

Distance sampling to determine kaka (*Nestor meridionalis septentrionalis*) density within Waipapa Ecological Area, Pureora

Terry Greene^{1*}, Alan Jones^{2,3}, Gillian Dennis^{2,4} and Thalia Sachtleben^{2,5}

¹Department of Conservation, PO Box 13049, Christchurch 8141, New Zealand

²Department of Conservation, RD 7, Te Kuiti, New Zealand

³Present address: 20 Stevenson Ave, Sawyers Bay, Dunedin 9023, New Zealand

⁴Present address: 3/10 Wiltshire Place, Tamatea, Napier 4112, New Zealand

⁵Present address: 1023 Olson Rd, Yakima, Washington 98908, USA

*Author for correspondence (Email: tgreene@doc.govt.nz)

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Abstract: Reliable information about population density and trends is essential for making valid inferences regarding conservation management. The suitability of point counts using distance sampling was examined as a means of monitoring a population of kaka (*Nestor meridionalis septentrionalis*), a large forest-dwelling parrot, inhabiting the Waipapa Ecological Area in the central North Island of New Zealand. Counts were conducted on 13 occasions between 2000 and 2007. The sampling design was tailored to maximise the detectability of kaka and to minimise violations of the four most important assumptions of distance sampling. Location errors and subsequent distance estimation errors were most likely to bias density estimates despite our attempts to minimise failures of this assumption. Densities estimated from counts conducted in October were similar between 2000 and 2007 (approximately 0.5 kaka ha⁻¹) with no evidence of either a positive or negative trend. Densities derived from counts in February or March were more erratic and seemed to reflect variation in the frequency and success of the preceding breeding season. Given the frequency of kaka breeding, the pest control regime during the study period, and our attempts to minimise violations of distance sampling assumptions, we are confident that the reported trends in density are realistic. Although distance sampling was found to give reliable density estimates of kaka at Waipapa, this may not be the case at other sites, particularly where kaka density is low, location error is high, forest structure or topography are more complex, or surveys of kaka are made part of more extensive multi-species surveys.

Keywords: abundance; assumptions; bias; population distribution

Introduction

Count data that reliably estimate trends in population distribution and density of birds and other wildlife are fundamental to effective conservation management, as they enable inferences to be made about the impact of management regimes and environmental disturbances through time (Thompson et al. 1998; Bibby et al. 2000; Sutherland 2006; Elphick 2008). Ideally, count methods must be easy to use, practical, cost-effective, repeatable, and provide 'reliable information' (Romesburg 1981). If valid inferences are to be made, it is essential that the biases and limitations of the count method(s) are recognised, understood and, if practical, minimised. While there are numerous ways to estimate the abundance and density of terrestrial bird populations (Thompson et al. 1998; Bibby et al. 2000; Williams et al. 2002), count data are usually treated as either indices of 'relative' abundance and density or alternatively, if detectability can be controlled, as estimates of 'absolute' abundance and density based on empirical modelling.

Indices of relative abundance generally assume that the number of birds counted (C) is consistently and linearly correlated with actual bird density (D) or abundance (N) (Dawson & Bull 1975; Thompson et al. 1998; Williams et al. 2002; Johnson 2008). Absence of adjustments to account for the probability of detecting target species, limited evaluation of index assumptions (Conn et al. 2004), or the use of post hoc calculations to account for variable rates of detection is problematic and has led to considerable criticism of index methods (Dawson 1981; Thompson et al. 1998; Rosenstock et al. 2002; Thompson 2002; Bart et al. 2004; Hutto & Young 2003).

Alternatively, the calculation of unbiased estimates of density (\hat{D}) based on empirical modelling requires the use of survey methods that account for incomplete and variable detectability (Thompson et al. 1998; Borchers et al. 2002; Williams et al. 2002; Skalski et al. 2005). Distance sampling (Buckland et al. 2001) includes a range of methods designed to provide reliable, temporally and spatially

comparable, and unbiased estimates of population density (\hat{D}) and abundance (\hat{N}) and has been widely advocated as a solution to the problem of variable detectability (Buckland et al. 2001; Rosenstock et al. 2002; Ellingson & Lukacs 2003; Buckland 2006).

Distance measurements, usually from a line (perpendicular) or point (radial) to the object of interest, are used to address variable detectability of individuals. These distances are then modelled using various forms of detection function and the best-fitted model is used to generate density and abundance estimates for a defined area. As long as the four critical model assumptions are met, robust, comparable, and unbiased estimates are theoretically possible (Buckland et al. 2001).

However, the difficulties of meeting these assumptions when surveying bird populations, particularly during multiple-species surveys and for species that are relatively uncommon, should not be underestimated (Hutto & Young 2002; Alldredge et al. 2007; Bächler & Liechti 2007; Johnson 2008). The ability to meet these assumptions may be compromised by the number of target species being counted, variation in their detectability, their natural history and rarity, the habitat in which they are found, the need to reduce the impact of assumption violations as much as possible, observer experience and, ultimately, the cost of doing so.

In this study we used distance sampling to estimate the density and population trends of a large forest-dwelling New Zealand parrot, the North Island kākā (*Nestor meridionalis septentrionalis*), in an area being intensively managed to reduce introduced predators (Moorhouse et al. 2003). We also explore our ability to meet the critical assumptions underlying distance sampling for this species and make suggestions for further research.

Methods

Study species

Kākā are large, sexually dimorphic (Moorhouse et al. 1999) parrots endemic to New Zealand (Higgins 1999). Formerly abundant and widespread in native forests over much of the country (Buller 1888), populations of both the North Island kākā and South Island kākā (*N. m. meridionalis*) have declined dramatically everywhere except on several predator-free offshore islands (Higgins 1999; Heather & Robertson 2005) and are now classified as nationally endangered (Hitchmough et al. 2007). This marked decline in distribution and number has been largely attributed to habitat destruction and the continued impact of introduced mammalian predators and competitors (Greene & Fraser 1998; Wilson et al. 1998; Veltman 2000; Moorhouse et al. 2003; Greene et al. 2004; Powlesland et al. 2009).

