

## Distance sampling techniques compared for a New Zealand endemic passerine (*Philesturnus carunculatus rufusater*)

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**Abstract:** The effectiveness of line- and point-transect distance sampling methods was compared for estimating the density of a conspicuous endemic passerine, the North Island saddleback *Philesturnus carunculatus rufusater*, in two forest habitats on Tiritiri Matangi Island, Hauraki Gulf, New Zealand. The reference population abundance in each habitat was calculated through an intensive capture, colour-banding, and resighting effort. Line transects consistently produced unbiased estimates of density for both sites at two time periods (morning and afternoon), and proved to be the most efficient of the distance sampling methods tested. Point-transect methods proved to be biased in this instance, consistently producing overestimates of density for this species, and were unreliable as indices of the small differences in density between habitats. Transect counts conducted from established walking tracks underestimated both density and the variance of estimated density. We conclude that in situations requiring estimates of absolute density for North Island saddleback, a series of randomly positioned line transects will accurately represent the density of individuals. Furthermore, this study highlights the need to pilot distance survey techniques on the species of interest to detect possible violation of the assumptions underlying these methods. We question the widespread use of point-transect counts for censusing avian species without such preliminary investigation, and recommend further comparisons of distance sampling methods in New Zealand with reference populations where opportunity provides.

**Keywords:** density estimation; mist netting; saddleback; Tiritiri Matangi Island

## Introduction

At all levels in the management and conservation of biological populations there is an underlying need for methods that produce accurate and reliable estimates of abundance (Bibby 1999; Witmer 2005). Currently, there is a strong and growing interest in the monitoring of terrestrial breeding bird populations in New Zealand (Spurr & Ralph 2006). However, the accurate and reliable estimation of abundance is elusive and repeatedly confounded by the enormous variation in the environment (e.g. weather, habitat, and season), species behaviour (e.g. individual conspicuousness and activity), and observer ability (Verner 1985; Bibby & Buckland 1987; Verner & Milne 1989; Diefenbach et al. 2003; Norvell et al. 2003). Therefore to yield unbiased estimates of density it is necessary to adopt survey methods that quantify the probability of detecting target species (White 2005).

Recent developments in distance sampling (Thomas et al. 2002; Buckland et al. 2004) have promoted line- and point-transect methods as a relatively inexpensive suite of techniques for estimating the absolute density of animals through modelling the probability of detecting survey subjects. These methods are based on distance measurements of all subjects near a line or a point. The three primary assumptions on which these techniques are founded are: (1) subjects on the line or point are detected with certainty; (2) subjects are detected at their initial location, before any movement in response to the observer; and (3) distances from the line or point to the subject are measured accurately (Buckland et al. 2001). Distance sampling is promoted as producing reliable estimates of animal density in the face of variability such as time of day and level of species activity (Buckland et al. 2001), and thereby may provide a solution in many situations when surveying populations.

Due to these qualities, distance sampling techniques have been the choice of researchers for a large and growing range of animal subjects. For instance, the ability to compare between sites was required by Brown and Boyce (1998) in butterfly surveys. The ease of application, few assumptions, and the probability of detection provided by distance methods led to their adoption in mammal surveys (e.g. Childs et al. 1998; Corn & Conray 1998; Dique et al. 2003; Focardi et al. 2005). Cassey and Ussher (1999) and Buford et al. (1996), each found distance sampling methods to be less stressful and more cost-effective than alternative available methods (e.g. mist netting, nest searching, and mark-recapture) for reptile and bird subjects.

All techniques for estimating wildlife abundance require evaluation across a range of different habitats and species, and very few studies have examined the accuracy of estimates of bird density for New Zealand populations (but see Gill 1980). In this paper we compare the results from line- and point-transect estimates with a reference population of a New Zealand endemic passerine, the North Island saddleback (NI saddleback) *Philesturnus carunculatus rufusater*, within two different habitats. We quantify the effect of count period at point transects (1-min vs 5-min) and the effect of count time (morning vs afternoon) on estimates of density for this species, and briefly compare the time efficiency of line- and point-transect methods. We also explore how the use of existing walking tracks for line transects as opposed to the random placement of the line transects will affect estimates of density.

