Birds: estimates of absolute density and abundance—distance sampling

Version 1.0

This specification was prepared by Terry Greene and Murray Efford in 2012.

Contents

Department of Conservation
Te Papa Atawhai

Synopsis

Distance sampling (Buckland et al. 2001) covers a variety of sampling methods where the absolute density of a bird population is derived from measurements of distances either perpendicular to a line (line transects) or radially from a point to the object of interest (point counts). For counts made at points, the observer records the distances to birds seen during a short, fixed time-period—a snapshot. Records beyond a fixed radius are usually discarded in the field or during analysis. Distance sampling accounts for the decline in the number of birds seen and heard with distance from the observation point or line. The distribution of detection distances is used to estimate the number of birds present but not detected, and the counts are adjusted accordingly. Variants of these sampling methods have been applied to bird populations surveyed from the ground, aircraft and boats (Tasker et al. 1984; Webb & Durinck 1992; Bibby et al. 2000; Buckland et al. 2001; B. Lloyd, unpubl. data).

Avian mobility, cryptic behaviours and complex habitat structure can easily invalidate distance estimation of population densities. But, provided model assumptions are satisfied, unbiased density estimates are possible. A pilot study that tests whether the key assumptions can be met realistically is strongly recommended before managers embark on a long-term avian monitoring programme using distance sampling methods.

Assumptions

- All birds or other objects of interest (such as burrows or nests) directly above or on the transect line or point are detected ($p(0) = 1$).
- Birds and other objects of interest do not move prior to detection during a count. A snapshot is usually obtained—all birds are detected as if stationary.
- Distances from a transect line or point to birds or other objects of interest are accurately measured.
- Individuals or clusters of individuals are detected independently of other such units.
- Sample points or line transects are distributed over the area of interest according to a probability-based sampling design (simple random, systematic, stratified, etc.).
- The bird population remains constant throughout the survey period.

Advantages

- If the assumptions hold, distance sampling can provide robust, unbiased estimation of density abundance.
- There is no need to count all birds within the sampled plots.
- Providing the first assumption holds, relatively little bias is introduced by pooling data from birds with different detection probabilities, i.e. the method is ‘pooling robust’. This is a very powerful feature of distance sampling.

- Population estimates derived from distance sampling can be compared legitimately across time and space.
- Analysis of distance data has been dramatically simplified by the software Distance[1] (Thomas et al. 2002).

Disadvantages

- Violation of critical assumptions may cause serious errors in density and abundance estimates. Application of the method to small, highly mobile or cryptic birds in forested or complex habitats can therefore be extremely problematic, as most detections are aural, not visual. Positive steps must be taken to reduce the impact of assumption violation.
- Density estimation of fast-moving birds, such as seabirds, is particularly problematic. It generally produces positively-biased results regardless of whether line transects or point counts are used. Specific sampling procedures must be adopted to minimise these impacts (Buckland et al. 2001).
- Sampling design must be considered on a case-by-case basis given the topography, vegetation and bird species to be monitored. Although point counts are less efficient than line transects and require a greater number of detections, they are more effective in rugged terrain, densely vegetated habitats and those habitats that are heterogeneous or highly fragmented. Universal sampling designs are unlikely to work.
- The minimum number of detections required to model the detection function is relatively large. As a rule of thumb, 60 detections are required as a minimum for line transect surveys compared with 80+ for point counts, but estimates tend to improve with the number of birds recorded. Distance sampling, therefore, is not likely to be suitable for rare species (often those of greatest conservation concern), particularly if it is necessary to stratify data to account for habitat and observer differences. Pooling data may alleviate this problem in some circumstances.
- In most cases extensive observer training and significant resources will be required to deal with the detection of all birds on a line or at a point, accurate distance measurement, complex habitat structure, behavioural characteristics of birds being surveyed and species-specific survey designs. Site-specific characteristics (e.g. vegetation density and terrain) often vary markedly across surveys. If the survey area is large, effective observer training might only occur in relatively few sites (Bart et al. 2004).
- Cost and effort required to obtain data suitable for unbiased and precise population estimates for many species often exceeds available funding.

Suitability for inventory

The expense of distance sampling is not usually justified for inventory. Specialist skills for design and analysis are also likely to be in short supply and expensive. Costs (labour and money) can be large and the results obtained often beyond that required for simple inventory. For these reasons, distance sampling is not recommended for compiling simple species inventories.

[1] http://www.ruwpa.st-and.ac.uk/distance/

Suitability for monitoring

It is appropriate to use this method in the following situations for monitoring:

If the critical assumptions (the first four listed in 'Assumptions') can be met and sufficient resources are available, distance sampling can provide robust and unbiased estimates of density for populations of birds. Comparison of valid density estimates over time and across space is possible and this is an advantage for monitoring programmes where the primary objective is to estimate absolute density and population size. However, the relative merits of absolute density estimates and indices for describing trend depend on their relative sampling variance (including the effect of operational overheads on sample size), the level of uncontrollable variation in detectability, and the intended audience.

Line transects and point count sampling methods are both available. Despite the efficiency advantages gained by using line transects (more animals encountered, large areas able to be covered, etc.), point counts are usually favoured for bird species that inhabit rugged and densely-vegetated terrain and where the habitats are highly fragmented or heterogeneous. Where a bird species' behaviour (e.g. its mobility) or habitat (e.g. detectability) precludes direct estimation of distance (i.e. distance from the point or line to the bird), indirect measurements to immobile objects like nests may suffice, provided those objects are relatively visible and commonly encountered (as occurs with colonially-nesting water birds and some other water fowl). Whatever the situation, distance sampling is unlikely to be suitable for monitoring rare or sparsely distributed bird species, as the minimum number of detections required to model the detection function is relatively large (60–80+).

Skills

Those responsible for survey design must:

- Be familiar with the relevant design issues pertinent to the use of distance sampling methods on bird populations (Buckland et al. 2001, 2004 devote many chapters to survey design and field methods). These issues include the critical assumptions and their impact on appropriate sampling design, definition of the sampling frame and sampling unit, the number of points or lines (and their length) and distribution of points or lines over the sampling frame.
- Have an understanding of the target species' spatial distribution (e.g. clumped or territorial) and potential for stratification. This understanding is also extremely useful and can markedly improve the precision of abundance estimates. A pilot study is strongly recommended (Thompson et al. 1998). It will provide useful information on the precision resulting from a given level of effort (i.e. power). It will also provide an idea of the expected encounter rate and detection function from which transect length or number of points required to reach predetermined levels of precision can be estimated.

Field observers must be:

- Familiar with target species (identification, behaviours, etc.)

- Able to consistently follow the designated sampling design and make accurate distance measurements
- Able to identify violations of assumptions and then understand the consequences for calculated abundance and variance estimates (see Borchers et al. 2002, p. 160)
- Have participated in some sort of training programme addressing the points above

Those responsible for analysis must have:

- Specialist statistical skills and familiarity with the program Distance

Resources

Distance sampling is usually more expensive than obtaining indices of relative abundance despite the relatively small amount of additional information collected in the field. This is particularly so if the species of interest is highly mobile and density is low to moderate, as more intensive sampling and/or more lines or points are required for reasonable precision. Forethought is required when designing the sampling programme to ensure the critical assumptions underlying distance sampling are met and sufficient data are collected. Additional sampling infrastructure is often required to ensure that lines or points are sufficiently well defined to minimise measurement error (e.g. tags, strings, etc.) from which measurements are made. All sampling programmes utilising distance sampling will require a significant training component to ensure observer competence in the data collection methods, equipment use, species identification and distance estimation. Consider testing of potential observers' visual and aural acuity—use only those who reach a set standard. If training and checks are not done, an additional cost will be the bias introduced by the violation of underlying assumptions.