The relative rarity of kākā in mainland forests means that encounter rates for most mainland kākā populations are now extremely low (Calder & Deuss 1985; O'Donnell & Dilks 1986; Moffat & Minot 1994; Elliott & Rasch 1995). Thus, meaningful counts of kākā using most survey methods, including distance sampling, will be challenging (Buckland et al. 2001). This situation is further exacerbated by the marked variability in diurnal and seasonal conspicuousness exhibited by kākā populations (Harrison & Saunders 1981; Calder & Deuss 1985). However, the vocal and behavioural conspicuousness of kākā, particularly during morning hours in spring and autumn, and their general reluctance to flee or approach careful observers suggest distance sampling has the potential to be a successful monitoring method in areas where kākā still persist in moderately high numbers (Johnson 2008).

Study site

The Waipapa Ecological Area (hereafter referred to as Waipapa) (38°25' S, 175°35' E) lies approximately 45 km north-west of Taupo and 7 km north of Pureora village and covers about 4000 ha of the Pureora Forest Park (Leathwick 1987) (Fig. 1). This area represents one of the most intact areas of dense podocarp forest remaining in the North Island, and is the site of an ongoing ecosystem restoration programme that aims to benefit a number of species. The climate of the area is cool and moist with a mean annual temperature of 10.3°C and an annual average rainfall of 1829 mm (King et al. 1996). The study site included approximately 1150 ha of relatively flat (540–580 m

a.s.l.) unlogged podocarp forest on podsolised yellow-brown pumice soils (Rijkse & Wilde 1977) at the southern end of Waipapa. Detailed descriptions of the predominant vegetation types covering the area can be found in Leathwick (1987) and King et al. (1996).

From 1993 to 2001, possums (*Trichosurus vulpecula*) and ship rats (*Rattus rattus*) were controlled at very low densities using a variety of traps, baits, toxins and delivery methods (for details see Moorhouse et al. 2003). The mustelid population may also have been suppressed through secondary poisoning (Murphy et al. 1998). Consequently, kākā nesting success and productivity within Waipapa was significantly greater than that observed in similar but unmanaged sites (Moorhouse et al. 2003; Powlesland et al. 2009). Between 2001 and 2007 pest management was reduced to a 'pulsed' regime on a consecutive 2-year-off, 2-year-on cycle with pest control (again using toxins targeting possums and rats) only occurring in 2004 and 2005 (I. Broekema, NZ Department of Conservation, pers. comm.).

Survey methods

North Island kākā were counted within 1150 ha of Waipapa (Fig. 1). Kākā were counted from points using a variant of the Variable Circular Plot Method (VCPM) (Fancy 1997; Marsden 1999; Nelson & Fancy 1999). Although line transects are generally considered more efficient and possibly less biased than point counts (Thompson et al. 1998; Buckland et al. 2001; Cassey et al. 2007), the often cryptic behaviour exhibited by kākā, and the structural complexity and density of this forested habitat, suggested point counts would yield higher encounter rates than line transects for effort expended. Forest height, density, and canopy complexity required active and intensive searching about points by trained observers or waiting until birds moved and revealed their locations.

Throughout the study area 131 point count stations were distributed systematically, with random start points, using a grid based on pre-existing possum and rat bait-station lines at 300-m centres (Fig. 1). All peripheral points were a minimum of 150 m from the forest edge to reduce the potential for edge effects in bird distribution and sampling of unimportant habitats such as pastoral grassland. This design ensured that the majority of forest habitat types within Waipapa were likely to be surveyed in proportion to the area covered and with equal probability of coverage. Each point was visited once during each of 13 sampling periods between October 2000 and October 2007. In practice, surveying all sample points took

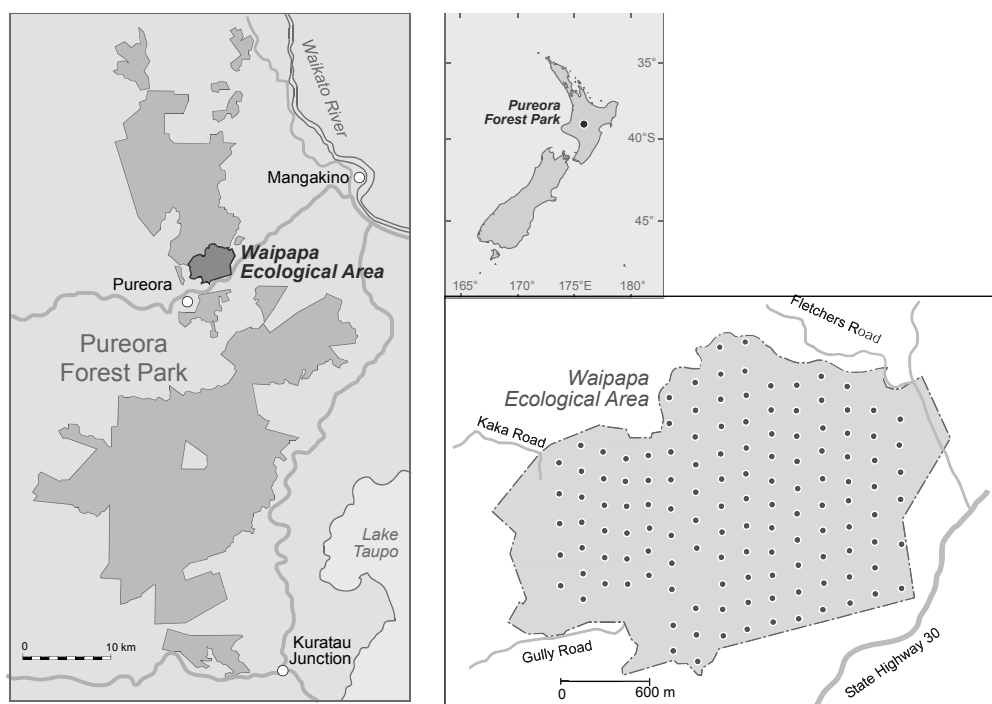


Figure 1. Location of study area and approximate distribution of sampling points (black dots) for kākā within the Waipapa Ecological Area, Pureora Forest Park.

