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Line-transect distance sampling compared with fixed-width strip-transect counts for assessing tomtit (*Petroica macrocephala*) population trends

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Abstract: Distance sampling and fixed-width strip-transect counts were compared as methods for estimating population trends of the tomtit (*Petroica macrocephala*) from late September / early October to early November 2004, before and after aerial 1080-poisoning for control of the brushtail possum (*Trichosurus vulpecula*). Two observers independently recorded the distance and compass bearing to tomtits detected along 36 transect lines in each of two forests (one prefed with non-toxic bait and one not prefed). From these data we calculated (a) male tomtit density in the program DISTANCE and (b) the number of male tomtits within 50 m of each transect line. The number of male tomtit detections increased from September/October to November, probably as a result of changes in bird behaviour. Detections peaked at 21–25 m from the transect lines, most likely indicating that some closer birds stopped singing on approach of an observer and were undetected. The mean detection distance did not differ significantly between observers in September/October but did differ in November, suggesting changes over time in the relative performance of the observers. Thus, several key assumptions underlying distance sampling were not met. The two methods produced similar population trends, indicating no difference in bias. Also, both indicated that poisoning with prefeeding had either no adverse impact on the tomtit population or no greater adverse impact than poisoning without prefeeding.

Keywords: birds; density; density index; sampling techniques; vertebrate pest control

Introduction

The tomtit (*Petroica macrocephala*) is a small, native, sexually dimorphic forest passerine in New Zealand that has suffered mortality following aerial application of bait containing 1080 (sodium fluoroacetate) for control of the introduced brushtail possum (*Trichosurus vulpecula*). Population level monitoring has shown the species to be adversely affected when operations using 1080-coated carrot bait have been preceded by 'prefeeding' with non-toxic carrot bait (Spurr 1981, 1994, 2000; Powlesland et al. 1998, 2000; Westbrooke & Powlesland 2005; Veltman & Westbrooke 2011). Prefeeding with non-toxic bait is done to increase consumption of toxic bait by possums (Coleman et al. 2007; Warburton et al. 2009). There is concern that it may also increase consumption of toxic bait by birds, but this has not been assessed previously. The present study was requested by the Animal Health Board and designed to directly compare the impacts of aerial application of 1080-coated carrot bait with and without prefeeding on tomtit population trends from before to after poisoning.

The impacts of mammalian pest control operations on short-term population trends of non-target bird species have been monitored previously using a variety of techniques. Examples include five-minute point counts (Spurr 1991, 1994, 2000; Miller & Anderson 1992; Empson & Miskelly 1999; Innes et al. 2004), territory mapping (Powlesland et al. 1998, 1999), radio-telemetry (Powlesland et al. 1998), colour banding (Powlesland et al. 1998, 1999, 2000; Davidson & Armstrong 2002), distance sampling (Westbrooke et al. 2003), and fixed-width strip-transect counts (Westbrooke et al. 2003; Westbrooke & Powlesland 2005). When considering techniques for this study we had to consider cost as well as bias and precision. Relevant to this, Westbrooke et al. (2003) found that the strip-transect technique was significantly less expensive than banding (and presumably radio-telemetry), and gave significantly tighter confidence intervals than banding or distance sampling for monitoring short-term population trends of tomtits. The strip-transect technique involves counting the number of birds detected within a fixed distance of transect lines, and the results are expressed as a simple index of abundance, viz. average numbers per transect (Bibby et al. 2000). The technique assumes that birds are equally detectable over time. Line-transect distance sampling, on the other hand, involves recording the right-angle distances of birds from transect lines, allowing estimation of the probability of detecting birds and calculation of bird density, viz. average numbers per

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hectare (Buckland et al. 2001; Broekema & Overdyck 2012). Thus, theoretically at least, distance sampling provides some robustness against potential changes in bird detectability, such as may occur over time. Because there was no added cost, as well as comparing the non-target impacts of 1080-poisoning with and without prefeeding, we also compared fixed-width strip-transects and line-transect distance sampling as techniques for monitoring the impacts.