Equipment for terrestrial surveys is relatively straightforward:

- Suitably trained people
- Maps of sample line or point distribution
- Marked lines or points (GPS location and/or tagged site)
- Binoculars
- Rangefinder or other aid to measuring distance (measuring tapes, etc.)
- Data sheets and notebook
- Suitable means of moving between plots (pair of legs or vehicles of various descriptions)
- Appropriate safety gear and first-aid procedures

The effort required to obtain a single estimate of density using distance sampling may be estimated approximately as follows: At the Waipapa Ecological Area in Pureora Forest Park, a target of 80 distance measurements can realistically be achieved for kākā using point counts arranged on a systematic 300 m grid within a 1100 ha area. To visit all 130 points once requires about 10 person-days of effort in good weather and in easy terrain. This approach can be expected to yield a density estimate with a variance of 15–20% of the mean.

Aerial surveys (usually only an option for large bird species inhabiting open terrestrial and aquatic habitats) will require aircraft that can fly slowly, are manoeuvrable, provide unrestricted forward and downward visibility and have sufficient range and capacity. Marine or freshwater shipboard surveys require a stable viewing platform with sufficient height above the water to maximise both visibility and accuracy of distance measurement, as well as providing sufficient room for independent observers. Vessel choice should reflect the behaviour of the target bird species, particularly the degree of responsive movement exhibited by those species. Vessel size, speed and noise produced will also influence vessel suitability. These considerations, along with the safety of observers, invariably inflate cost and resource requirements.

Minimum attributes

Consistent measurement and recording of these attributes is critical for the implementation of the method. Other attributes may be optional depending on your objective. For more information refer to 'Full details of technique and best practice'.

DOC staff must complete a 'Standard inventory and monitoring project plan' (docdm-146272).

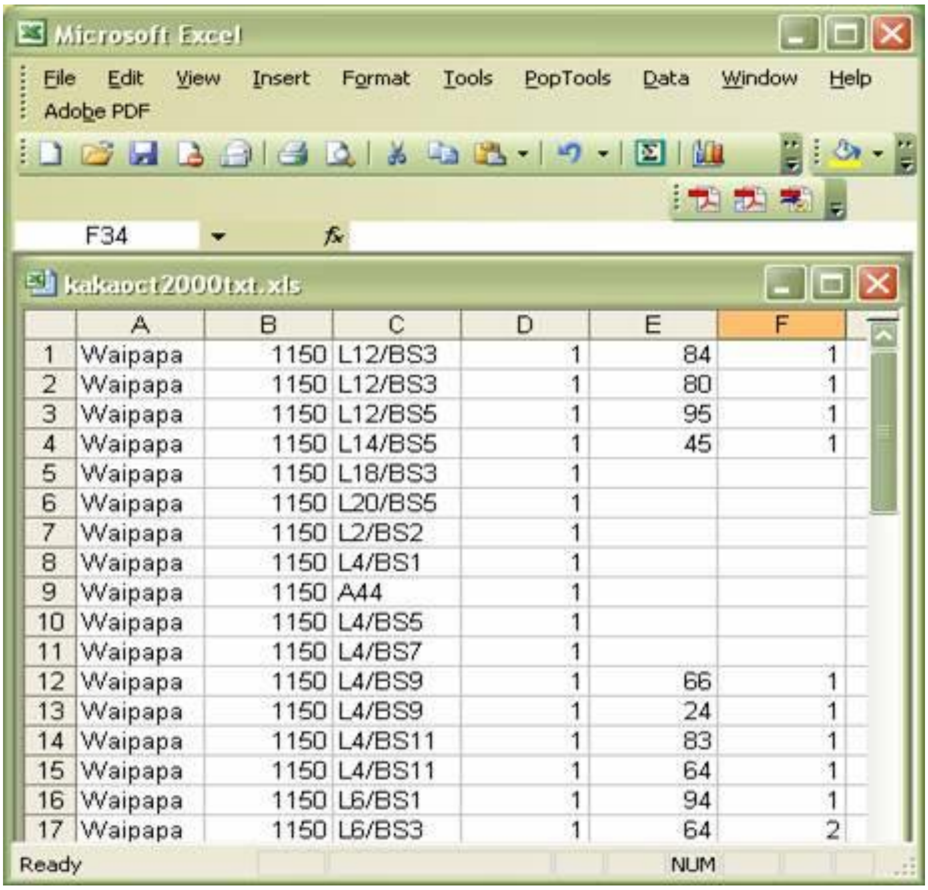
Minimum attributes to record:

- Record metadata, including observer's name and contact details, date of survey, time over which survey conducted (start/finish times) and weather details (rain, cloud, wind, temperature, sunshine minutes, noise—see Dawson & Bull 1975).
- Record location (eastings and northings and/or polygons) of survey area, sample area, lines or points and strata (if required). Habitat variables associated with line/point and stratum can also be recorded.
- Note line length or point count duration and sample effort (number of times line walked or point visited).
- Record number of target species (or objects of interest such as nests and burrows) seen or heard from the line or point.
- Record distance (to nearest metre) or distance interval from the line or point to each bird, object or cluster seen or heard. If the target species occurs in flocks, obvious pairs or other relatively tight aggregations (i.e. clusters), record the number of individuals within the cluster and the distance measured to the centre of the cluster (i.e. record only one distance measurement per cluster). It is also useful to record covariates that may help explain density (e.g. treatment, non-treatment, forest type).

Data storage

Copies of completed survey sheets should be forwarded to the survey administrator and entered into an Excel spreadsheet as soon as possible. Separate worksheets should contain details of sampling layout and other explanatory material. Data should be entered as column variables, saved as a text file and imported into Distance using the Import Data Wizard (Thomas et al. 2002). The imported data and associated analyses and output can be stored as ‘Distance Projects’ (Thomas et al. 2002). An example of the minimum data requirements and layout is provided below.

Examples of distance sampling data obtained for kākā using point counts are shown entered into an Excel spreadsheet (see Fig. 1) and in table form after being imported (using the Import Data Wizard) into the Distance analysis software (Fig. 2). Definitions of the column variables for both spreadsheets are provided in Table 1.



	A	B	C	D	E	F
1	Waipapa	1150	L12/BS3	1	84	1
2	Waipapa	1150	L12/BS3	1	80	1
3	Waipapa	1150	L12/BS5	1	95	1
4	Waipapa	1150	L14/BS5	1	45	1
5	Waipapa	1150	L18/BS3	1		
6	Waipapa	1150	L20/BS5	1		
7	Waipapa	1150	L2/BS2	1		
8	Waipapa	1150	L4/BS1	1		
9	Waipapa	1150	A44	1		
10	Waipapa	1150	L4/BS5	1		
11	Waipapa	1150	L4/BS7	1		
12	Waipapa	1150	L4/BS9	1	66	1
13	Waipapa	1150	L4/BS9	1	24	1
14	Waipapa	1150	L4/BS11	1	83	1
15	Waipapa	1150	L4/BS11	1	64	1
16	Waipapa	1150	L6/BS1	1	94	1
17	Waipapa	1150	L6/BS3	1	64	2

Figure 1. Distance data entered into an Excel spreadsheet.

