites and cannot be generalised on statistical grounds to wider areas. The design was based on the before-after-control-impact (BACI) approach common in environmental monitoring (Manly, 2001).

In analysing the banding, territorial counts, and distance sampling results, the aim was to establish estimates, with confidence bounds for the maximum, of the relative loss of tomtits in the treatment areas compared with the non-treatment. Therefore the difference, before and after, was contrasted between the treatment and non-treatment sites. Where appropriate, the average of the two treatment sites was used. In each case a one-sided 95 percent confidence bound for the maximum possible impact consistent with the data was used. Confidence intervals for the banding results were established by an "exact" binomial approach. For comparison, similar bounds were calculated for the previously reported results from Pureora Forest Park (Powlesland *et al*., 2000).

For distance sampling, once an appropriate model for the detection function and data grouping was established, density estimates were analysed using a permutation approach to test for significance and to create a confidence bound for the impact (Manly, 1997). This approach requires fewer assumptions than an ANOVA. For a permutation test for a significant difference in the contrast of change in tomtit densities, first the actual contrast was calculated. Under the null hypothesis of no change in density, the four density estimates at each of the three sites could be permuted (giving 6 distinct permutations at each site, and 216 in all). The value for the contrast could then be compared with the distribution of values of the contrast based on the permutations, to see whether it was consistent with the null hypothesis. A similar approach was used to create a confidence bound, by finding the largest size of hypothesised effect which fails to be rejected in a hypothesis test.

The differences between the territorial male counts for each transect were analysed using a bootstrap approach (Manly, 1997) on the contrast mentioned before to establish a maximum bound for the impact of the treatment. The resampling took place within each site. This approach was used instead of an ANOVA, as the data were highly discrete, with the differences only taking values –1, 0 and 1.

Table 1. Results from tomtit banding for this and previous studies.

Location	Reference	Year	Bait	Sowing rate (kg/ha)	1080 toxicity (% w/w)	Tomtits observed after/before	Point estimate of loss	95% confidence bound for loss*
Pureora Forest Park	Powlesland *et al.,* 2000	1996	Carrot	15	0.08	0/5	100%	>60%
		1997	Carrot	10	0.08	3/14	79%	>53%
			Non-treatment	-	-	9/9	0%	<28%
		1998	Cereal	5	0.15	14/14	0%	<19%
			Non-treatment	-	-	16/16	0%	<17%
Tongariro	This study	2001	Cereal	3	0.15	14/15	7%	<28%
			Non-treatment	-	-	15/15	0%	<18%

*One-sided 95 percent confidence bound using an "exact" binomial approach.

Results

Survival of banded male tomtits

Before the possum control took place, 15 banded male tomtits were present in each of the Access Road (non-treatment) and Kapoors Road (treatment) study sites. During the post-operational monitoring, all 15 were seen in the non-treatment area, and 14 of the 15 tomtits were seen in the treatment area. This provides a point estimate that 6.7% of tomtits died in the treatment area during the fortnight following the possum poisoning operation, possibly as a result of poisoning. Statistical analysis shows that there could not have been a loss of greater than 28% of tomtits, from an "exact" one-sided 95% confidence bound based on a binomial distribution. The banding results, together with those from earlier studies, are shown in Table 1.

Distance sampling

Model selection is an important aspect of gaining results from distance sampling. There are three choices to be made, based on the features of the data and centred on estimating the detection function: whether to stratify the data for fitting the detection function; what shape detection function to use; and what grouping of distances to use in data to estimate the detection function. The tomtit distance data displayed some particular features which are shown in the histogram for the pilot, pre-treatment and post-treatment phases (Fig. 2). The pilot data were not included in the density estimates, but are important for showing changes in the distances recorded through time.

The most evident feature of Figure 2 is the "bow-wave", that is a tendency for distance observations to peak about 7–9 m or more away from the line. We interpret this as resulting from tomtit avoidance of the observer, meaning the birds that initially were near the line were observed away from the line, rather than remaining quiet and being missed. Tomtits moved in response to the observer, but not to any great extent. It appeared that they moved slightly as the observer walked along the transect line. There was variation in the type of movement between individuals. Some birds moved closer, others moved away, and some were not disturbed by the observer at all. The distances were never great if the birds did move, and observers were confident they detected almost all birds on or near the line; that is, the bow wave is a true representation of the birds' response. Therefore to fit the detection function, we pooled the distance data into three wide groups (up to 15 m, 16 to 25 m, and over 26 to 35 m). We ignored recorded distances greater than 35 m in the distance sampling analysis.