Methods

The monitoring was undertaken in two c. 1000-ha blocks of forest about 10 km apart, one in Whareorino Forest (38º44′ S, 174º77′ E) and the other in Moeatoa Forest (38º37′ S, 174º70′ E), northern Taranaki. Within each block, we established 36 transect lines, each 250 m long, located systematically along parallel compass bearings in six rows of six transect lines. The first transect line was located randomly but in such a way that all transect lines were within the forest. Each line was marked with numbered plastic tape at 10-m intervals to assist with distance estimation. To save costs, there was no non-treatment block.

Non-toxic carrot bait was applied by helicopter to the Whareorino block at 2 kg ha^{-1} on 26–27 September 2004, and toxic carrot bait surface-coated with 0.08% 1080 (w/w) was applied by helicopter to both blocks at 3 kg ha^{-1} on 12–13 October 2004. This was part of a possum control operation undertaken by the Department of Conservation for the protection of conservation values.

The first bird survey was undertaken in late September / early October 2004, 2 weeks before the possum control operation, and the second bird survey in early November 2004, 3–4 weeks after the possum control operation (Table 1). The weather during the first survey in September/October was wetter and colder than during the second survey in November. However, counts were made only when there was no or little rain or wind. Light rain fell during some counts on 27 September. No counts were made on 28 September because of heavy rain.

Two observers with previous experience in counting birds (KMB and KWD) undertook the surveys. They also spent the equivalent of 2 days training together before the first survey. Within each treatment block, each observer surveyed each transect line once, completing 12 lines per day between 0800 and 1700 hours, for 3 days, before and after the poisoning operation. For each tomtit detected, the observers recorded the horizontal distance to the nearest metre from the start of the transect line to the observer (estimated by eye, with the aid of the 10-m line markers), the horizontal distance to the nearest metre from the observer to the tomtit (estimated by eye or ear, again with the aid of 10 m line markers), the compass bearing from the observer to the tomtit, whether the tomtit was male or female, adult or juvenile, and whether it was first encountered visually, heard singing (territorial song), or heard calling (contact call). The distance measurements and compass bearings to all male tomtits detected were then converted to right-angle distances from the transect lines. A generalised linear models analysis (GenStat 2006) was used to determine whether the calculated right-angle detection distances differed between block, observer, time, and the interaction between observer and time.

The program Distance 4.1 (Thomas et al. 2003) was used to calculate the number of male tomtits per hectare from the right-angle distances to all male tomtits. The model with the lowest AIC value and best visual fit to the data was the half-normal key function with hermite polynomial adjustment, fitted to the data truncated at 50 m and divided into two distance bands (up to 25 m and beyond 25 m). The peak of detections occurred in the first distance band. Unfortunately, there were insufficient distance measurements (average 3.5 per transect line) to estimate the density of tomtits separately for each transect line within the treatment blocks – Buckland et al. (2001) recommend at least 60 measurements – so we could not test the statistical significance of any block or time effects, or their interaction. However, we have used non-overlap of 95% confidence intervals with treatment block means as a surrogate measure of significance.

The number of male tomtits detected within 50 m on each side of each transect line (i.e. in an area of 2.5 ha per transect) was also calculated from the distance measurements and compass bearings recorded above (i.e. from the same data as used for calculating density in the program Distance). As noted by Westbrooke and Powlesland (2005), the strip-transect method does not require detection of all male tomtits within the strip, but does assume that the proportion detected in each time period is consistent in each treatment block. Changes in bird behaviour over time may affect the number of birds detected, but this will not affect the analysis of the treatment impact in

Table 1. Tomtit counting routine before (late September / early October 2004) and after (early November 2004) aerial 1080-poisoning for possum control, Whareorino and Moeatoa forests.