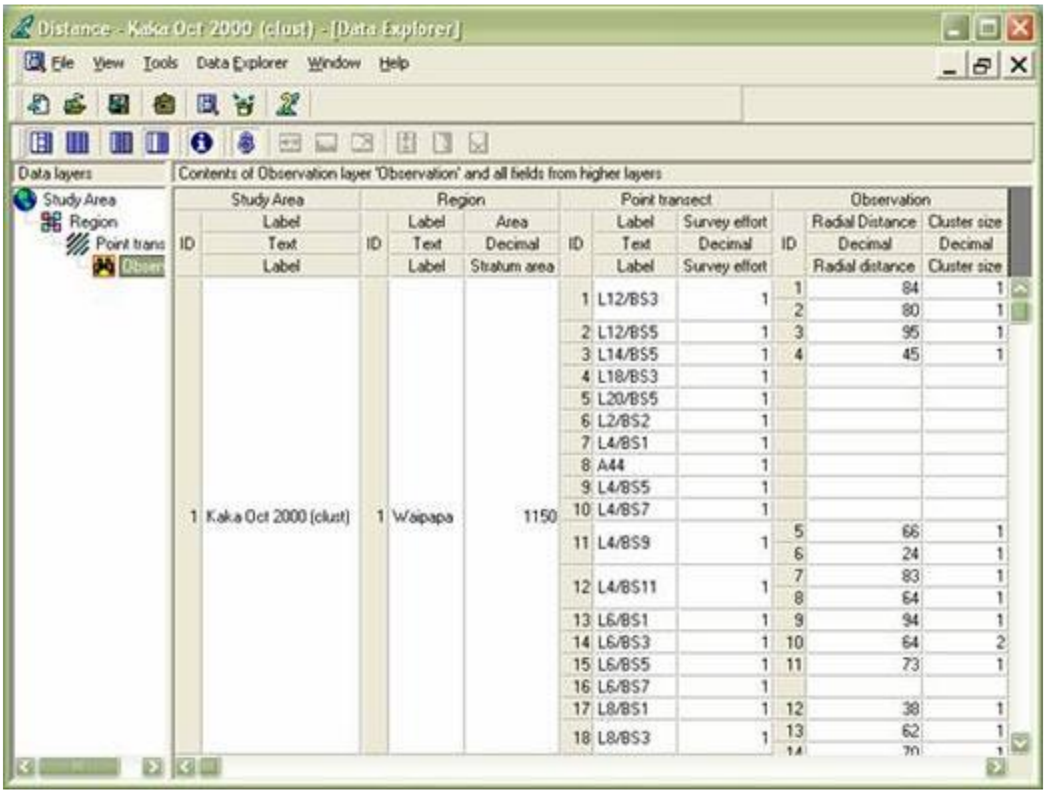


Figure 2. Distance data after importing a text file to program Distance.

Table 1. Definition of column variables.

Spreadsheet column	**Corresponding column in Distance**	**Explanation**
-	Study Area – Label	Distance inserts this by default (usually the filename).
A	Region – Label	Name of study area or stratum.
B	Region – Area	Area of region (ha) used to calculate abundance. If no area is entered, only density will be calculated.
C	Point transect – Label	Name of point (or line, if doing transects).
D	Point transect – Survey effort	How many times the point was visited. If this survey used line transects, the number of metres walked would be entered.
E	Observation – Radial distance	Radial distance in metres from the point (or perpendicular distance from line, if using transects).
F	Observation – Cluster size	Size of observed clusters.

Collate, consolidate and store survey information securely, also as soon as possible, and preferably immediately on return from the field. The key steps here are data entry, storage and maintenance for later analysis, followed by copying and data backup for security.

If data storage is designed well at the outset, it will make the job of analysis and interpretation much easier. Before storing data, check for missing information and errors, and ensure metadata are recorded.

Storage tools can be either manual or electronic systems (or both, preferably). They will usually be summary sheets, other physical filing systems, or electronic spreadsheets and databases. Use appropriate file formats such as .xls, .txt, .dbf or specific analysis software formats. Copy and/or backup all data, whether electronic, data sheets, metadata or site access descriptions, preferably offline if the primary storage location is part of a networked system. Store the copy at a separate location for security purposes.

Analysis, interpretation and reporting

Seek statistical advice from a biometrician or suitably experienced person prior to undertaking any analysis.

The user of Distance is directed to the software's user guide (Thomas et al. 2002) where the more complex mechanics of this analysis program are explained in detail. Buckland et al. (2001, pp. 48–50) suggest a useful strategy for the analysis of simple datasets and this is summarised below.

Exploratory phase

During this initial phase, the analyst should critically examine the data collected. Take particular care to code effort (the number of times a sample unit has been surveyed) correctly to avoid pseudoreplication (Thomas et al. 2002). Identify and correct any data entry errors and other anomalies. Plot the data as histograms in a variety of groupings so the data can be examined in detail. These histograms can be used to identify outliers, as well as potential violation of assumptions caused by the presence of 'heaping' (distances rounded to certain distances) and evasive movement (see Westbrooke et al. 2003). Data can be grouped to reduce these impacts. Buckland et al. (2001, p. 151) recommend truncation of larger distances (roughly 5% for line transects and 10% for point counts) to reduce the impact of outliers and improve model fit.

Model selection

Once a dataset has been prepared, several robust models describing the detection function should be considered. Distance provides several useful models or 'key functions' and associated adjustment terms (or 'series expansions') used to 'shape' detection functions to fit the data. Likelihood ratio tests, goodness of fit (GOF) tests and Akaike's Information Criterion (AIC) are all available as aids to objective model selection. Often the need for additional exploratory work becomes apparent at this point. Changes such as altering truncation point, regrouping distance intervals or pooling data across surveys might improve the fit of one or more of the candidate models. It is not unusual to find there are several competing models, some of which appear to perform poorly relative to other models (and can be discarded) and others that perform equally well. Model averaging can then be used to account for model selection uncertainty (Burnham & Anderson 2002).

Final analysis and inference

Selection of the model(s) believed to be the best fit for the data can now occur. Once a single model (or subset of models) has been selected, estimates of density and precision of these estimates can be made (along with relevant figures and graphs) then discussed in relation to any perceived failures of critical assumptions. Improved variance estimates can be obtained using bootstrapping routines and, if necessary, including a variance component to reflect model-selection uncertainty.

Case study A

Case study A: terrestrial distance sampling—line transects

Synopsis

Short-term population change and mortality of North Island tomtits (*Petroica macrocephala toitoi*) following an aerial 1080 possum control operation in Tongariro Forest were assessed using three survey methods. The first used resighting records of individually colour-banded territorial male tomtits (see ‘Bird Method Specification 2’ in Powlesland et al. 2000); the second derived density estimates from line transects using distance sampling; and the third made counts of territorial male tomtits on transect lines.

This study was designed to assess the three survey methods with limited replication, constrained site selection and no control over the application of treatment to the various sites. Therefore, the results can only be discussed in terms of the specific study sites and are unable to be generalised to wider geographic areas. This study should only be considered a pilot for future work.

Objectives

- Estimate the mortality experienced by tomtits during an aerial 1080 possum control operation using cereal baits.
- Compare the suitability of three count methods for short-term monitoring of tomtit populations.

Sampling design and methods

Three study sites, two treatment and one non-treatment, were established within the Tongariro Forest Conservation Area. All three sites were near the edge of a planned 1080 operational area, contained good populations of tomtits and were similar in terms of climate and habitat (previously logged podocarp forest). Three methods of monitoring tomtits were investigated: (1) monitoring of colour-banded male tomtits, (2) distance sampling of all tomtits encountered, and (3) counts of territorial males.

Pilot study

Distance sampling was carried out at two of the three study sites to refine field methods prior to the commencement of the main study. As a result, transect layout was adjusted slightly to avoid areas near roads where no bait was to be dropped and potential problems with tomtit avoidance of observers were highlighted.

