Estimating animal abundance by distance sampling techniques

Phillip Cassey
School of Biological Sciences
University of Auckland
Private Bag 92-019
Auckland

Published by
Department of Conservation
Head Office, PO Box 10-420
Wellington, New Zealand

This report was commissioned by the Science & Research Unit

ISSN 1171-9834

Reference to material in this report should be cited thus:

Cassey, P., 1999
Estimating animal abundance by distance sampling techniques. *Conservation Advisory Science Noies* No. 237, Department of Conservation, Wellington.

Keywords: Population estimation, animal abundance, distance sampling technique

Summary

Reliable and repeatable methods for estimating animal abundance are fundamental to the effective study and management of New Zealand species.

New Zealand scientists and conservation managers currently rely on measures of conspicuousness rather than density for indexing the sizes of many New Zealand animal populations.

Distance sampling offers a group of methods which estimate the absolute density of a population from the measured distances from the observer to each observed animal. Implicit to the theory is the idea that a large proportion of the population will go undetected as long as those individuals closest to the observer are detected with certainty.

Distance sampling was assessed in three situations: by computer simulation and in studies of island populations of tuatara *(Sphenodon punctatus)* and North Island saddleback *(Philesturnus carunculatus rufusater)*.

The technique provided estimates of density which proved to be accurate estimates of absolute density. These estimates were comparable with mark-recapture measures but at greatly reduced effort and less disturbance to the animals and environment.

Point counts, when used for estimating absolute density, demonstrated excessive bias for estimating density of saddleback. In this study, point counts proved unable to track the 'true' difference in density between habitats.

Conservation managers and scientists are recommended to adopt methods which will improve their accountability and knowledge of population density and species abundance. Distance sampling techniques should be included as a suite of methods which with further investigation will help advance New Zealand managers and scientists toward this.

1. Introduction

The effective management of animal species is greatly improved by the accurate knowledge of population distribution and abundance. Current practices in New Zealand are restricted by their heavy reliance on methods which are unable to estimate absolute density, or reliably compare the relative abundance of populations between studies, habitats, or species.

During this century, the accurate estimation of animal abundance has developed as a necessary requirement of both ecological research projects and wildlife resource management (Krebs 1985; Soule 1986). The monitoring of species is dependent on methods capable of accurately estimating the size of populations. The theory of population biology and conservation management explicitly requires accurate estimates of abundance to calculate minimum viable and effective population sizes.

The establishment of priorities for species recovery depends on estimates of population density. New Zealand priority setting (Molloy & Davis 1994) calls for accurate estimates of total population size as well as the reliable knowledge of whether populations are increasing or decreasing. Managers and scientists involved in the recovery process need to agree on criteria which incorporate accepted probability of persistence (Tear et al. 1995) and to then effectively monitor populations through their recovery and management.

1.1 ESTIMATING ABUNDANCE

Following the determination of species presence and distribution, two very different measures of abundance can be estimated during the sampling of an animal population. The first is absolute density and refers to a quantitative measure of numbers per unit area. If the relevant area is known, this can be converted into an estimate of population size, or abundance. The second is relative density and refers to population densities relative to a unit other than area, for example, per unit of habitat [skinks per upturned rock], per unit distance [possums per kilometre walked], or per unit time [birds per 5 minute count]. Relative density, is an index to population size and can be used if the actual size of a population is not required. Indices are generally based on the risky assumption that the sample represents a constant but unknown proportion of the population. Relative methods provide no understanding of the actual size of the population.

1.2 CURRENT NEW ZEALAND METHODS

New Zealand methods have been largely restricted to indices of relative abundance [5-minute bird counts, catch per unit effort, trapping counts]. The attraction of such methods is their ease of replication and effort. However, the development of relative measures, especially 5-minute bird counts (Dawson & Bull 1975), has led to their use being extended well beyond the circumstances for which they were initially designed (Cassey & Craig in prep.). Over two decades since Dawson and Bull first published their method it has been concluded that, when interpreting bird counts, it is seldom possible to distinguish the effects of changing density from those of changing conspicuousness (Gibb 1996). Natural variation in terrain and vegetation types between areas can result in very different rates of conspicuousness or catchability. This limits the reliability of counts which are confounded by variation due to habitat, season, and species rather than the primary difference in the density of animals.