	Date		Observer 1	Observer 2
Block	Pre-poison	Post-poison	Transects	Transects
Whareorino (prefeed)	26 Sep.	7 Nov.	A1–A6	C1–C6
			B1–B6	D1–D6
	27 Sep.	8 Nov.	C1–C6	A1–A6
			D1–D6	B1–B6
	29 Sep.	9 Nov.	E1–E6	F1–F6
			F1–F6	E1–E6
Moeatoa (no-prefeed)	1 Oct.	2 Nov.	A1–A6	E1–E6
			B1–B6	F1–F6
	2 Oct.	3 Nov.	E1–E6	A1–A6
			F1–F6	B1–B6
	3 Oct.	4 Nov.	C1–C6	D1–D6
			D1–D6	C1–C6

our trial provided any behavioural changes are similar in each block. The statistical significance of any changes in treatment block or time effects and their interaction were estimated using a linear mixed-effects model, where block, time, and their interaction were fixed effects and transect lines (within treatment blocks) were random effects (Crawley 2002).

Results

In total, 505 tomtit detections were made (observers, forests, and before and after 1080-poisoning combined); 95% were male, 2% were female, and 3% were unknown sex. Of the males, 98% were first detected by sound (mostly territorial song), 5–100 m from the observers, and 2% by sight, 1–25 m from the observers. Of those recorded as being detected within 25 m of observers, 89% were heard first and only 11% seen first. The percentages identified by sound and by sight were similar in late September / early October and early November. Nine of the 10 females were first detected by sound (contact calls), and all were within 40 m of the observers. Eight of the females were detected in late September/early October and only two in early November. The tomtits of unknown sex were all detected by sound (contact calls) in September/October.

The number of male tomtit detections (from sound and sight) increased from 110 in September/October to 205 in November (i.e. by 186%) in Whareorino Forest (the 'prefeed' block), and from 63 in September/October to 104 in November (i.e. by 165%) in Moeatoa Forest (the 'no prefeed' block). Observer 1 (KMB) made 53% of the detections in September/October and 57% in November.

The number of male tomtit detections (from both blocks and both time periods) peaked at 35–40 m from the observers (shown more coarsely as 31–40 m in Fig. 1), and 21–25 m at right angles from the transect lines (shown more coarsely as 21–30 m in Fig. 2) (see also Appendix 1). The mean right-angle detection distance differed significantly between treatment blocks ($F_{1,516}$ = 14.15, P<0.001) and observers ($F_{1,516}$ = 7.60, P = 0.006) but not over time ($F_{1,516}$ = 1.86, P = 0.174). However, there was a significant interaction between observers and time ($F_{1,516}$ = 4.34, P = 0.038). This was caused by a decrease in mean detection distance (± 95% confidence interval) from the first to second survey by Observer 1 (KMB) (from 32.8 ± 3.6 m to 24.7 ± 2.5 m) and an increase by Observer 2 (KWD) (from 30.1 ± 4.6 m to 34.4 ± 3.9 m).

The density of male tomtits per hectare, calculated in the program Distance, more than doubled from September/October to November in both forests (Fig. 3a). The 95% confidence intervals did not overlap the means between the two time periods in either forest, indicating the increases were significant. The increase in Whareorino Forest (the 'prefeed' block) (225%) was greater than in Moeatoa Forest (the 'no prefeed block') (207%), based on non-overlap of 95% confidence intervals and the means of the two forests in the post-poison survey.

Counts of the number of male tomtits per strip transect also roughly doubled from September/October to November in both forests ($F_{1,70}$ = 45.373, P < 0.001) (Fig. 3b). The increase in Whareorino Forest (the 'prefeed block') (201%) was greater than in Moeatoa Forest (the 'no prefeed' block) (154%) ($F_{1,70}$ = 4.413, P = 0.039).