This study was initially completed to fulfil the requirements of an MSc thesis (Cassey 1997) and has been previously summarised as an advisory note for the Department of Conservation (Cassey 1999). Recent developments in the free software DISTANCE (<http://www.ruwpa.st-and.ac.uk/distance/>) and the synthetic monographs by Buckland and co-authors (Buckland et al. 2001, 2004) have greatly increased the ease with which distance sampling studies can be planned, conducted, and analysed.

## Methods

### Study species

The North Island saddleback is a highly visible species that is not afraid of close approach by humans (Jenkins 1978). This species has weak powers of flight, and individuals are sedentary, carrying out all their activities of feeding, breeding and roosting in the same area of forest (Jenkins 1978). Although they hold their territories, or home areas, all year (Heather & Robertson 1996), they do not actively defend its boundaries by patrolling or skirmishing (Jenkins 1978). Rather, these territories appear to be the product of mutual avoidance behaviour mediated by very loud song. A social system has been described in which the avoidance

component in all aggressive events between birds appears to be greatly elaborated (Jenkins 1978). Territories are also small, which allows the establishment of large populations on small islands (Lovegrove 1996).

North Island saddlebacks are opportunistic in their feeding habits, and are both insectivorous and frugivorous (Lovegrove 1980). Despite being poor flyers, differential use of both horizontal and vertical space is apparent (O'Callaghan 1980), and their habitat requirements are broad, ranging from shrubland to tall forest (Lovegrove 1996). The following characteristics suggest the North Island saddleback would be an excellent candidate for distance sampling methods: they will not flee at the careful approach of an observer, they are not aggressively territorial and therefore will not react strongly in a positive manner (i.e. moving towards an observer as they enter the territory), and they are also both visibly and vocally conspicuous to allow for easy detection. Furthermore, for the purposes of this study, their habitat elasticity means they inhabit a range of habitats, thereby allowing comparisons of density estimation between these. However, we note they are also curious and this may affect their observed distance of detection (see below).

The North Island saddleback population was first established on Tiritiri Matangi Island via translocation in February 1984 (Lovegrove 1996). Since this time the population has been the subject of a large amount of research and was therefore already partially banded at the onset of this study. This population was also obviously numerous enough to provide the minimum number of detections that are generally considered necessary for distance sampling methods (60–80; Buckland et al. 1993). Furthermore, the North Island saddlebacks on Tiritiri Matangi are a closed population (no immigration or emigration), and due to the time of year (autumn and winter), their sedentary nature, and their weak powers of flight, the birds within each of the two study habitats were extremely unlikely to move out of the study patches, thereby biasing the results. It was assumed there was no mortality during the period of censusing.

### Study area

Tiritiri Matangi Island is a 220-ha scientific reserve in the Hauraki Gulf, North Island, New Zealand, approximately 28 km north of Auckland City (36°37' S 174° 54' E; Esler 1978). Two separate study areas were censused on the island. Each of these consisted of a double valley system with a south-west-facing aspect. The smaller site (Kawerau Bush) was a 7.7-ha remnant of fully mature coastal broadleaved canopy and upper understorey. The second site (Wattle Valley) was a 10.5-ha patch of regenerating scrub with dense ground cover and emerging understorey. Differences in the visibility of birds between the sites were expected due to these different habitat structures. The two habitats were c. 1 km apart at their closest point.