1.3 DISTANCE SAMPLING

Distance sampling describes a group of methods which estimate the absolute density of a population based on the observer to animal distance (Buckland et al. 1993). The theory derives from classical closed population sampling, where total counts are performed in representative samples of the larger area. The average of individual counts is then multiplied by the size of the total area being sampled to produce an estimate of absolute density. Distance sampling recognises that, during total counts [for example the well known method of strip transects], the ability to detect animals often declines towards the edge of the transect [i.e. those animals furthest from the observer are the hardest to detect]. Also animals observed outside the boundaries of the transect should not be wasted and left out of the analysis.

By estimating how the probability of detection declines with distance from the observer [e.g. how hard it is to detect animals the further they are away from you], distance sampling can calculate the effective area sampled and use that to convert the number counted to an estimate of density.

When an animal is detected, the distance is measured from the observer to the initial place of detection. Distances are measured either as perpendicular distances from line transects or as radial distances from point transects (Figures 1 and 2). These distances do not have to be measured precisely, and classing the detections into a number of distance classes [5 or more] will not decrease the efficiency of the density estimation procedure.

Detections are used to produce a histogram of detection frequency versus perpendicular distance from the observer (Figure 3).

The central concept of distance sampling is the estimation of the detection function g(y):

g(y) = the probability of detecting an animal, given that it is at a distance y from the random line or point

= prob (detection / distance y) .

It is assumed that animals at zero distance are detected with certain probability [i.e. g(0) = 1, so that animals on the line or at the point are certain to be detected]. Studies indicate that, as distance increases away from the observer, the probability of detection decreases. Variations in the shape of detection functions are expected when the conspicuousness of species varies between observers, habitats, and/or seasons. In practice the specific reasons why functions differ or why animals are undetected away from the observer are unimportant as long as care is taken to ensure that animals at zero distance from the observer are always detected. The method assumes that animals are detected at their initial location. However, experience shows that this is unnecessary as long as the observer attempts to record their location before movement is affected by the observer's presence.

Density is derived from the calculation of parameters directly associated with the form of the estimated detection function. Current methods for estimating the detection function and density are available through program DISTANCE (Laake et al. 1994). Information on distance sampling and free access to the manual and program are available from the Internet web site:

http://www-ruwpa.cs.st-ancl.ac.tik:80/ds.htm]

2. New Zealand studies

Three studies were conducted to assess the accuracy and precision of distance sampling techniques with both natural and computer-simulated populations.

2.1 AN ASSESSMENT OF PROGRAM `DISTANCE'

In the first study (Cassey & McArdle in prep.), simulated populations were used to assess the ability of current methods for analysing distance sampling data [namely program DISTANCE] to produce unbiased estimates of density. Populations were simulated to investigate the robustness of program DISTANCE to changes in the density, distribution, and detection of animals across sampling areas and transects. The simulations were therefore designed to represent situations where habitats varied extensively within a study area. It had been previously suggested (Buckland *et al.* 1993) that habitat homogeneity was an important assumption.

The simulations included two scenarios. The first examined the situation where all the study area was divided into transects, for example counting birds in a habitat remnant, or fish on a rock reef. The second investigated the situation where a relatively small percentage of the area had been sampled and transects could be thought of as a random sample from a population of possible transects.

In both cases, situations were simulated where transects differed in the density of animals and in the observers' ability to detect them. This reproduces the common situation where the study area incorporates local habitat differences and visibility and/or conspicuousness have differing relationships with distance. Despite attempts to confuse it, program DISTANCE performed extremely well in cases of both high density [200 animals per transect] and low density [40 animals per transect]. Density estimates were consistently either unbiased or only minimally biased. The estimate of precision [how reliable the density estimate is] was excessively conservative in the first scenario and slightly liberal in the second. It is discussed later how to design a sampling regime so that the precision estimate will be most applicable.

2.2 ESTIMATING SADDLEBACK ABUNDANCE

The second study (Cassey *et al* in prep.) compared the effectiveness [accuracy, precision, and cost] of line and point transect methods for estimating the abundance of North Island saddleback *(Philesturnus carunculatus rufusater)* in two habitats on Tiritiri Matangi Island. Research was conducted during April - July 1996, and the true densities of populations were known precisely through an intensive capture, colour banding, and resighting effort. Saddleback were abundant, and are highly conspicuous birds which establish well defined territories with a clearly distinguishable vocal maintenance system.

In both habitats, line transects were the only method which provided estimates not significantly different from the 'true' density [P > 0.3] (Figure 4). Both 1-minute and 5-minute point counts significantly over-estimated the 'true' density of saddleback at both habitats [P < 0.05]. Estimates of density from walking tracks were significantly lower than the 'true' density [P < 0.05] though they were not significantly different from line transect estimates. At both habitats, time of day made no detectable difference to estimates of density [P > 0.2] [ANOVA].