Monitoring banded tomtits

Male tomtits were captured and individually colour banded in all study areas several months prior to the planned possum control operation. An attempt was made to capture every second territorial male so the location of territory boundaries between neighbouring individuals and the number of males and territories along each transect could be determined. Monitoring of banded tomtits began 3 weeks before the distribution of toxic baits and took place again for a period of 25 days starting 2 weeks after the poison drop. It was necessary (and efficient) to play taped calls to adequately monitor the survival of banded tomtits.

Distance sampling

The density of the tomtit populations in each study area was estimated using distance sampling. The sampling design used in the field consisted of 20 (practical minimum number to ensure useful variance estimates; each line = sample unit) marked line transects (250 m long) arranged systematically in parallel lines 200 m apart to ensure no territory was bisected by more than one transect. The perpendicular distance from the line and sex of all tomtits seen or heard within 50 m was recorded as observers walked each transect. Observations were only made in the morning (when tomtits were most conspicuous) and when there was no rain or significant wind. Each transect was surveyed twice during both pre- and post-operation sampling periods. Observers received some training in the estimation of distances (using a hip chain to confirm estimated distances) and the identification of tomtit calls and song prior to commencement of sampling. Pre-operation sampling over an 11-day period was completed a fortnight prior to the poison drop at all three sites. Post-operation sampling occurred over 25 days starting 2 weeks after the toxic baits were distributed.

Territorial male counts

The location of all territorial male tomtits seen or heard singing within 50 m of either side of the line was noted. These counts were done at the same time as surveys for banded male birds and the distance sampling surveys in all three study areas during the pre- and post-operational survey period. During both periods, each transect was walked 3–5 times. Using this method, estimates of the number of territorial males on or near to each transect could be made before and after the application of the toxin.

Data collection

An example of the data sheet used to collect the required information for this study is provided in Table 2.

Table 2. Data sheet used for tomtit distance sampling at Tongariro Forest.

Tomtit Distance Sampling Data Collection Sheet—Tongariro Forest

Site: OPC Non-treatment site **Date:** 18 July 2003

Time start/finish: 0900-1142 **Observer:** NE & RW

Weather: Fine, no wind, frosty and cold

Time	Transect	Distance (m)	Heard/Seen	Sex
0904	68	3	H	M
0905	68	7	H	
0908	68	5	H	
0912	68	5	H	
0914	68	7	H	M
0915	68	12	H	
0920	61	6	H	
0933	61	14	H	
0935	61	5	H	

Results

Survival of banded male tomtits

A total of 15 banded male tomtits were present in both the treatment and non-treatment study sites prior to the application of toxic baits. Post-operational monitoring showed that all 15 tomtits were still present in the non-treatment area, but only 14 of the 15 banded tomtits were seen in the treatment area. This suggested that 6.7% (and no more than 28% based on upper bound of 95% confidence interval) of tomtits within the treatment blocks had died during the fortnight following the possum control operation.

Distance sampling

Analysis of pre- and post-operation tomtit monitoring data confirmed that tomtit avoidance of observers was likely to violate critical assumptions of the method. However, this movement was relatively small in scale and there was considerable variation between individuals. Some birds were noted to be attracted to observers whereas others either moved away or were not disturbed at all. Given the relatively small scale of movements and the conviction that all birds were detected on or near the line, a detection function was fitted to distance data pooled over three relatively wide groups (0–15 m, 16–25 m, and 26–35 m). This ensured that the ‘bow-wave’ effect was always included in the first group despite variations observed between the pilot, pre- and post-operations surveys (see Table 3, and Fig. 3). To further improve the detection function of the model, pre-treatment and post-treatment data were pooled between these periods then stratified for the two periods.

Table 3. 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)*			
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	

*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.

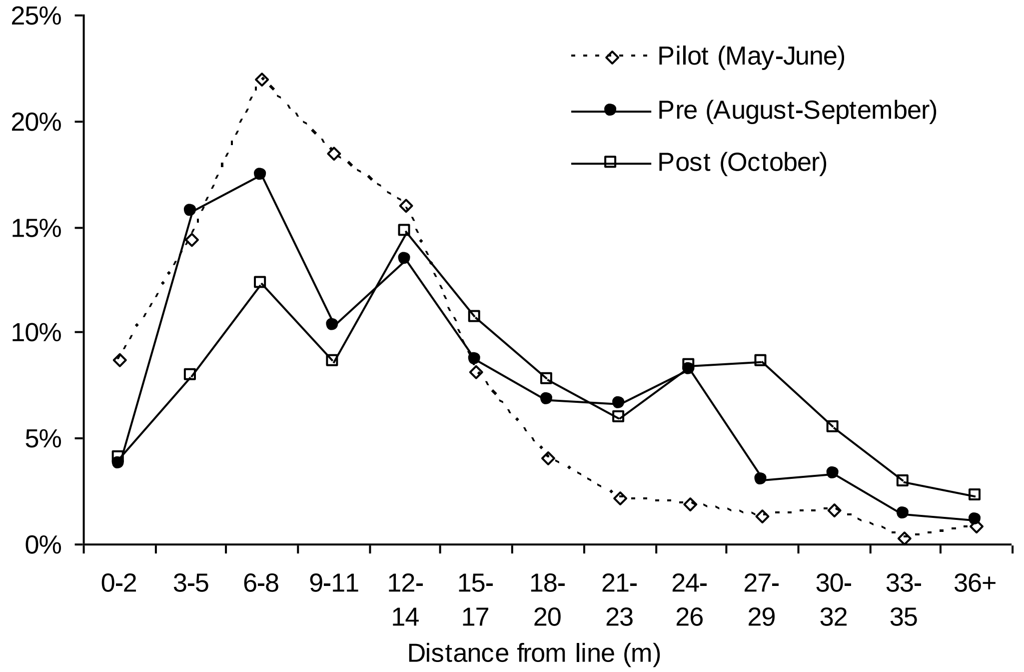


Figure 3. Percentage of distance sampling observations in 3 m distance classes, for three phases of the study: pilot (May–June 2001, n = 368), pre-treatment (August–September 2001, n = 439), and post-treatment (October 2001, n = 425).

Tomtit distance sampling figures

The impact of possum control on the tomtit population was not significant, with only a 3% reduction in average density (upper bound of 36%) in the treatment sites compared with the non-treatment site. Ancillary data collected on the sex of the birds encountered during the distance survey suggested that most records were male birds (79%) with only 3% female, and 18% unidentified.

Territorial male counts

Counts of territorial male tomtits exhibited high stability before and after the possum control operation, with 38 of the 60 transects showing no change and none showing a change of more than one up or down. Somewhat unexpectedly, a lower average decrease in the treatment areas was observed compared with that in the non-treatment area. The estimated impact of the possum control operation in this case was a decrease of 2% with a 95% upper confidence bound of 8%.

Limitations and points to consider

All three count methods used in this study indicated a negligible impact on tomtit populations of aerial 1080 possum control operations with low bait sowing rates and large bait size. All three count methods led towards the same conclusion, but the transect-based approaches (distance sampling and territorial male counts) required substantially fewer resources than the bird banding method for estimation of short-term impacts. Territorial male counts, in particular, showed particular promise for the delivery of low-cost, high-precision estimates.

Whilst less precise, the distance sampling approach is more attractive for the longer-term monitoring of tomtit populations given the method’s robustness (at least in theory) against changes in detectability (e.g. seasonal and annual changes in conspicuousness, habitat regeneration, etc.). However, the density estimates generated need to be considered with caution; firstly as tomtits are known to react to observers on the transect line, thus violating one of the critical assumptions of distance sampling; and secondly, the 23% ± 6% difference in distance estimates of density across both treatment and non-treatment areas a little over a month apart and in the same habitat suggests an artefact within the distance analysis itself. If an artefact of this size is plausible under relatively consistent sampling conditions, then there is potential for even greater margins of error when monitoring over a longer period with a greater range of observers in more varied habitat.