### Determining reference population abundance

Resident individuals in each habitat were caught and colour-banded over 6 weeks during April and May 1996 (Austral autumn). Birds were caught either with mist nets or at roost sites. Populations were sampled between breeding seasons when all individuals (juvenile and adult) were expected to exhibit strong site attachment. Resighting surveys were conducted at the end of each week of sampling and for 3 weeks following the banding programme. Surveys consisted of an observer walking random transects and using binoculars to identify every North Island saddleback encountered. Individuals were only recorded if they were seen well enough to identify their bands if these were present. Each resighting effort was conducted as a representative survey of the study area from a random transect-start-point. Individuals could be resighted several times, so that sampling was with replacement and followed an approximation of Bailey's binomial model as described by Seber (1982) and Pollock et al. (1990). The estimates and confidence intervals were obtained from a resighting model that was compiled in Microsoft Excel (GAF Seber, unpublished program).

### Distance sampling

The Department of Conservation, managers of the island reserve, gave permission for placement and sampling of five line-transects in each of Wattle Valley and Kawerau Bush. Transects were inconspicuously flagged with numbered markers, and all markers were removed at the end of the study. The first transect was placed randomly and orientated across the valley using a known compass bearing perpendicular to the direction of the valley. The four subsequent transects were systematically positioned parallel to the first at distances >80 m apart. Because transects virtually covered the entire study area they were positioned across the valley to incorporate most of the habitat variation within each transect so as to avoid bias from between-transect variation in the standard estimate of precision (Cassey & McArdle 1999) used by program DISTANCE (Thomas et al. 1998). As a consequence, we assumed any ordering of the population across the valley was random (Cochran 1977; Thompson 1992).

After flagging and before counts were conducted, transects were left for 4 days to familiarise birds with the minor changes in habitat. Transects were walked at a slow continuous pace and detections were recorded from both visual and aural cues by a single observer (PC). Counts were only conducted in fine weather, as long as less than 0.1 mm of rain had fallen in the previous 24 h and wind was less than Force 5 (Beaufort scale). In total, 64 sampling events were conducted, four of each method (line, track, 1-min point, 5-min point), in each habitat (Wattle Valley and Kawerau Bush), and during each time period (morning and afternoon). Morning counts began between 0700 and 0730 hours and afternoon counts between 1500

and 1530 hours. The order of counts was randomised and no morning-afternoon combination was ever repeated between subsequent days. The sampling alternated each day between the two habitats and counts were completed by the end of July 1996.

Transects were started (and finished) 10 m inside the habitat boundaries to reduce possible edge effects in the distribution of birds between the habitat interior and margins. Transects ranged from 149 to 296 m in length and extended across the entire forest patch. Two previously established walking tracks through Wattle Valley and Kawerau Bush were also used for track counts and were 635 and 350 m long respectively. The walking tracks were never more than 1.5 m wide and were predominantly under canopy cover.

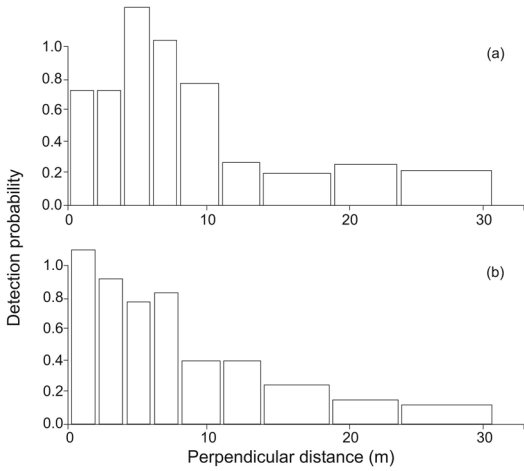
Distance measurements (ranging from 0 to 31 m) were made with a calibrated optical rangefinder. Sightings were grouped in nine perpendicular distance intervals between 0 (<2, <4, <6, <8, <11, <14, <19, <24) and 31 m. As long as detections are correctly assigned to distance categories, general statistical theory indicates very little efficiency is lost by grouping sighting data (Buckland et al. 2001).