The distance histograms also show a changing pattern (Fig. 2). The data from the pilot survey in late May and early June have a very clear peak in the 6–8 m range, and decline steadily from that peak. The pre-treatment data from late August and early September show a similar peak but drop off more slowly and unevenly with distance. By October, however, the peak appears to have moved to 12–14 m, and there are a lot more records of distances greater than 20 m. This pattern fits in with the known seasonal pattern of tomtit song — with mainly quiet calls in winter, and increasing frequency of louder territorial song production by males through spring (Heather and Robertson, 1996).

The groupings used in the distance analysis ensured the peaks were included in the first group. Further, we tried fitting detection functions to the pre-treatment and post-treatment data using models that pooled between the periods, and models that stratified data for the two periods. Based on minimum AIC, the preferred model stratified by period, with a half-normal shape for the detection function. The results for this model are given in Table 2.

The impact of the treatment was estimated as an average change of –0.09 (a reduction of 3% of the average density) in the treatment sites compared with the non-treatment site. This impact is not significant on a permutation test. Moreover, none of the alternative Distance models examined indicated significant impacts of the treatment. From the data in Table 2 we calculated a 95% upper confidence bound on the impact as –1.05, i.e., a 36% reduction in tomtit density was the maximum compatible with these results.

Data collected on the sex of birds during distance sampling show that records were predominantly from males, with 79% recorded as males, 3% as females, and 18% unidentified.

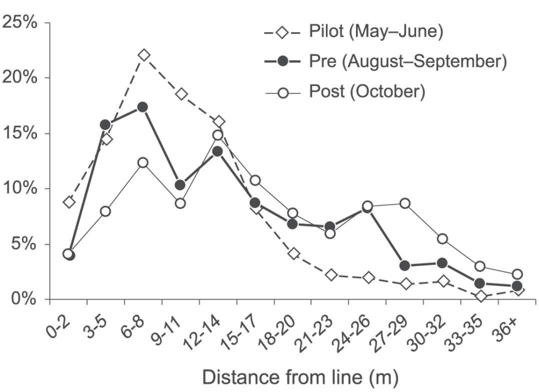

Figure 2. Percentage of distance sampling observations in 3-metre distance classes, for three phases of the study: pilot (May–June 2001, *n* = 368), pre-treatment (August–September 2001, *n* = 439), and post-treatment (October 2001, *n* = 425).

Table 2. Tomtit results from banding, distance sampling and male territorial counts by site and pre/post-treatment. Observations that could have been affected by the treatment are shown in bold.

	Non-treatment	Treatment	
	Access Rd	Kapoors Rd	Taurewa Loop
Sightings of banded male tomtits (after/before)	15/15	**14**/15	-
Distance sample density estimates (birds per ha)[1]			
Pre-treatment	3.15, 3.63	3.42, 2.70	3.43, 3.77
Post-treatment	3.06, 2.22	**2.52, 2.27**	**2.77, 2.39**
Average change by treatment	–0.75	–0.84	
Average territorial male counts per transect			
Pre-treatment	2.65	2.65	1.9
Post-treatment	2.55	**2.35**	**2.1**
Average change by treatment	–0.1	–0.05	

[1]Tomtit density estimates from distance sampling. There are two density estimates for each category, from the replicates of distance sampling. The model for a half-normal-shaped detection function used data pooled into three groups (0–15, 16–25 and 26–35 m), stratified between pre- and post-treatment.

Table 3. Number of transects, by pre-treatment and post-treatment territorial male counts and by site. Each entry in the grid gives the number of transects with the given combination of pre-treatment and post-treatment counts, indicated in italics, for each site. For example, the 3 in the top left hand corner of the grid shows that there were three transects at Access Rd which had a count of 1 both before and after treatment, while the 1 immediate below it corresponds to a single transect having a count of 2 before and 1 after treatment. The numbers in bold, on the diagonal of the table, correspond to transects with no change.

	Site		Post-treatment count *1*	*2*	*3*	*4*
Pre-treatment count	Access Rd (Non-treatment)	*1*	**3**			
		2	1	**2**	2	
		3		2	**6**	
		4			1	**3**
	Kapoors Rd (Treatment)	*1*	**1**	2		
		2	1	**4**		
		3		3	**5**	
		4			4	
	Taurewa Loop (Treatment)	*1*	**6**	1		
		2	1	**4**	3	
		3			**4**	1

Territorial male counts

Between one and four males were counted per transect, with an overall average of 2.37. Details of all the counts are given in Table 3, and averages for each site before and after the operation in Table 2. Reflecting the territoriality of male tomtits, the counts showed very great stability before and after the operation, with 38 of 60 transects exhibiting no change, and none changed by more than one up or down. The estimate of the poison impact based on the chosen contrast had a point estimate of 0.05, unexpectedly indicating a slightly lower average decrease in the treatment areas than in the non-treatment area. The loss of tomtits would not have been greater than 0.2 per transect, i.e., less than 8.5% of the average transect count, based on a bootstrap 95% confidence bound.