Although the evasive movements of tomtits seem to be relatively consistent, it is probably wise to treat such estimates as a ‘robust index’, focusing on the trend rather than the density estimates themselves, particularly as there is some doubt whether grouping the distances eliminated the ‘bow-wave’ effect. Responsive movement may have affected birds throughout the width of the strip without this being apparent in the shape of the histogram of detections. One potential solution to this problem is to investigate the efficacy of point counts as a means of generating less biased estimates. Appropriate field sampling at fixed points may go some way to control observer-induced bird movement. However, such a change may make things worse, as much of the variation in detection in this instance seemed to occur at larger distances.

How can we explain the decline in density estimates in terms of distance sampling (assuming the cause has something to do with bias introduced by distance analysis)? There are at least four entirely plausible explanations: (1) $p(0)$ (detectability on the line) varies seasonally (e.g. although some individual males sing more strongly as spring goes on, others go quiet or generally become more secretive so they cannot be located), (2) the reaction of birds to the observer changed seasonally, (3) the accuracy of the distance estimates varied systematically with season for some reason (changing observers?), or (4) the shape of the true detection function changed seasonally for some reason, but this was obscured in the analysis by the coarse grouping of observed detection distances used to deal with responsive movement.

Although the majority of birds seen and heard on transects were male (and males were seen and heard at all distances), some females (usually seen close to the line) were included when calculating density estimates. Although this increased the number of observations available to model the detection function (which is a good thing), it also means we are unable to treat the generated estimates as an index of only the male population. Rather, the estimate includes the males along with an unknown proportion of the female population only seen close to the line, a quantity that may not remain stable over time if detectability varies.

Caution is also required when using the Distance analysis software. Reliance on use of the default settings without question should be avoided despite the complexities of the program. Similarly, some of the general recommendations made by Buckland et al. (2001) about the way analysis should proceed should also be treated with caution. For example, truncation of observations or the pooling of data across samples can make things worse. Variations in bird behaviour and detectability, survey timing, changes of observer and numbers of birds recorded, many of which are survey or site specific, will all contribute to making each analysis unique. This degree of subjectivity in analysis is a major problem. More detailed reporting of distance analyses would go some way to show exactly what detection functions have been fit—sample sizes, number of parameters, goodness of fit, detection probability plots, encounter rates and sampling variances should be reported, and detection distances of observers compared.

This study also highlights the need for sufficient observer training. A more rigorous approach, perhaps with built-in performance criteria for observers, was required. If distance data are to be collected to the nearest metre (and this is the preferred option), then observers must attempt to make these measurements as accurately as possible. Failure to do so can result in ‘heaping’ about round numbers (e.g. 5, 10, 20 m), thereby reducing both the resolution with which the detection function can be modelled and the options for pooling distances into appropriate groups or ‘bins’ during analysis. Similarly, there should be consistent measurement of distances out to a predefined maximum designated in the sampling design. Slight measurement error at larger distances from the line can be dealt with effectively by increasing the size of distance groupings and ensuring that data are allocated to the correct distance ‘bin’ during analysis.

References for case study A

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. 432 p.

Powlesland, R.G.; Knegtmans, J.W.; Styche, A. 2000: Mortality of North Island tomtits (*Petroica macrocephala toitoi*) caused by aerial 1080 possum control operations, 1997–1998, Pureora Forest Park. *New Zealand Journal of Ecology 24*: 161–168.

Westbrooke, I.M.; Etheridge, N.D.; Powlesland, R.G. 2003: Comparing methods for assessing mortality impacts of an aerial 1080 pest control operation on tomtits (*Petroica macrocephala toitoi*) in Tongariro Forest. *New Zealand Journal of Ecology 27*: 115–123.

Case study B

Case study B: Terrestrial distance sampling—point counts

North Island Kaka, Dick Veitch (DOC).

Synopsis

Distance sampling was used to estimate the density of North Island kākā (*Nestor meridionalis septentrionalis*) and kererū (*Hemiphaga novaeseelandiae*) within 1150 ha of the Waipapa Ecological Area within Pureora Forest Park. The utility of distance sampling as a means of monitoring medium- to long-term population trends for both species was also assessed, as was the ability of this study to meet the most important underlying assumptions. A specialised sampling protocol was developed in an attempt to address assumptions, maximise detections and account for specific species behaviours. Point counts arranged on a systematic grid were used to sample both the kākā and kererū populations.

Objectives

- Investigate the application of distance sampling methods to two large bird species (kākā and kererū) that inhabit New Zealand forests.
- Determine whether the critical assumptions of distance sampling can be met for these species.
- Identify trends in population estimates (if any) and assess whether these can be explained in terms of seasonal variation and management actions.

Sampling design and methods

This was a pilot study to investigate whether distance sampling was a viable means of monitoring kākā and kererū populations in the medium to long term.

North Island kākā and kererū were counted in a 1150 ha area of the Waipapa Ecological Area. This area was relatively flat and covered in unlogged podocarp forest. Point count sampling was chosen over line transects because of the often cryptic behaviour exhibited by both kākā and kererū, and the density and structural complexity of this forested habitat. Too few of either species would have been seen from a walked transect, with detection of birds overhead being particularly problematic. Forest density and canopy complexity necessitated active and intensive searching or waiting until a bird moved and revealed its location. Over 130 points were distributed systematically (from what was essentially a random start point) throughout the study area using a 300 m grid based on pre-existing possum bait-station lines. This design ensured that the majority of habitat and vegetation types within the Waipapa Ecological Area were likely to be surveyed in proportion to their area. Each point was visited once during each sampling period (usually 10–14 days) in October 2000, March and October 2001 and 2002, and February 2003. A minimum target of 80 distance measurements to individuals of each species during each sampling occasion was set in an attempt to maximise estimate precision. Sampling was done between 1 hour after sunrise and 11:30 a.m. (after which fewer birds were heard), and only when the weather was good (no significant rain or wind) to maximise seasonal and diurnal detectability (i.e. the efficiency with which birds were counted).

Observers approached each point with caution to avoid flushing kākā or kererū. If this did occur (< 5% of observations), the distance from the point from which they were flushed to the intended count point was measured. A count period of 10 minutes was used to detect kākā and kererū within a radius of 100 m. A snapshot measurement of the distances from the defined count point to each bird detected (seen or heard) was taken at the end of this period. Horizontal distances to all birds were recorded to the nearest metre relative to the count point using a laser rangefinder and pieces of tape that marked the 10 m point. This often necessitated observers moving away from the count point for brief periods to ensure accurate measurements.

All birds were recorded as clusters (of one or more) and analysed as such as initially there was uncertainty over the scale (temporal and numeric) and frequency of natural aggregations and the impact that aggregation might have on detection probability for both species. A cluster (of more than one individual) was defined as any social group, flock, aggregation or obvious pair of birds that appeared to be interacting socially over a small spatial scale (< 10 m) and whose presence seemed dependent on the presence of other individuals of the same species. The number of individuals within a cluster was counted and the distance measured to the geometric centre of the cluster.

Kākā or kererū flying into or over the plot area were recorded, but ignored in the analysis as their inclusion tends to inflate density estimates (Buckland et al. 2001). Every effort was made to avoid counting birds more than once, by noting the location of birds seen or heard, listening for movement within the survey area (both species have relatively noisy wing beats), ignoring birds more than 100 m from the point and ensuring the count points were 300 m apart. Birds flying out of the plot area were only recorded if their point of origin could be identified and measured. Particular attention was paid to detecting birds at or close to the point. Given the structural complexity of the forest and sometimes cryptic behaviours exhibited by kākā and kererū, the immediate area surrounding the point (a radius of 20 m from the point) was checked again at the end of each count period for birds that had been present but undetected. Fewer than five birds from both species over the entire count period were detected in this way.