During separate replicate point counts, random flagged markers were chosen from each of the five transects. A 5-min wait before beginning the count was used as a standard method to allow birds to adjust to the presence of the observer. Point-transect radii were truncated in the field at 31 m and detections grouped into eight distance categories between 0 (<4, <6, <8, <11, <14, <19, <24) and 31 m. Counts were recorded for 1- and 5-min periods to examine the potential effect of differences in encounter-rates on corresponding density estimates. The first minute of 5-min counts was examined separately for estimating the density from 1-min counts.

The observer (PC) had unimpaired hearing and vision, and was unaware of the actual size of either population at the time of observation. At all times the observer located the individual birds in the initial location at which they were first detected and any birds that obviously flew onto the transect or point were not sampled.

### Density estimation

Detection functions,  $g(y)$ , were modelled based on the histograms of perpendicular and radial distance measurements (e.g. Fig. 1). Appropriate functions were selected through the free software DISTANCE (Thomas et al. 1998) based on the models currently recommended by Buckland et al. (2001) and using manual comparison of goodness-of-fit statistics and Akaike's information criterion (Akaike 1974; Buckland et al. 1997). No data truncation was necessary and in all cases either the half-normal model (with Hermite polynomial expansion) or hazard-rate model (with a cosine expansion) as described by Buckland et al. (2001) provided the best fits to the distance frequency data for both line- and point-transect methods. It was assumed that objects on the line or



**Figure 1.** Example of detection probability histograms for perpendicular distance detections of NI saddleback from (a) walking-track and (b) random-line transects in Kawerau Bush.

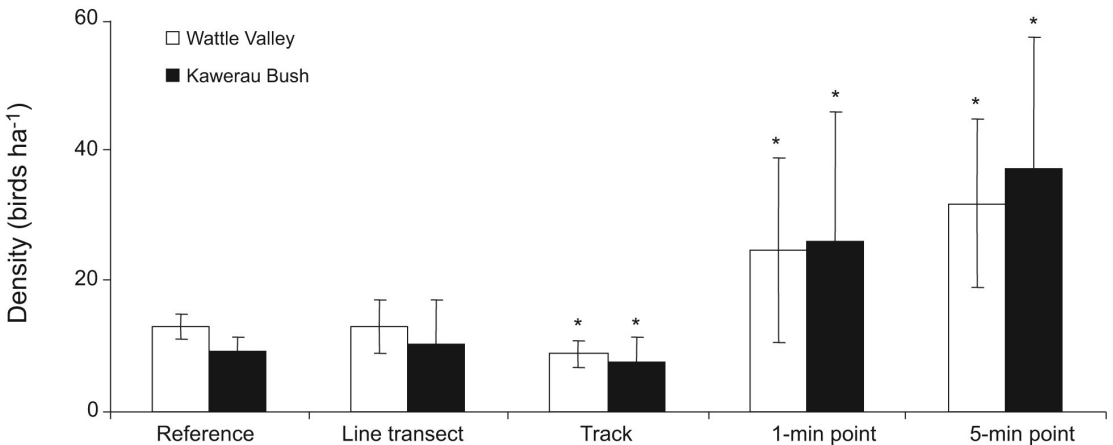
point were detected with certain probability. Individual density functions (and estimates) were calculated for each of the combinations of site, technique, and time. For random line transects (at a single site and for a given time period) the number of transects for the encounter rate estimation was five and the effort per line was four times the line length. For point transects (at a single site and for a given time period) the number of transects for

the encounter rate estimation was five and the effort per line was two randomly chosen survey points. For track transects, program DISTANCE implemented the Poisson assumption  $var(n) = n$  for the situation where a single unit is sampled without replication.

For each site, weighted analysis of variance (ANOVA; mean density weighted by the inverse of the variance) was used to determine the effect of time (morning and afternoon) and method (line transect, track transect, 1-min and 5-min point transects) on estimates of density. Multiple pair-wise comparisons were conducted using multiple range tests to compare treatment means following ANOVA (Day & Quinn 1989). *T*-tests were used to determine absolute deviations between the reference population and density estimates. A 5% level was used for detecting significant differences. All statistical analyses were performed using SAS (SAS Institute Inc. 1994). Quoted density estimates are individuals per hectare with 95% confidence intervals.