The time spent counting saddleback was far greater for line transects at both sites than it was for either period of point count (Table 1). More total time, however, [i.e. count time + travel time between points and transects + waiting periods] was spent in executing 5-minute point counts and there was no difference between 1-minute point counts and line transect counts.

2.3 ESTIMATING TUATARA DENSITY

In the third study (Cassey & Ussher in prep.), the precision and cost of line transect estimates of tuatara *(Sphenodon punctatus)* density on Lady Alice Island were compared with mark-recapture estimates. In contrast to the species sampled in the second study, tuatara are known to violate both the assumptions of no movement in response to the observer prior to initial detection, and absolute detection on the transect line. Mark-recapture assumptions are equally violated, as a certain proportion of the population is essentially uncatchable at each sampling event due to the burrowing habit of tuatara. Methods were therefore assessed as to their differences as indices of density rather than their absolute accuracy.

Mark-recapture methods took twice as many nights to implement and used three times the personnel involved during each line transect sample. Encounter rate [tuatara per transect metre] significantly decreased following the mark-recapture study [P = 0.0005]. An individual was detected on average every 42 metres before mark-recapture and 69 metres after mark-recapture. Line transect estimates of density [95% C.I.] before and after mark-recapture were 17.7 [14.3, 21.9] and 13.6 [9.8, 18.8], respectively. The density estimate from mark-recapture was 15.3 [12.1, 18.6]. Density estimates from line transect and mark-recapture methods were not significantly different [P > 0.35] (Figure 5).

3. Discussion

The persistence of relative density methods for "guesstimating" the abundance of New Zealand wildlife populations has greatly hindered the assessment of the effectiveness of ecological studies and species management. The reliable knowledge of abundance is necessary for all aspects of species management, yet current methods are unable to present results with any level of accuracy and are totally inadequate for the effective monitoring of populations.

Distance sampling is a cost effective method for estimating the absolute density of animal populations which needs to be considered by New Zealand managers and scientists involved in the study or monitoring of animal abundance. The application overseas of distance sampling to a wide range of animal species (cetaceans, fish, birds, large and small mammals [including squirrels, primates, elephants], and insects) and indices of animal presence (nests, tracks and faeces) is an indication of the potential use for the method with New Zealand populations. Distance sampling is especially important as an alternative for species which are traditionally counted with relative methods, namely, introduced and endemic birds, reptiles and mammalian pests.

The ready availability of methods specifically designed for the interpretation and analysis of distance sampling data provides researchers with an important tool for aiding in the summary of their own studies. The accuracy and precision of methods which rely on automated model selection techniques needs to be investigated, so that researchers are made aware of their limits and the practical situations in which methods are likely to 'break down'.

The results from a number of simulated population scenarios analysed by program DISTANCE indicated that if distance sampling data are collected reliably from a homogeneously distributed population it can be expected that estimates of density will be presented accurately and with correct estimates of variance. The precision of density estimates and the accuracy of variance estimates is greatly increased by both the homogeneous distribution of the population [i.e. small variation in number of animals encountered per transect] and the number of transects/points sampled [i.e. preferably more than 10. Note that this does not include resampling of a single transect/point] .

Simulations identified that when sampling a large percentage of the total habitat [e.g. within bush patches on Tiritiri] variance estimates produced by the program DISTANCE will be excessively conservative if there is considerable variation in the number of animals encountered between transects. If it is possible to stratify a habitat [dividing it up by areas of known differences in density], replicate transects must be run within strata. This will provide precision estimates without making restrictive assumptions and avoiding the problems of between-strata variance. Otherwise, if there is a known structural gradient in density within a habitat [such as increasing density from the top of the valley to the bottom], transects may be aligned parallel to the gradient so that encounter rates are similar between transects even though they vary within.

The study into the density of saddleback in two habitats on Tiritiri Matangi Island indicated that random line transects provided a more cost effective and reliable method than point transects for estimating abundance. It was concluded that a random design of replicate transect lines should always be used rather than a single transect along an established track, even when there are small representative walking tracks with considerable canopy cover such as those on Tiritiri Island. Results suggested that track estimators can under-estimate the density of saddleback. With species that are attracted to tracks, the effect will be to overestimate density.