The estimates of treatment impact, as percentages, are summarised: from banding, the point estimate was a 7% decrease (95% upper confidence bound for decrease of 28%); from distance sampling, 3% decrease (36%); and from territorial male counts, 2% increase (8%).

Costs of each technique

The resources required for the techniques can be divided into two categories: those required for banding, and those associated with the transect-based approach: distance sampling and territorial male counts. The banding approach required approximately 480 h for capture, banding and re-sighting of the birds during pre- and post-operational monitoring, plus about NZ$300 in equipment costs, and the short-term use of approximately NZ$2,500 worth of sound and mist-netting equipment. In contrast, the distance sampling method required approximately 384 h of field work (including 220 h for setting up the transects and 65 h for training in field and computer techniques associated with distance sampling), plus NZ$300 in equipment costs, and the short-term use of a range-finder worth about NZ$1,000. The least-costly technique was the territorial male count method, which involved about 260 h of field work including the setting up of transects, plus NZ$300 in equipment costs.

Discussion

This study supports the hypothesis that tomtits are significantly less susceptibile to 1080 poison operations when low rates of cereal bait application are used. The tomtit study of Powlesland *et al*. (2000), performed at a similar cereal sowing rate, also found minimal loss immediately following the bait drop. Tomtit sensitivity to poison operations at high sowing rates of carrots (10–15 kg/ha) has unquestionably been demonstrated in earlier studies at Pureora (Table 1). From the results to date, it appears that low sowing rates (3 kg/ha) of large (12 g) cereal baits has little impact on tomtit populations in comparison to results from carrot bait operations (10–15 kg/ha, 6 g baits) (Powlesland *et al*., 2000). However, recent carrot bait operations have been carried out at 3–5 kg/ha and so further research is required to determine whether this low sowing rate also causes minimal tomtit mortality. Potentially both type of bait and sowing rate may influence tomtit mortality.

Of the techniques applied, the counts of territorial males appear to have the most promise for providing high-precision estimates of short-term impacts of aerial 1080 operations on tomtit populations. In contrast with the other approaches, this takes full advantage of the territorial habits of male tomtits. Further, this approach is based on transects designed to provide distance sampling estimates of population density. Once transects are established, distance sampling can be repeated as needed, for example annually, to provide the basis for longer-term monitoring of tomtit populations. The distance sampling approach appears more attractive for longer-term monitoring, as it provides some robustness against changes in detectability. In contrast, the approach using counts of territorial males requires an assumption of ‘all other things being equal’, which seems reasonable for measuring a short-term impact in weeks, but much less so for monitoring over years. This transect-based strategy was significantly less expensive and provided more precise estimates than the banding approach we also trialled.

Although our study focussed on monitoring male tomtits, we are not aware of any evidence indicating a difference in the foraging behaviour between the sexes that might make females more prone than males to being poisoned during aerial 1080 possum control operations. Tomtits in the central North Island start nesting about mid-September (Knegtmans and Powlesland, 1999), and so some pairs in Tongariro Forest would have been involved in courtship feeding at the time of the poison drop (19 September) and during the following fortnight when tomtit mortality from poisoning was most likely to occur. Therefore, such females were probably at much the same risk of being poisoned as males because they would have received some food from their mates.

We see three areas for further research. First is to carry out annual distance sampling counts at the three Tongariro sites to determine any medium to longer term changes in the tomtit population density. This is planned by the Tongariro-Taupo Conservancy of the Department of Conservation as part of on-going monitoring programmes. Second is to establish the optimal seasonal timing for distance sampling estimation of tomtit population density. From the analysis of all the distance sampling carried out, including pilot work, winter appears an attractive time to gain good distance sampling estimates. Therefore, a series of distance sampling counts at intervals through the winter of 2002 was carried out. Third is to fill in the gap in knowledge about the impact of carrot baits at lower sowing rates, as are now commonly used. The results to date for cereal baits at low sowing rates (high tomtit survival), and carrots at higher sowing rates (low tomtit survival) leaves a significant information gap. This may best be filled by some form of paired comparisons of cereal and carrot baits in a series of field operations.

The case-study evidence, all from operations with successful results as measured by residual trap-catch of possums, that cereal bait operations with low sowing rates and large bait size have little, if any, immediate impact on tomtit populations should be taken into account when planning aerial 1080 operations. This is especially so given the contrasting evidence that carrot operations, at least at high sowing rates, have been shown to impact negatively on tomtits.