## Results

Abundance of the reference population (95% CI) was calculated as 137 (123–156) individuals in Wattle Valley and 72 (65–82) in Kawerau Bush. Reference population density was significantly greater in Wattle Valley than it was in Kawerau Bush (Fig. 2). Resightings indicated that across the two patches more than 90% of birds were banded, and the total number of sightings over the surveys was more than double the reference population (*N*), i.e. each bird was seen on average at least twice.



**Figure 2.** Comparison of pooled densities (birds ha<sup>-1</sup>) between the reference population, and line- and point-transect estimates of NI saddleback density at two sites on Tiritiri Matangi Island, 1996. Asterisks indicate significant differences (*P* < 0.05) between the distance sampling estimate and the reference population for each respective habitat. Error bars are 95% confidence intervals around the estimate.

In total 160 point transects and 96 (random and track) line transects (c. 22 km long) were completed. The time spent counting NI saddleback at both sites was greatest for line transects, but the greatest total time (i.e. count time + travel time between points and transects + waiting periods) was spent doing 5-min point counts (Table 1). There was no consistent difference between the time taken to do 1-min point-transect and line-transect counts. However, whereas almost 100% of the time on line transects was spent counting NI saddleback, only 9–12% of the time on 1-min and 35–43% on 5-min point counts was actually spent counting.

Density estimates were significantly different between distance sampling methods ( $F_{4,4} = 68.5$ ,  $P < 0.001$ ). At both sites, random line transects were the only method that provided density estimates not significantly different from the reference population (Wattle Valley:  $0.01 \pm 0.13$  (estimate  $\pm$  SE),  $t = 0.08$ ,  $P = 0.95$ ; Kawerau Bush:  $0.90 \pm 0.49$ ,  $t = 1.83$ ,  $P = 0.32$ ; Fig. 2). Both point-count methods significantly overestimated the density of individuals at both areas. Five-minute point-transect counts were the most biased of the methods tested, overestimating abundance and producing estimates that were significantly different from all others (Fig. 2).

Despite Wattle Valley having a third more birds per hectare than Kawerau Bush, neither line- nor point-transect methods were able to detect a significant difference in density between the sites ( $F_{1,4} = 0.7$ ,  $P = 0.45$ ). Track-transect estimates from both sites were significantly lower than the reference population density but not the random-line-transect estimates (Fig. 2).

At both sites, time of day made no detectable difference in estimates of density ( $F_{1,4} = 1.97$ ,  $P = 0.23$ ).

## Discussion

The North Island saddleback is a conspicuous and highly vocal passerine species that utilises all vertical sections of a habitat; from the leaf-litter to the canopy. Due to the high proportion of banded birds at the two sites and the number of sightings over the surveys being more than double the reference population, we are confident that resightings served as unbiased references of population abundance (Seber 1982; Brownie 1987; Arnason et al. 1991). Therefore, the reference population density results from this investigation provided a reliable benchmark against which to rate the performance of the line- and point-transect methods for this species.

Of the methods examined in this study only line transects provided consistently unbiased estimates of density, given the differences in detection rate and habitat structure between sites and time of day. Point-transect methods, which have been developed almost exclusively for sampling avian communities (Reynolds et al. 1980; Ralph & Scott 1981; Buckland 1987; Roeder et al. 1987),

resulted in consistent overestimates of density for both habitat types (see also Buckland 2006).