two observers a minimum of 10 half-days to complete. A minimum target of 80 distance measurements (Buckland et al. 2001) recommend 80–100 observations for point counts) to individual or groups of kākā during each sampling occasion was set in an attempt to maximise the precision of detection functions. Counting commenced no earlier than one hour after sunrise and was usually completed prior to midday (when kākā become less obvious), and was conducted 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) (Harrison & Saunders 1981; Buckland et al. 2001).

Observers approached each point with caution to avoid flushing undetected kākā at or close to the point. If birds were flushed and were able to be identified (<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 min was used, to try to maximise detection of kākā within a radius of 100 m (birds beyond this distance were ignored), increase the probability of detecting birds at zero distance (Marsden 1999), and minimise the chances of birds moving undetected into the count area from outside and reduce the chances of an observer counting the same bird more than once. Each 10-min period was also divided into five 2-min blocks (between 2000 and 2003 only) to assess the optimal length of the count period. Kākā were located throughout the 10-min count and distance measurements were recorded at the end of this period using the ‘snapshot’ approach advocated by Buckland et al. (2001) and Buckland (2006).

Horizontal distances to all birds (or clusters) were recorded to the nearest metre relative to the count point, using a laser range-finder (Bushnell Yardage Pro 500™). Distances less than the minimum focal distance of the rangefinder (5–14 m depending on the model) were estimated visually, paced out, or measured using a tape. Distances to those birds only heard or not clearly seen (the majority) were estimated where possible by measuring the distance to vegetation at an equivalent distance. This often meant that observers moved away from the count point for brief periods to ensure the accuracy of measurements.

As there was initial uncertainty over the scale (temporal and numeric) and frequency of natural aggregations and the impact that aggregation might have on detection probability for kākā, all birds were recorded as clusters (of one or more). 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. Where birds were encountered as clusters, the distance to the approximate geometric centre of the cluster and the number of birds in the cluster were also recorded (Marsden 1999). Most detected clusters were of birds that were heard and not seen. This potentially biased density estimates as we were often unable to confirm group sizes, but as the majority of those birds that were seen were alone this bias was likely to be small.

Kākā flying into or over the plot area were recorded, but ignored in the analysis to avoid overestimates of density (Buckland et al. 2001). Every effort was made to avoid counting birds more than once, by noting the location of birds seen or heard and listening for movement within the survey area (kākā have relatively distinct and noisy wing beats and can also drop considerable amounts of debris when feeding). Birds flying out of the plot area were only recorded if their point of origin could be identified and the distance to that point 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, the immediate area surrounding the point (an approximate radius of 20 m from the point) was checked again (by walking around the point and focusing on the area above the point) at the end of each count period for birds that had been present but undetected (Marsden 1999).

Several preliminary counts were conducted prior to October 2000 to check the feasibility of implementing distance sampling methods and the general survey design. These pilot counts allowed us to assess the likelihood of achieving the required number of detections and to estimate the precision of the chosen sampling design. We also made a

preliminary evaluation of our ability to meet the critical assumptions of distance sampling based on our field observations and how we might improve the initial sampling design to minimise bias arising from such failure.

Kākā density estimation

Data were examined and analysed using the free software DISTANCE (<http://www.ruwpa.st-and.ac.uk/distance>) (Thomas et al. 2002). As distance measurements were thought to be accurate and there was little apparent movement of kākā in response to observers, data were left ungrouped (i.e. not aggregated into distance intervals) during analysis (Buckland et al. 2001). Histograms of the radial distance measurements were constructed and detection functions, $\hat{f}(r)$, were fitted using those models and appropriate expansion functions recommended by Buckland et al. (2001). Data truncation within the 100-m limit imposed on field observations was judged unnecessary, as for almost all survey occasions the detection function at the 100-m truncation point was less than 0.1 (i.e. $\hat{g}(w) < 0.1$) (Buckland et al. 2001) and truncation consistently reduced model fit and precision for both pooled and individual count periods. Good model fit, using comparison of Akaike’s Information Criterion (AIC), goodness of fit statistics (GoF), and Q-Q plots (Buckland et al. 2001, 2004; Burnham & Anderson 2002), was usually attained using half-normal or uniform models with varying numbers of adjustment terms.

The precision of the detection functions and derived estimates were assessed in two ways. Firstly, individual surveys were treated as subsets of all records with density estimates for each survey computed using a pooled detection function. This approach maximises the sample size and produces precise density estimates for all survey periods provided that the detection function remains constant over time. Secondly, density estimates were derived from detection functions calculated for individual surveys.

Results

A minimum of 116 points (March 2005) and a maximum of 131 points (October 2001 and March 2002) were visited during each of the 13 survey periods between October 2000 and October 2007. Kākā were observed at 44% of points for all surveys and were seen at 30–63% of points during any one survey period. Distances to a total of 1396 kākā were recorded. Of these, only 107 clusters (8%) of more than one bird (range 2–5) were noted. Modal cluster size was one and the mean cluster size for all detections was only 1.2 (95% CI = 1.08–1.30). As the impact of clusters on density estimates was likely to be minimal (L. Thomas and D. Borchers, CREEM/RUWPA University of St Andrews, pers. comm.), cluster size was ignored during analysis.