Data collection

An example of the data sheet used to collect the required information for this study is provided in the Table 4.

Table 4. Example of data sheet used for a distance sampling study.

Conservancy Waikato	Location Waipapa Ecological Area
Grid Ref. T17 E 1234567 N 7654321	Date 14 October 2003
Observer Alan Jones	Official Sunrise (NZST) 06:30 hrs
Forest Type Rimu and matai dominated podocarp forest with tawa understorey	
Weather Fine and sunny with no wind or rain.	

Point #	Start time	2 min period	Species	Distance to cluster (m)	Clust size	Seen	Heard	Perched	Fly out	Fly in/over	Ad	Juv.
L7BS4	08:00	1	Kaka	27	1		✓	✓			?	?
		3	Kaka	55	1		✓	✓			?	?
		3	Kereru	15	1	✓		✓			✓	
L7BS6	08:15											
L7BS8	08:30	2	Kaka	85	2		✓	✓			?	?
		4	Kaka	47	1		✓	✓			?	?
L9BS1	09:00	1	Kaka	22	1		✓	✓			?	?
		1	Kereru	35	1		✓	✓			?	?

Data required for the various cells are defined as follows:

Conservancy	In which conservancy is the survey being conducted?
Location	Where in the conservancy is the survey being conducted (e.g. Waipapa Ecological Area)?
Grid Ref	Reference point for the start of the survey (include map series and sheet number).
Date	Date on which these counts were conducted.
Observer	Who was responsible for collecting this data?
Sunrise	When was official sunrise for this particular day? (This information can be sourced from local newspapers, tide tables and many handheld GPS units.)
Forest type	General description (e.g. podocarp/tawa, beech, etc.) in which these counts were conducted.
Weather	General description of weather in which counts were conducted for a given day. More objective scoring (see five-minute bird count method) can be used.
Point No.	Number of point count conducted.
Start time	Time that the 10-minute count commenced.
2 min period	Which 2-minute period (1–5) the birds were first seen or heard. This is not necessary for all surveys. In this case the information was used to look at the optimal count period (90% of birds detected in first 7 minutes).
Species	What species was counted (e.g. kākā or kererū).
Distance	Distance (to nearest metre) to the centre of the cluster.
Cluster size	How many birds in the cluster (one or more).
Seen	Mark if bird was seen.
Calling	Mark if bird was heard (if both seen and heard mark both).
Perched	Mark if bird was perched (i.e. stationary or not flying).
Fly out	Was the bird seen flying out of the count area (100 m radius) during the count period?
Fly in / over	Was the bird seen flying into or over the count area during the count period?
Ad. / Juv.	Mark only if sure of age (adult or first year juvenile) of each bird.

Results

On most sampling occasions sufficient data were collected for kākā over a 10-day period by two observers to allow analysis to proceed; the exception being October 2002 when only 52 observations were made. This was not the case for kererū. Sufficient data were only collected during the March counts; observations of kererū in October were invariably far fewer (n = 22–58). Data were examined using the program Distance and left ungrouped during analysis. Truncation within the 100 m limit imposed on field observations was judged unnecessary as $g(x)$ < 0.1 at 100 m and model fit (i.e. AIC values) tended to deteriorate with further truncation (Buckland et al. 2001). Good model fit (using AIC and GOF) was usually attained using half-normal or uniform models with varying numbers of adjustment terms (Fig. 4). Pooling data across surveys did not appear to improve model fit or precision, so separate density estimates were calculated for all survey occasions. Although information on cluster size was collected, relatively few distance measurements were to clusters of two or more birds (e.g. for kākā, < 13% of observations were clusters of > 1 bird; mean cluster size = 1.2). Therefore, the impact of clusters on density estimates could be ignored during analysis (L. Thomas and D. Borchers, pers. comm.). For those sampling occasions where more than one model adequately explained the data model, averaging procedures were used to account for model selection uncertainty.

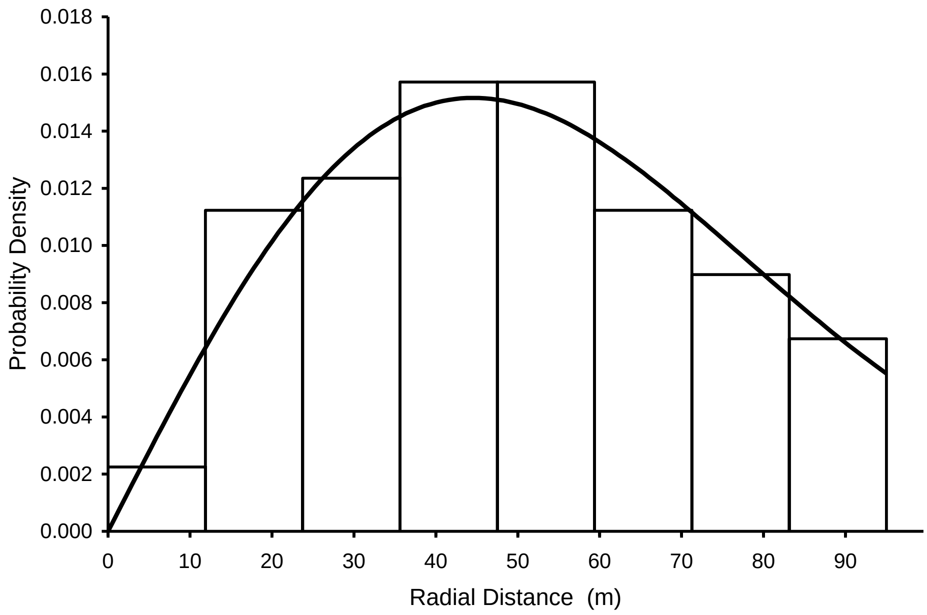


Figure 4. One example of the kākā probability density ($\hat{f}$) graph for March 2001. The curve represents the detection function (model = half-normal with nil adjustment terms required) for radial distance measures. Goodness of Fit Chi-*P* = 0.94 (*n* = 75).

Kākā density within the Waipapa Ecological Area was consistently estimated at between 0.6 and 0.8 birds per ha over a 3-year period following intensive pest control (see Table 5 and Fig. 5). The slightly higher density figure estimated for March 2002 seemed to be a response to increased productivity reflecting the somewhat patchy distribution of newly fledged juveniles and the first significant breeding since distance sampling commenced. The low density figure calculated for October 2002 appeared to be an artefact of lower than usual sample size (*n* = 52, instead of the targeted 80 measurements), in combination with high levels of post-fledging mortality. These results are consistent with general impressions of kākā density, productivity and background predator levels (T. Greene, unpubl. data).

Table 5. Kākā and kererū density, Waipapa Ecological Area, 2000–2003.