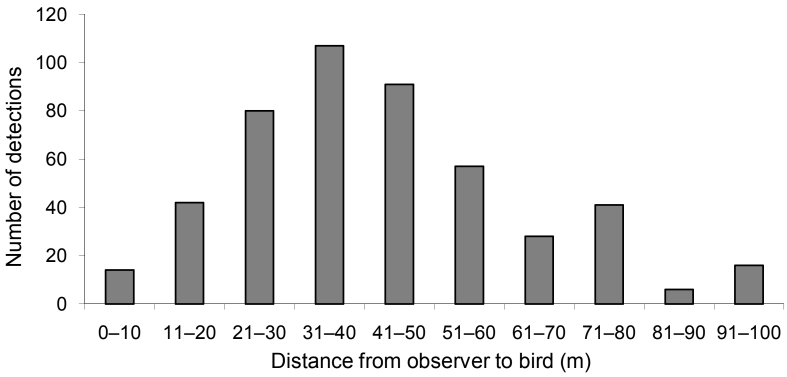

Figure 1. Distance from observer to male tomtits when first detected (n = 482 detections).

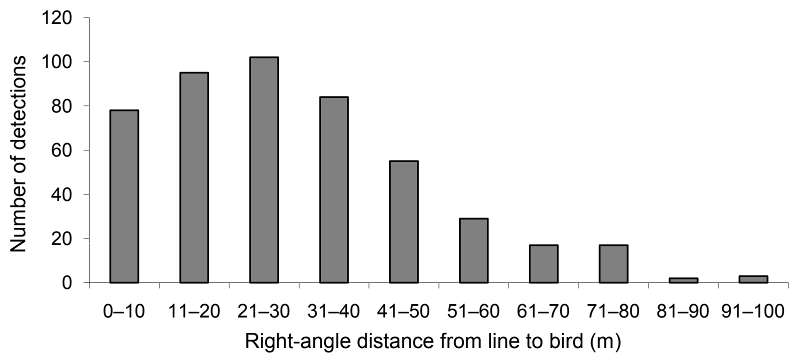

Figure 2. Right-angle distance from transect line to male tomtits when first detected (n = 482 detections). The data were divided into two bands (0–25 m and 26–50 m for analysis in the program Distance).

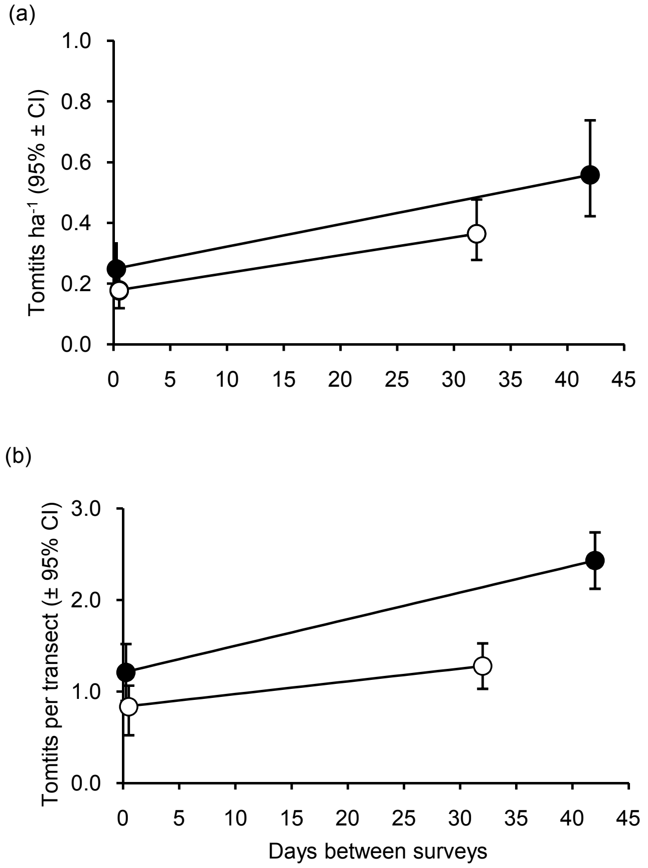

Figure 3. Male tomtits (a) number per hectare estimated from distance sampling, and (b) number counted per transect, both mean ± 95% CI, in the 'prefeed' block in Whareorino Forest (●) and 'no pre-feed' block in Moeatoa Forest (○), before and after 1080-poisoning (which occurred between days 10 and 15).