Around 80% of birds were detected within the first 7 min of the count period (Fig. 2). However, the data also indicate that an asymptote in detections only occurs after 10 min. This suggests that either a significant number of kākā were not detected for most of the count period, or birds were constantly moving into the plot area. Searches of the area immediately surrounding each count point detected fewer than 10 birds and suggested that detection of kākā over time was largely a function of the large size of plots (31.4 ha) and the density and complexity of forest structure rather than any systematic undetected movement into the area.

More than 75 distance measurements to either individuals or clusters (range 75–200) were recorded for all but one of the survey periods (October 2002) and could usually be achieved within a 2-week period by two observers. However, only 52 distance measurements to kākā were recorded in October 2002, making estimation of a useful detection function difficult. Without an accurate model of the decline in detection probability of kākā with increasing distance from the observer for the area surveyed, accurate and precise estimates of population density will not be possible.

Although the detection probability ($\hat{f}(r)$) for kākā within Waipapa declined relatively slowly and in a uniform fashion over

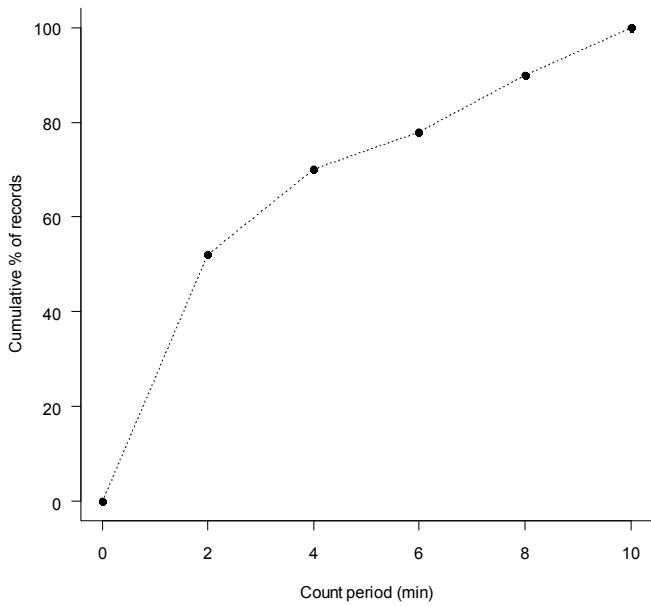


Figure 2. Cumulative percentage of kākā detected in 2-min intervals within the 10-min count periods used during point counts employing distance sampling.

the 100-m-radius area surveyed, adjustments must be made (i.e. transformation of detection probabilities into probability densities) to account for the increased area surveyed as distance from the point increases (Fig. 3). We then compared density estimates from uniform, half-normal, and hazard-rate detectability models, firstly, pooled across count periods between October 2000 and February 2003 and, secondly, for all individual count periods.

A half-normal model with no adjustments was found to be a good general fit (GoF $P = 0.30-0.94$) for all data pooled across survey periods and was used in the first instance to derive density and abundance estimates (Table 1). Subsequent independent modelling of the data for each of the survey periods highlighted a number of competing models ($\Delta AIC < 3$; Burnham & Anderson 2002) with good fit (Table 2). Uncertainty surrounding model selection was addressed using a model averaging procedure (Burnham & Anderson 2002) that introduces an additional variance component to better reflect the precision of density and confidence interval estimates (Table 2).

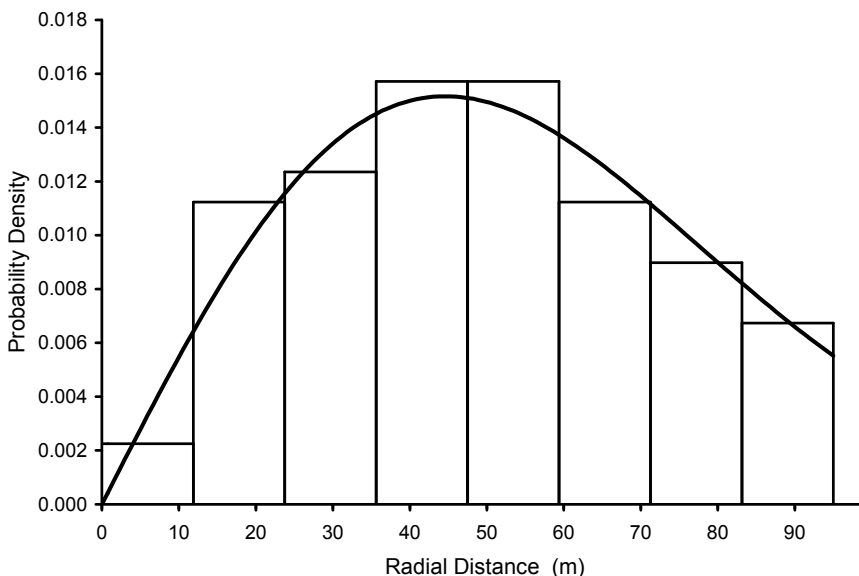


Figure 3. Typical example of a kākā probability density (\hat{f}) graph obtained using program DISTANCE for the Waipapa Ecological Area in March 2001. The curve is the detection function (model = half-normal with no adjustment terms and a GoF Chi- $P = 0.94$ ($n = 75$)) representing the probability that a kākā will be detected at a given distance.

With the exception of October 2002, estimates of density and abundance between October 2000 and February 2003 are very similar for both stratified and independent analyses, and a common value for $\hat{g}(0)$ might be assumed. However, as there were variations in survey timing, bird behaviour and observers, a common value for $\hat{g}(0)$ seemed unlikely. Additionally, the sum of AIC values calculated across all strata (i.e. for survey periods between October 2000 and February 2003) is considerably lower than the AIC value from the pooled analysis for the same period. The use of a common global detection function, therefore, did little to improve either model fit or precision (Buckland et al. 2001). Thus, detection functions were fitted separately for each survey period and these results used in preference to those derived from the limited pooled-analysis estimates.