Acknowledgements

We would like to thank Anna Grant, Rob Whyman, Craig Mumme and Dan Smale for their major contributions to the field work; to Peter Morton, Cam Speedy, Harry Keys and other staff of Tongariro/ Taupo Conservancy for their assistance and support. We also thank the following for their advice and assistance on statistical and distance sampling issues: Peter Johnston of AgResearch, Invermay; Terry Greene and Michael Ryan of Science and Research Unit, Department of Conservation; Rosemary Barraclough of University of Auckland; Steve Buckland and Len Thomas of Research Unit for Wildlife Population Assessment, University of St Andrews, Scotland. Thanks to Clare Veltman of Science and Research Unit, Department of Conservation, and the referees for their comments on drafts of this paper.

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.

Brockie, R. 1992. *A living New Zealand forest*. David Bateman Ltd., Auckland, N.Z.

Brown, K.; Innes, J.; Shorten, R. 1993. Evidence that possums prey on and scavenge birds' eggs, birds and mammals. *Notornis 40:* 169-177.

Buckland, S.T.; Anderson, D.R.; Burnham, K.P.; Laake, J.L.; Borchers, D.L.; Thomas, L. 2001. *Introduction to distance sampling: estimating abundance of biological populations*. Oxford University Press, Oxford, U.K.

Bull, P.C.; Gaze, P.D.; Robertson, C.J.R. 1985. *The atlas of bird distribution in New Zealand*. Ornithological Society of New Zealand Inc., Wellington, N.Z.

Cowan, P.E. 2001. Advances in New Zealand mammalogy 1990-2000: brushtail possum. *Journal of the Royal Society of New Zealand 31:* 15-29.

Department of Conservation. 1994. *National possum control plan: a strategy for the sustained protection of native plant and animal communities, 1993-2002*. 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.

Harrison, M. 1978a. The use of poisons and their effect on birdlife. *In:* Anon. (Editor), *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.

Heather, B.D.; Robertson, H.A. 1996. *The field guide to the birds of New Zealand*. Viking, Auckland, N.Z.

Innes, J. 1995. The impacts of possums on native fauna. *In:* O'Donnell, C.F.J. (Compiler), *Possums as conservation pests*, pp. 11-15. Department of Conservation, Wellington, N.Z.

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.

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

Manly, B.F.J. 1997. *Randomization, bootstrap and Monte Carlo methods in biology*. Chapman and Hall, London, U.K.

Manly, B.F.J. 2001. *Statistics for environmental science and management*. Chapman and Hall/CRC, Boca Raton, Florida, U.S.A.

Morgan, D.R. 1994. Improved cost-effectiveness and safety of sodium monofluoroacetate (1080) possum control operations. *In*: Seawright, A.A.; Eason, C.T. (Editors), *Proceedings of the science workshop on 1080*, pp. 144-150. The Royal Society of New Zealand, Wellington, 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 useage in aerial operations to control possums. *Proceedings of the 50th New Zealand Plant Protection Society Conference:* 391-396.

National Possum Control Agencies. 2001: *Protocol for monitoring possum populations.* National Possum Control Agencies, Wellington, N.Z.

Nugent, G.; Sweetapple, P.; Coleman, J.; Suisted, P. 2000. Possum feeding patterns: dietary tactics of a reluctant folivore. *In:* Montague, T.L. (Editor), *The brushtail possum: biology, impact and management of an introduced marsupial*, pp. 10-23. Manaaki Whenua Press, Lincoln, N.Z.

Payton, I. 2000. Damage to native trees. *In:* Montague, T.L. (Editor), *The brushtail possum: biology, impact and management of an introduced marsupial*, pp. 111-125. Manaaki Whenua Press, Lincoln, N.Z.

Powlesland, R.G.; Knegtmans, J.W.; Styche, A. 2000. Mortality of North Island tomtits (*Petroica macrocephala toitoi*) caused by aerial 1080 possum control operations, 1997-98, Pureora Forest Park. *New Zealand Journal of Ecology 24:* 161-168.

Sadleir, R. 2000. Evidence of possums as predators of native animals. *In:* Montague, T.L. (Editor), *The brushtail possum: biology, impact and management of an introduced marsupial*, pp. 126-131. Manaaki Whenua Press, Lincoln, N.Z.

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

Editorial Board member: Ian Jamieson

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.

Veltman, C.J.; Pinder, D.N. 2001. Brushtail possum mortality and ambient temperatures following aerial poisoning using 1080. *Journal of Wildlife Management 65:* 476-481.