Traditionally the development of point counts in New Zealand has been as a measure of relative abundance or conspicuousness. Combining point count methods with the measurement of distance allows the estimation of absolute density. However, on Tiritiri the results indicated that the behaviour of saddlebacks, in particular their high mobility, could heavily bias the estimates of abundance. Perhaps most alarming was their excessively low efficiency compared with line transects. Despite requiring comparable effort much of it was wasted as waiting or transit time between points. During line transects this time is used to count birds. The confidence intervals in Figure 4 clearly show the reduced precision of the density estimates from point transects [1-minute and 5-minute]. In the study on Tiritiri point transects proved unable to track the 'true' difference in density between habitats.

Our experience of the reliable estimation of population densities from detections based on a combination of visual and aural cues provides strong evidence against Dawson and Bull's (1975) statement that distance sampling methods are useless in New Zealand situations where birds are heard rather than seen. It is concluded that, if observers understand the principles of distance sampling and are experienced with the species and its environment, the estimation of distance, at least into broad distance classes, will not provide any practical difficulties. The program DISTANCE will produce reliable estimates of density, and very little efficiency is lost if measurements are grouped [and assigned correctly] into distance intervals [e.g. 0-5, 5-10, 10-25, 25-40, 40-65, 65-100 metres].

Line transect estimators also proved to be a cost effective relative index for the estimated density of species known to violate both the assumptions of no movement in response to the observer prior to initial detection and absolute detection on the transect line. Despite the problems already mentioned with relative indices, methods need to be developed which can cost effectively monitor differences in tuatara populations. This is made exceedingly difficult when an unknown proportion is underground and essentially undetectable. Distance sampling estimates of tuatara density from a single population on Lady Alice Island were not detectably different from a mark-recapture estimate. However, line transects created less animal stress and less environmental disturbance, and required significantly less cost in time, effort and people.

4. Recommendations

Distance sampling is a cost effective method for estimating the absolute density of many animal populations, compared with relative density methods based solely on animal conspicuousness.

The results from three studies have indicated that distance sampling, and especially line transect estimators, offers considerable potential for the accurate, reliable, and cost effective estimation of abundance in New Zealand animal populations. In all populations where encounter rate is sufficient to generate enough detections, definitely no less than 40 within a study, distance sampling should be investigated for the research, management, and monitoring of population abundance.

The advancement and acceptance of distance sampling techniques in New Zealand will only come from their future study by researchers who are interested in promoting a degree of accuracy and accountability that previous studies have lacked. It needs to be accepted that, if the understanding of animal abundance is important for the future management and monitoring of wildlife resources, the real challenge of finding efficient ways for obtaining accurate estimates of abundance has to be addressed. Distance sampling is one suite of methods which with further investigation will help advance New Zealand managers and scientists toward this.

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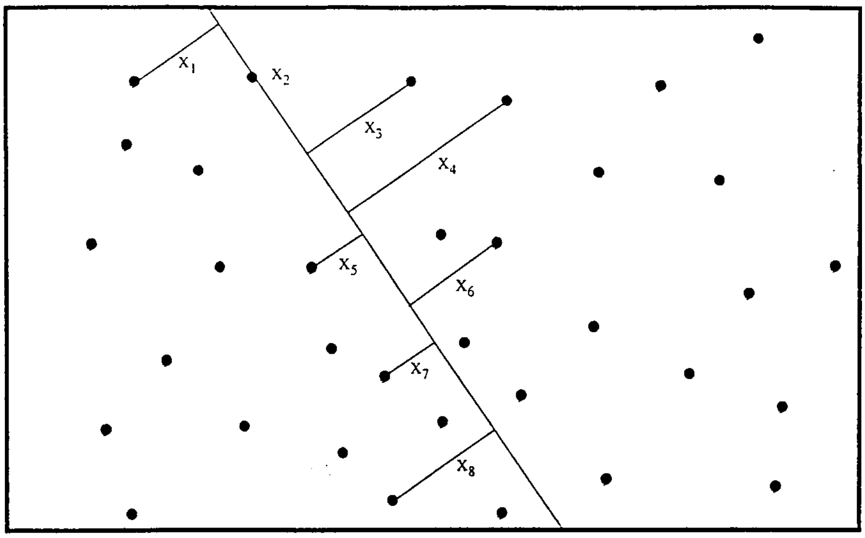

Figure 1. Line transect sampling method showing a single, randomly placed, line of length L. Eight objects (n = 8) were detected at perpendicular distances x_1, x_2, . . ., x_3. In practice, many lines would be used to estimate the population.