The model-averaged density estimates and corresponding 95% confidence intervals are graphed separately (Fig. 4) for surveys conducted in October (pre-breeding) and February–March (post-breeding). Density estimates for kākā in October show little in the way of a trend and this is reflected in the slopes of the simple linear regression models fitted to the data. When the density estimate for October 2002 is included (Fig. 4a) the trend estimate (slope) is slightly positive (+0.007 with 95% CI of $-0.05, +0.07$). If this data point is removed (because of the small sample size, poor model fit, unreliable density estimate) (Fig. 4b) the trend becomes slightly negative (-0.006 with 95% CI of $-0.02, +0.03$). Regardless, any trend over the 7-year survey period is minimal.

Although the density estimates for February–March surveys (Fig. 4c) are generally less precise than those seen in October, the estimates are (with the exception of March 2006) of the same general magnitude as the density estimates calculated for the October survey periods.

Discussion

Evaluation of distance sampling assumptions

Perhaps the most important assumption of distance sampling is that all objects of interest (in this case kākā) are detected with certainty at or close to the sample point ($g(0) = 1$) (Buckland et al. 2001; Bächler & Liechti 2007). When the absolute detection probability is less than one, density is underestimated proportional to the decrease in $g(0)$.

Due to the often cryptic nature of kākā, the complex forest structure (multi-tiered), and high vegetation density within Waipapa, we anticipated difficulties in meeting this assumption. Consequently, considerable effort was made to minimise violations of this assumption by undertaking surveys during seasons and at times of day when kākā

Table 1. Kākā density (\hat{D}) and abundance (\hat{N}) estimates for the Waipapa Ecological Area derived from a global detection function pooled across survey periods from October 2000 to February 2003. Parameter and variance estimates based on the model with the smallest Akaike's Information Criterion (AIC) value.

Season	Model (Key+adjust.)	n	GoF ¹ Chi- P	\hat{D} & \hat{N} %CV	\hat{D}	\hat{D} 95% CI	\hat{D} 95% bootstrap CI	\hat{N}	\hat{N} 95% CI	\hat{N} 95% bootstrap CI
Oct. 2000	Hnorm.+herm ²	89	0.62	18.7	0.56	0.39–0.81	0.36–0.84	646	448–931	415–961
Mar. 2001	Hnorm.+herm	75	0.94	20.0	0.61	0.42–0.91	0.39–1.15	706	478–1043	454–1324
Oct. 2001	Hnorm.+herm	127	0.69	15.9	0.64	0.47–0.87	0.44–1.18	734	538–1002	502–1361
Mar. 2002	Hnorm.+herm	97	0.47	16.8	0.81	0.58–1.12	0.50–1.91	930	669–1293	574–2200
Oct. 2002	Hnorm.+herm	52	0.31	27.2	0.24	0.14–0.41	0.13–0.48	275	162–467	154–550
Feb. 2003	Hnorm.+herm	99	0.30	17.6	0.61	0.43–0.87	0.41–0.83	705	500–995	470–956

¹GoF = godness of fit.²Half-normal model with a Hermite polynomial adjustment term.**Table 2.** Model averaged density (\hat{D}) and abundance (\hat{N}) estimates for kākā in the Waipapa Ecological Area using independent detection functions for each survey period between October 2000 and October 2007.