	Kākā			Kererū		
Survey Date	Density/ha	95% CI	*n*	Density/ha	95% CI	*n*
October 2000	0.56	0.36–0.76	89	0.29	0.17–0.49	44
March 2001	0.60	0.37–0.84	75	1.51	1.0–2.3	164
October 2001	0.63	0.45–0.81	127	0.33	0.21–0.51	58
March 2002	0.88	0.55–1.21	97	2.63	2.14–3.22	195
October 2002	0.21	0.09–0.34	52	0.14	0.07–0.27	22
February 2003	0.60	0.40–0.80	99	0.84	0.43–1.65	81

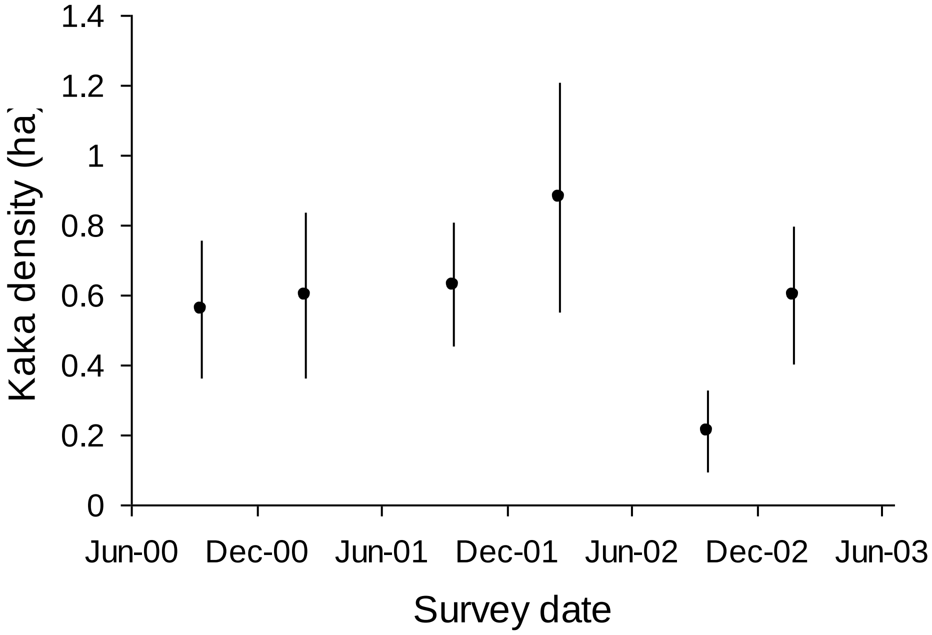


Figure 5. Density of kākā (kākā/ha) from October 2000 to February 2003.

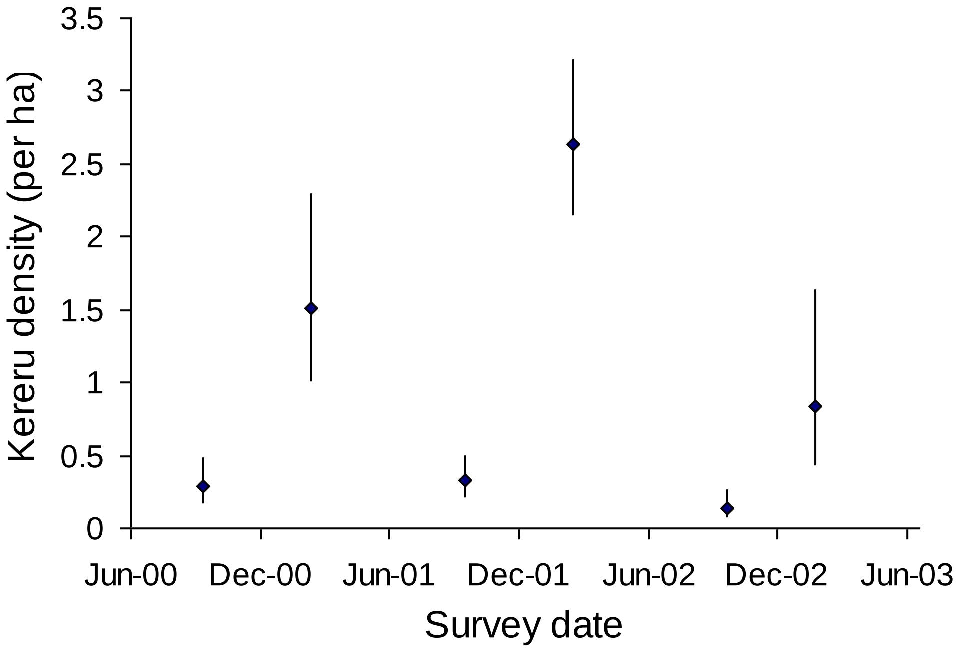


Figure 6. Density of kererū (kererū/ha) from October 2000 to February 2003.

In comparison, the kererū within the Waipapa Ecological Area showed marked seasonal changes in density (0.14–2.63 birds per ha) (see Table 5 and Fig. 6). Kererū densities were relatively low within the study area in spring but then increased dramatically by early autumn. At least two explanations for these dramatic changes in numbers are possible. Firstly, the increase might have been caused by the influx of kererū from the wider geographic region surrounding the Waipapa Ecological Area to feed on seasonal foods such as the fruit of tawa, hīnau, mataī and miro (T. Greene, unpubl. data). Secondly, kererū resident within Waipapa might have moved out in spring to feed on high nitrogen content leaves (such as clover, kōwhai, willow, tree lucerne) within surrounding habitats. Alternatively, both movement events might affect kererū density to some degree within this area on an annual basis.

Limitations and points to consider

Point-based distance sampling shows considerable promise for the long-term monitoring of kākā and kererū population trend within the Waipapa Ecological Area. Without a carefully considered sampling design specific to the site and the species being monitored, many of the critical assumptions of distance sampling are unlikely to be met. The use of point counts on a systematic grid may not be as resource and time efficient as line transects (Buckland et al. 2001), but in structurally complex vegetation and rugged terrain, the observer is more likely to achieve complete detection of birds near a focal point, than when moving along a line.

In this study, ensuring that the distances recorded to birds were accurate was one of the most difficult requirements. Not surprisingly, dense vegetation often impeded direct and accurate location of calling birds from the count point (although it is worth noting that distance estimation from calls is also very difficult where vegetation is sparse). The use of laser rangefinders did not necessarily solve this problem as leaves and branches often blocked the signal. The potential for measurement error was reduced somewhat by training observers in the estimation of distance (covering the use and limitations of rangefinders, the importance of adhering to the sampling protocol, defining the point to measure to (e.g. to trees), moving away from the point to get a better distance estimate, etc.), using a count period of 10 minutes (a longer period over which to get more accurate distance measures) and the ability of observers to move away from the point during the count to get a better 'view'. Limited grouping of distance data during analysis was used when it was obvious model fit could be markedly improved as a result.

Although distance sampling is considered robust against changes in detectability (e.g. seasonal and annual changes in conspicuousness, habitat regeneration, etc.), it is probably wiser to concentrate on the trends in density, rather than the calculated density estimates themselves, assuming any bias (e.g. annual- or habitat-related variation in conspicuousness) is consistent until the effect of significant assumption violations can be quantified. Thus, users of distance sampling methods should carefully consider the supposed advantages of the method and whether the same information (i.e. trend) could be gained more cheaply, and perhaps more reliably, using other methods.

The inability to meet the target number of observations (n = 80), rather than a failure of critical assumptions, was assumed to be the cause of the surprisingly low density estimate (compared with the general trend) calculated for kākā in the October 2002 survey period. This reinforces the need for a minimum of 80 distance observations to be obtained in a given sampling period. If this number cannot be achieved by a single visit to each point (or line), then repeat visits (with the number noted in the 'effort' column) should be made until this target is reached.

Interestingly, the low numbers of kererū seen during October surveys seemed to reflect the actual density of birds within the Waipapa Ecological Area at the time, even though the relatively high precision of the estimates is rather suspicious for such low numbers of observations. The extreme differences between October and March counts for kererū become particularly important when considering a single annual survey. As a general rule, the greater the number of observations, the greater the precision of the estimate. However, despite the high number of observations and high density estimates for kererū in March, the standard errors for the estimates were quite large. This might reflect increased clustering of birds during this period as they actively compete with one another for fruit. Clearly there needs to be careful consideration of many factors when deciding on the most appropriate time to count kererū.