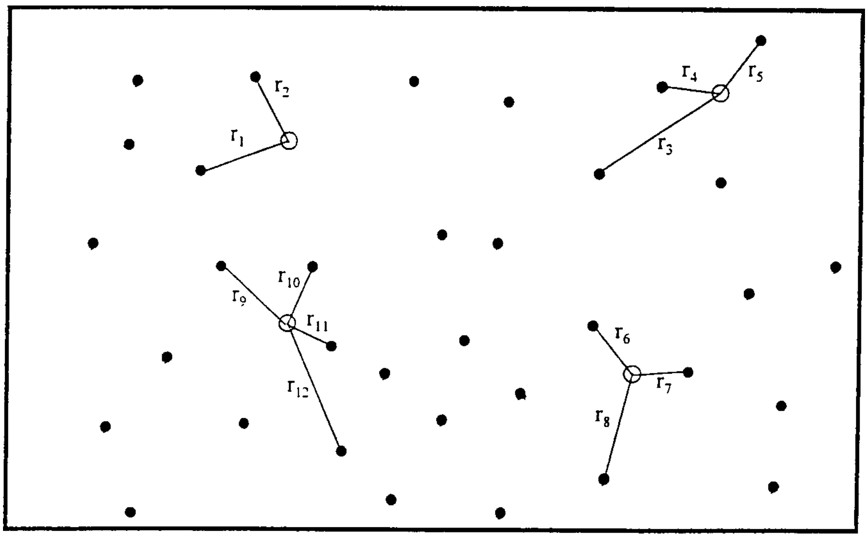

Figure 2. Point transect sampling method showing four randomly placed points (k = 4), denoted by open circles. Twelve objects were detected at sighting distances r_1, r_2, . . ., r_{12}.

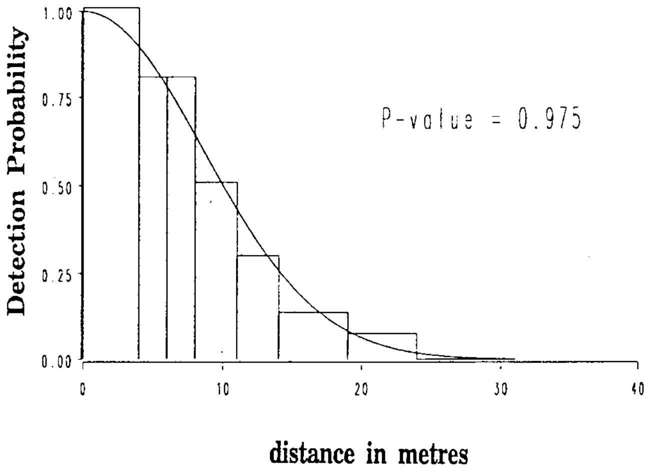

Figure 3. Histogram of example data using 8 distance categories. The detection function g(y) for line transect surveys is expected to decrease monotonically as distance increases. The fit of the half normal detection function is shown.