Season (n)	Model ¹ (key + adjust.)	Δ AIC ²	GoF ³ Chi- P	\hat{D}_i	\hat{D} & \hat{N} %CV	w_i (Akaike weight)	\hat{D}^4 ($\sum w_i \hat{D}_i$)	log 95% CI (bootstrap)	\hat{N}^5 ($\sum w_i \hat{N}_i$)	log 95% CI (bootstrap)
Oct. 2000 (89)	Hnorm+herm.	0.0	0.90	0.56	18.7	0.35	0.56	0.36–0.76 (0.32–0.81)	644	414–874 (368–931)
	Unif.+cos.	0.15	0.91	0.60	16.7	0.33				
	Unif.+poly.	1.29	0.83	0.53	16.5	0.19				
	Hazrate+cos.	2.03	0.82	0.51	22.8	0.13				
Mar. 2001 (75)	Hnorm+herm.	0.0	0.88	0.61	20.0	0.38	0.60	0.37–0.84 (0.26–0.95)	690	426–966 (299–1092)
	Unif.+cos.	0.13	0.89	0.62	17.3	0.36				
	Hazrate+cos.	2.03	0.69	0.57	25.7	0.14				
	Unif.+poly.	2.30	0.96	0.58	19.8	0.12				
Oct. 2001 (127)	Unif.+poly.	0.0	0.98	0.57	12.1	0.32	0.63	0.45–0.81 (0.37–0.89)	725	518–931 (426–1023)
	Hnorm+herm.	0.20	0.96	0.64	15.9	0.29				
	Unif.+cos.	1.20	0.99	0.72	14.0	0.18				
	Unif.+cos.	1.60	0.83	0.67	14.8	0.15				
Mar. 2002 (97)	Unif.+cos.	0.0	0.89	0.89	17.5	0.46	0.88	0.55–1.21 (0.23–1.53)	1012	633–1391 (265–1759)
	Hnorm+herm.	0.47	0.83	0.87	19.3	0.37				
	Unif.+poly.	2.02	0.79	0.88	22.4	0.17				
	Unif.+cos.	0.0	0.73	0.17	17.8	0.46				
Oct. 2002 (52)	Hnorm+herm.	0.34	0.99	0.24	27.2	0.39	0.21	0.09–0.34 (0.0–0.48)	242	104–391 (0–552)
	Hazrate+cos.	2.27	0.86	0.26	58.1	0.15				
	Hnorm+herm.	0.0	0.83	0.61	17.6	0.30				
Feb. 2003 (99)	Unif.+cos.	0.09	0.78	0.63	14.9	0.29	0.60	0.40–0.80 (0.38–0.82)	690	460–920 (437–943)
	Unif.+poly.	1.23	0.76	0.56	15.3	0.16				
	Unif.+poly.	1.54	0.75	0.59	17.7	0.14				
	Hazrate+cos.	2.14	0.80	0.54	20.9	0.11				
Oct. 2003 (100)	Unif.+cos.	0.0	0.74	0.59	17.74	0.40	0.60	0.47–0.72 (0.37–0.82)	684	519–849 (399–969)
	Hazrate+cos.	0.97	0.75	0.62	29.78	0.24				
	Hnorm+cos.	1.30	0.60	0.57	19.07	0.21				
	Unif.+poly.	1.93	0.68	0.59	20.02	0.15				
Oct. 2004 (95)	Unif.+cos.	0.0	0.01	0.51	17.70	0.33	0.49	0.39–0.59 (0.28–0.70)	565	297–833 (166–964)
	Hnorm+cos.	0.23	0.01	0.49	18.84	0.30				
	Hazrate+cos.	0.79	0.01	0.52	33.43	0.23				
	Unif.+poly.	1.68	0.01	0.41	15.68	0.14				
Mar. 2005 (119)	Unif.+cos.	0.0	0.01	0.56	18.64	0.43	0.54	0.38–0.70 (0.33–0.76)	623	288–957 (222–1023)
	Hnorm+cos.	1.10	0.01	0.50	17.49	0.25				
	Unif.+poly.	1.50	0.01	0.57	21.53	0.20				
	Hazrate+cos.	2.60	0.01	0.52	55.70	0.12				
Oct. 2005 (141)	Unif.+cos.	0.0	0.44	0.72	14.14	0.46	0.73	0.60–0.87 (0.47–1.00)	843	591–1095 (438–1247)
	Hazrate+cos.	1.73	0.50	0.82	31.30	0.19				
	Unif.+poly.	1.77	0.35	0.72	16.02	0.19				
	Hnorm+cos.	2.03	0.33	0.67	14.78	0.17				

Mar. 2006 (200)	Unif.+cos.	0.0	0.94	1.39	18.46	0.51	1.43	0.82–2.04 (0.60–2.21)	1645	0–3859 (0–4237)
	Unif.+poly.	1.38	0.93	1.34	17.82	0.25				
	Hazrate+cos.	1.48	0.88	1.61	31.36	0.24				
Oct. 2006 (84)	Unif.+cos.	0.0	0.25	0.55	20.90	0.46	0.53	0.31–0.77 (0.48–1.04)	617	269 965 (0–1273)
	Hnorm.+cos.	0.52	0.28	0.51	21.80	0.36				
	Unif.+poly.	1.88	0.18	0.54	22.52	0.18				
Oct. 2007 (118)	Unif.+poly.	0.0	0.91	0.50	13.21	0.32	0.51	0.39–0.62 (0.37–0.64)	583	359–806 (342–824)
	Hnorm.+cos.	0.27	0.86	0.55	17.15	0.28				
	Hazrate+cos.	0.81	0.92	0.46	17.25	0.21				
	Unif.+cos.	1.12	0.88	0.51	29.79	0.18				

¹Model consisting of a key function (uniform, half-normal or hazard-rate) and an adjustment term (cosine, simple polynomial or hermite polynomial).

²AIC values rescaled as simple differences ($\Delta_i = AIC_i - \text{minimumAIC}$).

³GoF = Goodness of Fit.

⁴Model-averaged density estimate.

⁵Model-averaged abundance estimate.