Five-minute point-transect counts were the most biased of the methods tested. Bias resulting from 5-min counting periods has recently been illustrated by Buckland (2006). Longer counting time-periods allow greater opportunity for birds to move within the survey area, and potentially into closer proximity to the observer where they are more likely to be detected. They also increase opportunity for new birds to enter the counting area and for individuals to be counted more than once. The underlying theory of distance sampling assumes each count is 'instantaneous' and individuals are therefore detected, or not, in their initial location before either random or directional movement. Hiby (1986) reported that random movement before detection can be tolerated provided the speed of the observer walking a line transect is appreciably greater than the movement of animals (c.  $3\times$ ). The problem is considerably more serious for point transects, for which the observer is stationary (Buckland et al. 2001). Any subsequent increase in detections close to the centre of a point transect would inflate the ensuing density estimates (Buckland et al. 1993). However, although such factors as movement within the survey area may have contributed to the 5-min estimates being greater than those yielded by the 1-min estimates, these cannot be proposed to explain the overestimation of abundance yielded from the 1-min point transect counts. It is also highly unlikely that double-counting of individuals was a problem in this study, especially during 1-min counts, as on average less than two North Island saddlebacks were detected per point.

When interpreting these results it is particularly important to consider the character of this species. Despite the fact that North Island saddlebacks will not aggressively move towards an observer in an attempt to guard their territory, they are acknowledged to be a curious species (Heather & Robertson 1996). It is possible, therefore, that curiosity led to some more subtle and undetected movement towards the observer during the 5-min pre-count waiting period, before point-transect counts commenced. The absence of a similar movement towards the observer during the walking-line transects would not be unusual as birds are acknowledged to sometimes react differently to a moving or stationary person (e.g. Conant et al. 1981). If such a reactive movement took place then this would have inflated density estimates yielded by the point-transect methods. Although both 1-min and 5-min counting periods were trialled in this study, differing pre-count waiting-time periods were not, and it may also be best for a particularly reactive species to trial a point-count method without a waiting period (e.g. Buckland 2006).

Count periods in previous avian studies have varied from 1 to 20 min, and are typically 1–5 min in passerine surveys (Ralph & Scott 1981). Yet, despite their reputed utility, neither 1-min nor 5-min point methods were able

to adequately record the instantaneous distribution of North Island saddleback in either habitat, or subsequently estimate abundance. Scott and Ramsey (1981) concluded that count periods of different lengths are required for species with dramatically different behaviour such as rates of movement and conspicuousness. Buckland (2006) has recommended a quick count of birds after a prescribed waiting period to yield a 'snapshot' or instantaneous recording of birds 'frozen' in a moment of time, rather than the use of a standard counting time period. In contrast, Marsden (1999) recommended the use of 10-min point-transect counts over line transects for surveying parrots and hornbills in Indonesia, due to the long count periods required to detect these species at zero distance and the unlikelihood of double-counting these conspicuous species. Therefore, it is sensible to assume that such a snapshot should ideally be species specific, developed according to species characteristics. These contradictions also emphasise the absolute importance of determining an appropriate survey method and counting period on a species-specific basis, and the value of piloting survey methods where possible.

Transects along tracks underestimated the true density without being significantly different from random-transect estimates in both study sites. This indicates that the local density of NI saddleback around the tracks may indeed be biased despite the apparently benign character of these. Bias could have arisen because tracks are unrepresentative of habitat features within the sites, or through some form of track avoidance by individuals (Buckland 1985). Such track avoidance has been demonstrated for some non-avian species such as deer (Ward et al. 2004), and can be visibly

discerned from the histograms of detection probability in Kawerau Bush (Fig. 1). Error estimates for walking tracks (Fig. 2) were based on the Poisson assumption (see Methods) and are likely to underestimate the true uncertainty of the estimator  $D$ .

In terms of time- and cost-effectiveness, line transects proved to be the most efficient of the methods used here, as the majority of time spent in the field was used in actively sampling (Table 1). In contrast, the time spent moving between the point transects and on the pre-count waiting period was effectively lost sampling time.

Traditionally, early-morning counts are recommended due to higher bird activity and singing rates (Robbins 1981; Skirvin 1981). Dawson (1981) reported to the contrary, that the 'better' studies suggest extreme times of the day such as dawn will make a substantial contribution to the variance of the counts; the practical alternative being to count over a longer period near the middle of the day (Dawson & Bull 1975). During this study there was no significant difference in bias between morning and afternoon estimates of abundance. However, in sampling situations where time or resources are limited, since afternoon counts generated fewer observations (see also Bollinger et al. 1988), these may not be time- or cost-effective.