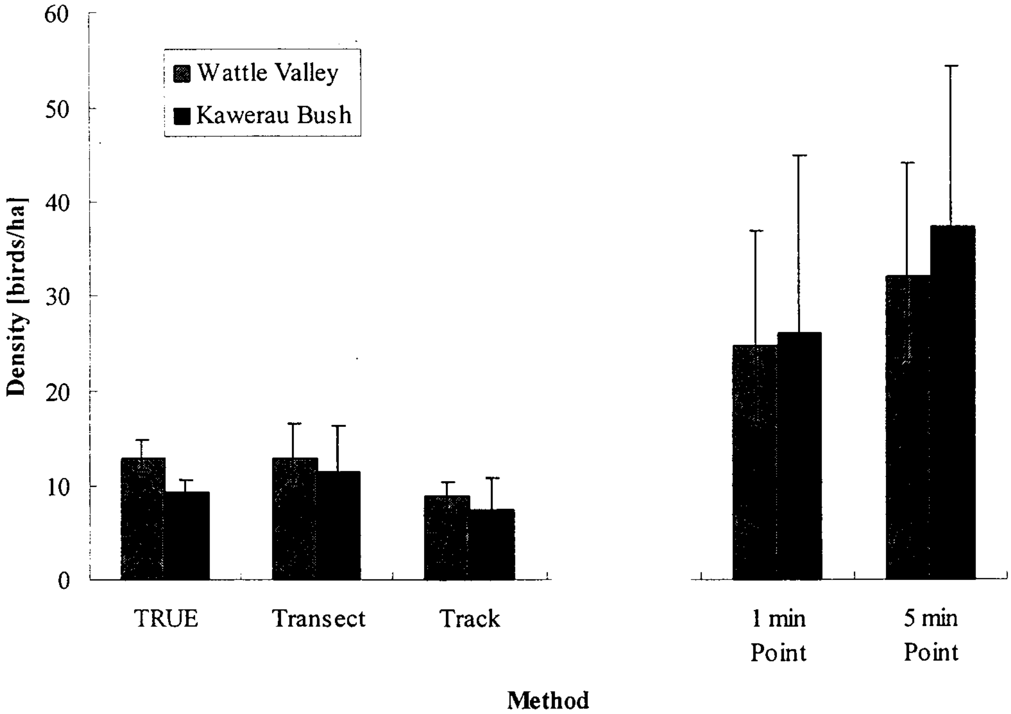

Figure 4. Comparison of pooled densities [birds/hectare] between 'TRUE', and line and point transect estimates of saddleback density at two sites on Tiritiri Island, 1996.

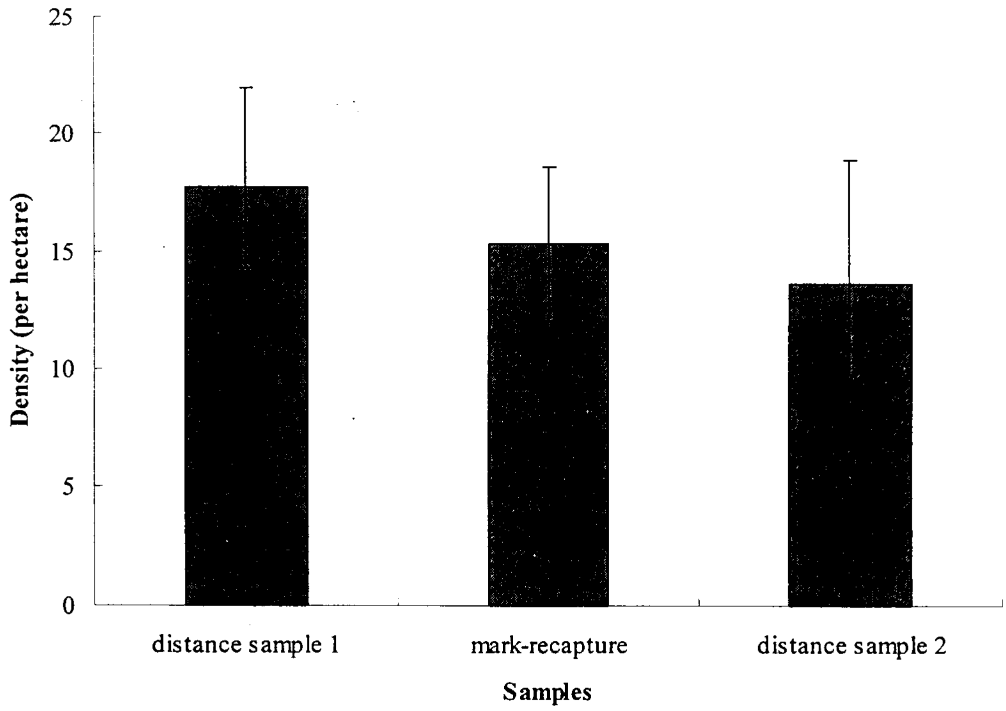

Figure 5. Tuatara density from line transect and mark-recapture samples on Lady Alice Island.

Table 1. Number of saddleback detected during line and point Tansects at different times [morning and afternoon] at two sites on Tiritiri Island, 1996. The field time spent on each count method is included.

Site	Method	Time	Encounter	Count	Effort' Total	Encounter Rate' (birds/minute)
Wattle Valley	Transects	AM	166	446	448	0.37
		PM	152	416	419	0.37
	1 min point	AM	45	36	420	1.25
		PM	40	36	436	1.11
	5 min point	AM	99	180	564	0.55
		PM	77	180	580	0.43
Kawerau Bush	Transects	AM	117	348	351	0.34
		PM	95	362	365	0.26
	1 min point	AM	62	32	334	1.94
		PM	47	32	344	1.47
	5 min point	AM	112	160	462	0.70
		PM	87	160	472	0.54

[a] Count effort = minutes spent observing birds; total effort = count effort + travel between points or Tansects + waiting periods.

[b] Time used is total effort