Discussion

The two methods produced similar trends (i.e. a similar increase) in male tomtit abundance (or index of abundance) between late September / early October and early November, independent of treatment, indicating no difference in bias ('accuracy') between them. However, the increase in male tomtit abundance (or index of abundance) between the two time periods, measured by both techniques, does not make biological sense. The number of male tomtits could not have increased because the species is sedentary (Higgins & Peter 2002) and we did not see any fledglings. The apparent increase in abundance presumably reflected increased conspicuousness of male tomtits as a result of changes in behaviour (e.g. increased number singing and/or increased frequency of singing) from September/October to early November, as the breeding season progressed (the main breeding season is October to December). Thus, in this study, distance sampling failed to account for changes in detectability of birds between the two time periods and did not improve the bias of the population trend estimates derived from strip-transect counts. As expected, the 95% confidence intervals were smaller for transect counts than for distance sampling, indicating that the former was more precise. Westbrooke et al. (2003) also found greater precision for transect counts compared with distance sampling of tomtits.

The high percentage of male tomtits detected by sound rather than sight reflects partly the time of year (i.e. spring, when males sing strongly) and partly the dense vegetation cover and uneven terrain. Detection by sound rather than sight is a phenomenon typical of forest birds (Dawson & Bull 1975; Dawson 1981; Scott et al. 1981; Bibby et al. 2000; Moffat & Minot 1994; Rosenstock et al. 2002; Farnsworth et al. 2005; Kissling & Garton 2006). Even male tomtits close to observers (within 25 m) were mostly heard rather than seen. Few female tomtits were detected, probably because at that time of year most would have been sitting on eggs or chicks (Higgins & Peter 2002).

The change in mean detection distance of tomtits between our two observers over time indicates changes in their relative performance, such as their ability to estimate distance. Such changes have been noted before (Sauer et al. 1994; Kendall et al. 1996; Norvell et al. 2003; Kissling & Garton 2006; T.R. Simons, North Carolina State University, pers. comm.). The ability of observers to estimate distance to birds heard but not seen is known to be affected by several factors, such as observer age, hearing ability, experience, and training, and also distance of the bird from the observer, orientation of the bird (towards or away from the observer), and background noise (including the number and diversity of birds singing or calling near the observer) (Kepler & Scott 1981; Scott et al. 1981; Diefenbach et al. 2003; Kissling & Garton 2006; Alldredge et al. 2007; Simons et al. 2007). Our two observers differed in age, experience, and training, so the changes we observed, over even a relatively short period of time, were perhaps not surprising. In one trial in the USA, even trained, experienced observers overestimated distance to close birds (less than 30 m from observers), underestimated distance to birds at intermediate distances (37 m from observers), and overestimated distance to more distant birds (more than 57 m from observers) (Alldredge et al. 2007). Inaccurate measurement of distance violates one of the key assumptions of distance sampling, namely that the distance to each detected bird is accurately measured or accurately assigned to a distance band (Buckland et al. 2001).

The peak of male tomtit detections 21–25 m at right-angles from the transect lines, and 35–40 m from the observers, indicates that some closer birds stopped singing on the approach of an observer and were undetected, and/or moved away before being detected. Our personal experience suggests the former explanation is most likely, and that tomtits then tend to move toward observers before moving away. Cessation of singing on approach of an observer and unavailability of birds to be detected has been noted for other bird species (McShea & Rappole 1997; Diefenbach et al. 2003). Westbrooke et al. (2003) also found a 'bow-wave' in tomtit detections, but their peak of detections was only 7–9 m at right-angles from the transect lines. We cannot explain why our peak was two to three times further away than theirs, unless the seasonal time difference of about a month between the two studies affected bird detectability (their study was in late August / early September and October, ours in late September / early October and early November). Also, the vegetation in our study sites may have been denser, terrain more uneven, and/or our observers less skilled in their ability to estimate distance to birds heard but not seen. Westbrooke et al. (2003) pooled their data into three distance bands, ensuring that the peak was included in the first distance band. We had to pool our observations into two distance bands to achieve the same result. The apparent inability of observers to detect tomtits on or close to the transect line and the possibility of tomtits on or close to the transect line moving or becoming silent violate two further assumptions of distance sampling, namely that all birds on the transect line are detected (or detected with known probability) and birds do not move (or change behaviour) in response to the observer before detection (Buckland et al. 2001; Farnsworth et al. 2005; Johnson 2008).