Caution is also necessary when using the Distance analysis software. Avoid uncritical use of the default settings. Similarly, treat with caution some of the general recommendations made about the way analysis should proceed. For example, truncation of observations or the pooling of data across sample occasions did not appear to improve model fit for either kākā or kererū data—it often made things worse. Possible explanations include a lucky choice of truncation point in the sampling protocol (i.e. where truncation within 100 m was not required) and the models not being robust enough to variations in detection probability. Sources of variation could have included the use of different observers (with differing abilities) and the marked seasonal changes in the behaviour of kākā and kererū. Variations in bird behaviour and detectability, survey timing, changes in observer and numbers of birds recorded, many of which are survey or site specific, will all contribute to making each analysis unique. Thus, it is extremely important to document analyses fully and justify all choices of method.

References for case study B

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Greene, T.C.; Jones, A. (in prep.): Monitoring the population density trends for kākā (*Nestor meridionalis*) within the Waipapa Ecological Area, Pureora Forest Park.

Full details of technique and best practice

Distance sampling can be used to estimate the density of bird populations directly and indirectly from line transects and from points. Arguably the method is best applied to relatively sedentary and moderately common populations of birds (using direct counts) or related objects such as nests and burrows (using indirect counts). As a rule of thumb, line transects are best used in open habitats where the objects of interest are easily detected, sparsely distributed (given that line transects are more efficient), and unlikely to move in response to the observer prior to detection. Point counts are best where habitats for survey are densely vegetated and/or patchy, topography is challenging, the birds of interest are reasonably common and are not generally attracted to observers. Whatever sampling units used, they should all be laid out using some sort of probability-based sampling design.

Obviously then, the way distance sampling is employed to count birds (directly or indirectly) will vary depending on circumstance (e.g. species, habitat, distribution, etc.) and a generic guide to best practice is therefore impractical. Nevertheless, some general guidelines for distance sampling using line transects are possible:

- Survey objectives should be carefully considered and explicitly defined. For example, are you interested in the entire population or just the breeding population? Will burrow density give you the data you require? Will the survey provide robust information on impact of management action? What are the objectives of any long-term monitoring? Is an estimate of absolute density required? (etc.)
- The population of interest must be carefully defined in both time and space. What will be sampled? Where will it be sampled? When will it be sampled?
- A random probability-based sampling design should be used to maximise inference and provide accurate variance estimates (random sampling, systematic sampling, stratified random sampling, etc.). Sampling design, length, number and layout of lines should be tailored to the anticipated distribution and density of the population to be counted. Assess how much sampling effort is needed and specify how it will be allocated spatially (e.g. is stratification needed) and temporally, relative to the precision required.
- A minimum of 15–20 replicate lines/points should be surveyed to adequately estimate (a) the variance of encounter rates and (b) appropriate confidence intervals.
- The variance of population estimates must be calculated according to the sampling design employed.
- Write a sampling protocol specific to the monitoring programme being conducted. This should explicitly state the objectives, sampling design (including details of line and point layout, particularly if counts are to be repeated on a regular basis; allocation of observers to transects, etc.), observer training requirements, data collection rules, minimum data requirements and provide guidance on how to compile official data sheets.
- All observers should be capable of identifying the target species or the objects of interest relating to the species' presence. If burrows or nests are being counted, observers must be able to distinguish occupancy or use and whether they were constructed by the target species. A comprehensive training programme is required. Minimum standards (i.e. performance criteria) for observers may need to be instituted.
- Every attempt must be made to ensure the main assumptions of distance sampling are met. This can be extremely difficult for birds that are highly mobile, inhabit densely-vegetated areas, and/or are either sparsely distributed or extremely common. Practitioners should be prepared to discuss potential failures of assumptions and the impact they might have on density estimates.
- Analysis of distance data should proceed with caution. Reports should be comprehensive and include details of encounter rates and detection probabilities with associated sampling variances, plots of calculated detection functions, model fit (more recent versions of Distance also use QQ plots and Cramér-von Mises statistics) and analysis of the impact of any measured covariates (e.g. impact of a change of observer).

Potential problems and solutions

Distance sampling will not work well for all (or perhaps even most) bird species. Behavioural peculiarities, the types of habitats being sampled (particularly densely-forested habitats) and population densities all have some effect on the ability of observers to meet the method's key assumptions. Although good sampling design can go some way to reducing bias and increasing accuracy and precision, the difficulties are likely to be intractable for some species and problematic at best for most. Examples of such problems include bird species (such as NZ robins) that are attracted to observers or those (such as blackbirds) that flee prior to detection, very cryptic species (e.g. all nocturnal species, banded rails and crakes) or those that are rare and/or are thinly distributed across the landscape (e.g. NZ falcon, shining cuckoo). Multiple-species or 'community' surveys of bird density and abundance using distance sampling methods can be particularly troublesome if birds are encountered in large numbers (observers tend to be overwhelmed), movement is significant (double-counting becomes difficult to assess), accurate distance measurement is difficult (e.g. when vegetation is dense) and sample sizes are small for some species (Hutto & Young 2002, 2003). For these reasons, it is important to examine the degree to which the assumptions of distance sampling are likely to be violated before commencing long-term monitoring of bird species using this method.

Robust sampling design is essential regardless of the species to be monitored or the site at which distance sampling is to be deployed. Rigorous selection of a large number of sampling points using a random or systematic design is a good start and can be helped by using the design component of the Distance software. Failure to detect all birds directly above the point or line can be minimised by enforcing a count protocol. It should clearly stipulate the focus for detections as the point (or line) and the immediate area surrounding it; the count duration should be tuned to the species being surveyed (e.g. 7–10 minutes for kākā and kererū and 2–5 minutes for passerines); and the count should focus on only those species of interest and ignoring others (to avoid being overwhelmed by common species of no interest).

Accurate distance measurement is particularly hard to do even when using skilled observers trained in distance estimation with access to measurement devices such as optical and laser rangefinders. Estimation of distances within forested habitats is often to perceived rather than actual locations and can therefore be of questionable accuracy (Alldredge et al. 2007). Distance perception is influenced by environmental noise (weather, stream, traffic, etc.) and the number, orientation and diversity of birds calling nearby. Assigning detected birds to intervals can ease this situation (but this is not a guaranteed solution)—the challenge then becomes defining the number of intervals and the most appropriate interval 'cutpoints' (Buckland et al. 2001). It is likely that uncertainty in distance measurements to auditory detections is much greater than most researchers assume—most observers appear unable to differentiate distances beyond 65 m. Estimates of avian abundance derived from such counts are likely to be biased (sometimes substantially so) and thus deserve careful scrutiny (Alldredge et al. 2007).

Opportunities for the application of distance sampling methods from aerial platforms in New Zealand appear to be rather limited. Large highly-visible birds such as albatrosses and gannets can probably be counted more efficiently using aerial or terrestrial photographic interpretation, plot sampling or total counts (in some cases) given the relatively small areas in which they occur (Pihl & Frikke 1992; Moore 2004). Although there is considerable potential for using distance sampling to estimate the density of birds at sea, attempts to do so in New Zealand waters are almost non-existent and are likely to be problematic given the huge numbers (overwhelming the ability of observers to both count and estimate distance to them) that are sometimes encountered. A current large-scale pilot application of distance sampling methods to the seabirds inhabiting the Marlborough Sounds (B. Lloyd, pers. comm.) may prove to be an exception.

References and further reading

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Appendix A

The following Department of Conservation documents are referred to in this method:

docdm-146272	Standard inventory and monitoring project plan