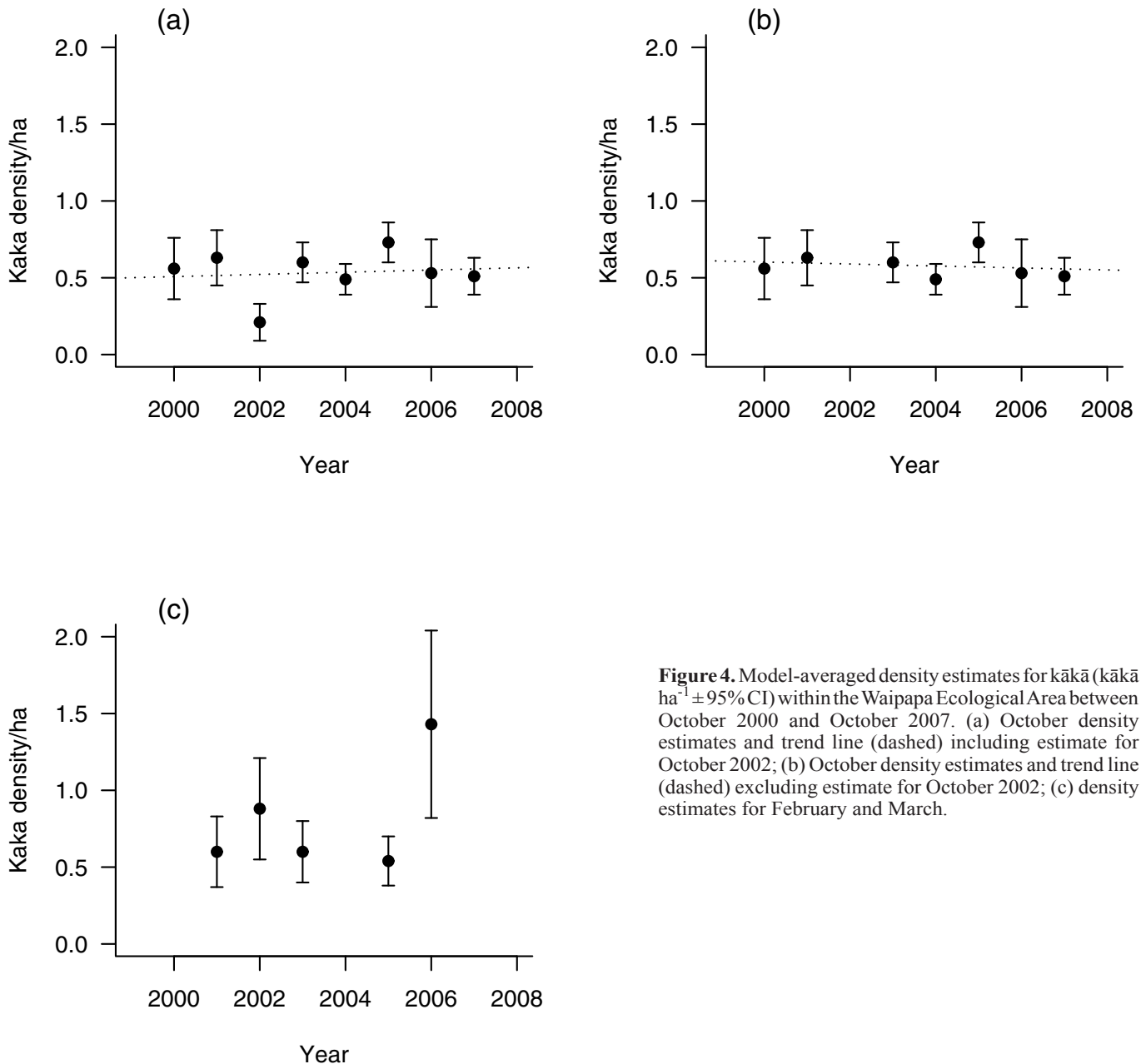


Figure 4. Model-averaged density estimates for kākā (kākā ha⁻¹ ± 95% CI) within the Waipapa Ecological Area between October 2000 and October 2007. (a) October density estimates and trend line (dashed) including estimate for October 2002; (b) October density estimates and trend line (dashed) excluding estimate for October 2002; (c) density estimates for February and March.

were most vocal, ensuring that all counts were made over a relatively long (10 min) location period, and training observers. Intensive scans of the area immediately surrounding each survey point and immediately following each count revealed very few birds (<1% of all birds detected) not previously detected during the 10-min count period. We are therefore confident that most birds at or near the point were detected and thus confident that the assumption $g(0) = 1$ was met (Buckland et al. 2001).

We also found that undetected movement of kākā in response to observer presence (the second important assumption of distance sampling) was insignificant. When detected, kākā were usually high above the ground and generally ignored observers moving quietly about on the forest floor. In the few instances where birds were recorded moving in response to the presence of an observer, their loud calls or distinctive audible wing beats usually enabled observers to accurately determine the position from which they had departed. Undetected kākā movement was potentially more problematic, as there was a risk of counting the same individual more than once. Fortunately kākā are relatively immobile over short time frames, and undetected movement, particularly when in close proximity to an observer, is likely to be rare. Although Fig. 2 suggests that a count period longer than 10 min is likely to record higher numbers of kākā, counts of longer duration also increase the time (and cost) taken to cover the area being surveyed, the risk of counting individuals more than once, and the risk of undetected movement into the area biasing density estimates upward. We are, therefore, confident that the assumption of no movement in response to observer presence prior to detection was met for kākā inhabiting Waipapa.

The accurate measurement of distances to individuals or groups is also an important assumption of distance sampling methods. Accurate distance measurements are particularly important for point counts, as bias arising from measurement error varies geometrically with distance (Bibby et al. 2000). Point counts of kākā in this study relied primarily on auditory (>90% of observations) rather than visual cues and were potentially subject to errors from sound attenuation caused by call quality and orientation, habitat structure, environmental conditions and observer acuity (Bibby et al. 2000; Buckland et al. 2001). These errors can be substantial and can result in severely biased estimates of abundance (Allredge et al. 2007). To minimise violations of this assumption and reduce the scale of these errors, we ensured that all observers were trained to use laser rangefinders to record distances. Training also enabled observers to become familiar with the behavioural traits of kākā. Kākā are large and often quite noisy birds that tend to call loudly from tall emergent trees. Such calls are useful for locating more distant individuals (out to 100 m), particularly as observers had the ability to move away from the point to better assess call location. The low levels of kākā movement during the relatively long count period, low encounter rates, and the ability to concentrate on detection of species-specific cues improved measurement accuracy and further reduced the impact of distance measurement error.

Despite these efforts and in the absence of proven error-modelling-methods that produce unbiased density estimates (Allredge et al. 2007), bias is inevitable and, until its magnitude can be quantified, interpretation of kākā density estimates should be made with some caution. Poor model fit (GoF = 0.01) for the October 2004 and March 2005 surveys was likely the direct result of using observers with limited familiarity with kākā behaviour and calls, resulting in increased location and distance estimation errors (Buckland et al. 2001).

The systematic distribution of sample points along parallel lines ensured equal coverage probabilities throughout a defined area of Waipapa. Although this is simply good study design (Thompson et al. 1998), it should be noted that practical constraints can often make the application of such designs extremely difficult, particularly in areas that are densely forested, steep, or difficult to access. The 300-m spacing of points ensured that point selection was independent of both kākā distribution and any real and/or perceived environmental gradients, and meant there were plenty of replicate points from which encounter rate variances and realistic confidence intervals could be

constructed. We are, therefore, confident that of all the assumptions discussed thus far, this assumption is the most likely to have been met and the least likely to have contributed toward biased density estimates.