Even if absolute biases are large, a counting technique can still be valuable if it tracks changes in population density (e.g. DeSante 1981; Bollinger et al. 1988). At the sampling intensity used (i.e. length of transect lines and number of point counts) none of the methods were able to identify the local (significant) difference in density of a third more birds per hectare at Wattle Valley than Kawerau Bush. Random-line-transect techniques, however, did

**Table 1.** Number of NI saddleback detected during line and point transects at different times (morning and afternoon) at two sites on Tiritiri Matangi Island, 1996. The total effort spent on each count method is included. For line transects the total effort includes the time spent detecting birds and the time traversing between transects. For point transects the total effort includes the 5-min waiting period and the time spent walking between points. Encounter rate is the number of birds detected per minute spent counting.

Site	Method	Time	Encounter	Total effort	Encounter rate (birds minute <sup>-1</sup> )
Wattle Valley	Line transects	a.m.	166	448	0.37
		p.m.	152	419	0.37
	1-min point transects	a.m.	45	420	1.13
		p.m.	40	436	1.00
	5-min point transects	a.m.	148	564	0.74
		p.m.	115	580	0.58
Kawerau Bush	Line transects	a.m.	117	351	0.34
		p.m.	95	365	0.26
	1-min point transects	a.m.	62	334	1.55
		p.m.	47	344	1.18
	5-min point transects	a.m.	112	462	0.56
		p.m.	87	472	0.44

show an (albeit non-significant) higher density in Wattle Valley in contrast to point counts.

The results from this study do not encourage confidence in point-transect methods for estimating absolute density or detecting relative population differences in this species. In contrast, line-transect estimators provided a reliable record of North Island saddleback density at both sites and indicated that with improved precision could possibly also satisfactorily track the small-scale changes common between seasons and habitats. To increase the precision of estimates of the sampling variance it has been subsequently recommended (e.g. Buckland et al. 2001, p. 108) that in future studies a larger number of transects are used to calculate the 'between-sample component' of the overall variance for the estimate of density. In particular, Buckland et al. (2001) have subsequently recommended 20 or more transects within a stratum to estimate the encounter-rate variance accurately. There are also now a range of techniques suggested for increasing the number of transects in an area (such as running a second set of transects perpendicular to the first set, or running different transects with a random starting point on each survey day; Buckland et al. 2001, 2004). In addition, Buckland et al. (2001) provide a method for estimating the length of transects required to achieve a desired coefficient of variation (e.g. 0.10 or 10%). In our case this would require increasing the total length of transects by a factor of more than 10 at both sites (Wattle Valley = 11.8 $\times$ ; Kawerau Bush = 15.8 $\times$ ).

The development of point-transect methods is intimately associated with counting birds yet the very behaviour of birds, namely their highly variable rates of mobility, conspicuousness, and behaviour, can heavily bias estimates of density. In this study, random-line transects produced reliable estimates of absolute density. It is not yet known how species- and habitat-specific these results are, but they indicate that line transects more sufficiently accommodate the behaviour of North Island saddleback than do point transects. Added to their greater time- and cost-effectiveness, random-line transects appeared to provide managers and scientists with a more precise and useful tool for estimating species density than point transects. Recently, Brunton and Stamp (2007) have identified different age-specific seasonal trends in North Island saddleback density between mature and replanted forest patches on Tiritiri Matangi Island. The remarkable congruence between our density results and their recent study for both Wattle Valley and Kawerau Bush at a similar time of year suggests the North Island saddleback population, at least in these two mature forest patches, has remained at a stable maximum over the last ten years (Brunton & Stamp 2007). We strongly encourage the comparison of point- and line-transect methods with other New Zealand reference populations where opportunity provides.

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