Other species in New Zealand likely to violate the assumptions of distance sampling include the North Island and South Island robin (*Petroica longipes* and *P. australis*) and New Zealand fantail (*Rhipidura fuliginosa*), which are attracted to observers, and Eurasian blackbird (*Turdus merula*) and song thrush (*T. philomelos*), which flee from observers. The unsuitability of distance sampling for some species does not mean unsuitability for all species. For the North Island saddleback (*Philesturnus rufusater*) on Tiritiri Matangi Island, both Brunton and Stamp (2007) and Cassey et al. (2007) found line-transect distance sampling produced unbiased estimates of density, but point-count distance sampling did not (Cassey et al. 2007). In line-transect distance sampling, the peak of saddleback detections was on or close to the transect line, implying that all birds on and close to the line were detected (Brunton & Stamp 2007). However, point-count distance sampling overestimated saddleback abundance, perhaps because birds (known to be curious) moved towards observers during the pre-counting period (Cassey et al. 2007). Habitat may also be important. Our study on tomtits was done in dense forest where most birds were heard, whereas the Brunton and Stamp (2007) and Cassey et al. (2007) studies on saddlebacks were done in small forest fragments where all birds were seen.

The high probability that distances to birds heard but not seen were inaccurately measured and the apparent inability of observers to detect tomtits on or close to the transect line, for whatever reason, mean that several key assumptions of distance sampling were not met. The estimates of absolute density (male tomtits per hectare) calculated in the program Distance must therefore be considered unreliable. This is unfortunate because, theoretically, distance sampling provides protection against changes in bird detectability, such as between habitats or seasons (Buckland et al. 2001; Rosenstock et al. 2002; Thompson 2002; Norvell et al. 2003; Farnsworth et al. 2005; Kissling & Garton 2006; Brunton & Stamp 2007; Broekema & Overdyck 2012). However, as with strip-transect counts, distance sampling provides at least an index of population density that can be used for measuring population trends (Johnson 2008). This is especially true in before-after-control-impact (BACI) trial designs.

The slightly greater increase in tomtit detections in the 'prefeed' block compared with the 'no prefeed' block, from before to after poisoning, indicates that poisoning with prefeeding had either no adverse impact on the tomtit population or no greater adverse impact than poisoning without prefeeding. That is, prefeeding with non-toxic bait did not appear to predispose tomtits to eat toxic bait when it became available, or if it did tomtit detections did not decrease as a result. The slightly different trends in tomtit detections in the two blocks could have been a consequence of a number of factors such as differences in habitat, predator density, and weather at the time of the survey. The conclusion that poisoning with prefeeding had either no adverse impact on the tomtit population or no greater adverse impact than poisoning without prefeeding must be regarded as tentative because the trial was unreplicated. Furthermore, we cannot tell whether the treatments (poisoning with or without prefeeding) had any adverse impact or not because, to keep costs down, there was no non-treatment block. We can conclude only that both treatments had the same impact. Previous assessments of prefed 1080-carrot operations have shown short-term adverse impacts on tomtit populations, but the impacts have been less at bait application rates of 3–5 kg ha^{-1} than at 10–15 kg ha^{-1} (Spurr 1981, 1994; Powlesland et al. 1998, 2000; Westbrooke & Powlesland 2005). Thus, the low bait application rate of 3 kg ha^{-1} in the prefed Whareorino operation may have reduced any potential impact on tomtit populations, and also may have reduced the contrast between poisoning with and without prefeeding.

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