A thorough understanding of an animal's ecology and behaviour is clearly important to study design. Generally, we found the kākā population within Waipapa a good candidate to sample using distance sampling methods, with the most likely sources of bias being location error and the accuracy of distance measurements. However, without knowledge of the actual number of kākā within Waipapa, a more objective approach to testing the sampling method is unlikely. That said, there is obvious potential for further employment of distance sampling as a monitoring tool for single-species bird monitoring programmes in New Zealand and, where possible, application of the method should be investigated and encouraged.

Kākā density

With the exception of the October 2002 and March 2006 surveys, the general trend for kākā at Waipapa between 2000 and 2008 was stable but with discernable pre- and post-breeding seasonal variation. Fortunately the seasonal pattern reflected an expected slight increase in kākā density between October and March in years kākā bred (2001–02, 2003–04, 2004–05 and 2005–06). Although the sample size was small, this seasonal pattern was more apparent when breeding years corresponded with reductions in predator (stoats, possums and rats) numbers (2001–02, 2004–05 and 2005–06). For example, between October 2001 and March 2002 kākā density increased by 0.25 birds ha^{-1} within Waipapa. Density decreases between March and October survey periods presumably reflect a combination of post-breeding juvenile dispersal from the study area and relatively high juvenile mortality over the following winter period.

The comparatively low figure obtained in October 2002 (Table 2; Fig. 4a) appears to be an artefact of the low number of recorded observations (and consequent model construction difficulties) (Diefenbach et al. 2003) and should be regarded as a significant underestimate given the much higher March 2003 estimate and the fact that no breeding was recorded during this period. The much higher kākā density calculated for March 2006 is harder to explain. We do know that this survey followed a breeding year when numbers of highly mobile and noisy juveniles were present, increasing the risk of double-counting individuals (density inflation) and increasing the variance of detection probabilities (reduced precision). Whatever the cause, it seems clear that this density figure was unusually high, particularly given the results of subsequent surveys.

Despite the density of kākā within Waipapa (approx. 0.5 birds ha^{-1}) appearing high in comparison with other comparable mainland habitats (O'Donnell & Dilks 1986; Greene & Fraser 1998; Moorhouse et al. 2003), the calculated estimates are supported by the small percentage of birds (6.5%) recaptured during tagging operations over the survey period and the apparently high survival rate of breeding-age adults (T. Greene, unpubl. data).

Even though the use of a linear trend model is comparatively simple, it is easy to interpret and informative enough to explain relatively short time-series (Thomas et al. 2004). The lack of any obvious trend in October kākā density estimates within Waipapa between 2000 and 2007 suggests the density of birds is static. Although kākā are known to have attempted to breed at least four times over this period, predator control (principally targeted at possums and rats) occurred in only four of the eight survey years (2000–01, 2001–02, 2004–05 and 2005–06) and was not always entirely successful in maintaining low predator densities (H. Matthew and I. Broekema, NZ Department of Conservation, pers. comm.). Additionally, egg mortality was high and overall productivity relatively low for much of the survey period (Powlesland et al. 2009) and there was no evidence for recruitment of radio-tagged juveniles into the Waipapa breeding population.

Fertility problems and poor hatching success caused by population age structure or genetic bottlenecks (Briskie & Mackintosh 2004) seem unlikely explanations for the relatively low productivity (at least in comparison with other sites where predators were being controlled),

as substantial levels of genetic variability, maintained by ongoing gene flow, have been reported from mainland kākā populations (Sainsbury et al. 2006). The observed lack of juvenile recruitment seems simply to be a function of dispersal into and mortality in surrounding areas (population sinks) where there was no pest control and failure of transmitters before breeding activity could be detected. Thus, it seems likely that kākā density has reached a point beyond which further population increases are doubtful without further significant investment in frequency, intensity, and extent of the current predator control programme.

Implications for management

The measurement of trend from density estimates derived from multiple survey occasions is of particular interest to conservation managers. Identification of trends becomes especially important for managing threatened species such as kākā that have erratic breeding cycles of variable quality (Powlesland et al. 2009). Using density or abundance estimates to assess the success (or otherwise) of management actions (e.g. large-scale sustained pest control programmes) is only possible if long-term population changes can be separated from short-term fluctuations in numbers and the trend estimate is reasonably precise (Thomas et al. 2004). Repeated measures at the same survey points and the use of density estimates from a consistent time of year (October) reduces seasonal variation (e.g. the influence of erratic productivity for March estimates) and increases the precision of trend estimates.

Although the density estimates and short-term trends for the Waipapa kākā population seem reasonable, distance sampling methods may not always work well for all kākā populations. Behavioural peculiarities, the types of habitats being sampled (forest height, foliage density, topography), and population densities all have some effect on the ability of observers to meet distance sampling's key assumptions. Many of these issues can potentially be addressed within a multiple-covariates distance sampling (MCDS) framework (Marques et al. 2007) – an analysis approach available in more recent versions of the DISTANCE analysis software (Thomas et al. 2005).

The apparent effectiveness of our survey design in minimising assumption violations and the consistency of our October kākā density estimates relative to the number of birds captured in the area suggest that our assessment of population trend is realistic and consistent with the breeding frequency of kākā and the pulsed nature of predator control within Waipapa. Future changes in this trend are, however, inevitable as pest control regimes change and resource levels fluctuate. Thus, managers need to carefully consider: (1) how to maintain consistent study design and sampling protocols over the long term, (2) the scale of any population change likely to be of concern, and (3) the most appropriate intervention if these trigger points are exceeded. It is also worth noting that estimates of kākā density tell us little about the demographic structure of kākā populations and we strongly recommend that information on other parameters such as sex ratio and survival are collected periodically to calibrate population trend estimates and to inform and improve our predictive population models.

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