



Distance sampling to estimate densities of four native forest bird species during multi-species surveys

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Abstract: The suitability of line-transect-based distance sampling to robustly estimate population densities of bellbird (*Anthornis melanura*), kererū (*Hemiphaga novaeseelandiae*), North island tomtit (*Petroica macrocephala toitoi*) and tūī (*Prosthemadera novaeseelandiae*) during concurrent multi-species surveys was investigated. Densities were estimated annually from 2006 to 2009 at three sites within Coromandel Forest Park, New Zealand. The line-transect distance sampling method appeared to be suitable for estimating population densities of kererū, tomtit and tūī for little additional cost than a single-species survey. Potential violation of the three most important distance sampling assumptions was expected to have been minimised for these species; however, distance estimation errors were most likely to bias density estimates. In this study, the line-transect distance sampling method was not found to be suitable for estimating bellbird densities.

Keywords: bellbird; kererū; tomtit; tūī

Introduction

Predation by introduced pest mammals is the primary cause of current declines in New Zealand forest bird populations (Innes et al. 2010). Effective pest control programmes are known to improve the breeding success and survival of native forest bird species, such as the North Island kōkako (*Callaeas wilsoni*) (Innes et al. 1999), kererū (*Hemiphaga novaeseelandiae*) (Innes et al. 2004) and North Island kākā (*Nestor meridionalis septentrionalis*) (Moorhouse et al. 2003). To assess the effectiveness of pest control programmes and plan to maximise pest control efficiency, conservation managers require reliable data that estimate bird population density trends combined with data that show concurrent pest densities (Basse et al. 2003). Methods that robustly detect changes in the densities of vulnerable forest bird populations and mammalian pests are therefore important for effective conservation management (Bidley 1999; Bidley et al. 2000; Williams et al. 2002).

Five-minute bird counts (Dawson & Bull 1975) have been widely used to provide an index of relative abundance for bird populations in New Zealand (Gaze & Clout 1983; Spurr et al. 1992; Innes et al. 2004; Spurr & Anderson 2004; Hartley 2012). Indices of relative abundance depend on real bird abundance, and the detectability of the species of interest. The accuracy and reliability of estimated abundance are often influenced by variation in the environment, species behaviour and observer

influences (Bidley & Buckland 1987; Diefenbach et al. 2003; Marques et al. 2007; Innes et al. 2012).

Distance sampling has been widely promoted as a solution to the issue of variable detectability (Buckland et al. 2001; Buckland 2006). Distance sampling is a set of methods in which distances to detected species from a line or point are used to estimate the probability that a target species is detected. These distances are then modelled using various detection functions and applied to generate density and abundance estimates. Distance sampling methods can produce reliable estimates of animal densities when they meet three assumptions: (1) subjects on the line or point are detected with certainty; (2) subjects are detected at their initial location, before any movement in response to the observer has occurred; and (3) distances from the line or point to the subject are measured accurately (Buckland et al. 2001). In addition, sufficient sightings of birds must be made so that the method can generate reliable density estimates. Buckland et al. (2001) suggest a minimum of 60 detections for line-transects.

Distance sampling methods trialled on New Zealand forest birds have successfully estimated population densities of kākā (Greene et al. 2010), North Island saddleback (*Philesturnus rufusater*) (Brunton & Stamp 2007; Cassey et al. 2007) and North Island tomtit (*Petroica macrocephala toitoi*) (Westbrooke et al. 2003). The difficulty of meeting the three primary assumptions of distance sampling, and producing accurate and reliable density estimates, should not be

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underestimated, and may be influenced by species behaviour, variation in their detectability, their rarity, the habitat in which they are found and the number of species counted (Alldredge et al. 2007; Bächler & Liechti 2007; Johnson 2008). Further studies to test distance sampling techniques on New Zealand forest birds have been recommended (Cassey et al. 2007; Greene et al. 2010, 2012).

This study investigates whether distance sampling can robustly estimate population densities of four selected forest bird species (bellbird (*Anthornis melanura*), kererū, North Island tomtit and tūi (*Prothemadera novaeseelandiae*)) during concurrent multi-species surveys. We determined if the three critical distance-sampling assumptions were met and comment on the performance of the method for each of the species monitored.

Methods

Study species

Bellbird, kererū, North Island tomtit and tūi were monitored because they represent several important guilds required for the healthy functioning of forest ecosystems. They have high fecundity and are vulnerable to predation by possums (*Trichosurus vulpecula*) and ship rats (*Rattus rattus*), and are easily detected (Heather & Robertson 1996; Higgins & Davies 1996; Higgins et al. 2001; Higgins & Peter 2002).

The bellbird is a sexually dimorphic (average weight: male 32.5 g; female 25 g) honeyeater endemic to New Zealand forests (Higgins et al. 2001). Both sexes sing year around to defend breeding territories and/or food resources, but song types and singing behaviour are different between sexes (Brunton & Li 2005). As the breeding season (September–January) progresses, the frequency of female singing sessions increases while male singing decreases (Heather & Robertson 1996; Brunton & Li 2005).

Kererū are a large (average weight 650 g) endemic New Zealand fruit pigeon (Higgins & Davies 1996). Kererū are often very cryptic when perched in the canopy but are easily distinguished by their wing beats in flight. Kererū are most conspicuous during the breeding season (September–February) when both sexes, but particularly males, perform display dives (Heather & Robertson 1996). Other noticeable behaviour includes chases, calling, and wing-flicking (Heather & Robertson 1996).

Tomtits are a small (average weight 11 g), common, sexually dimorphic, insectivorous endemic New Zealand forest passerine (Higgins & Peter 2002). Male tomtits are easily detected due to their loud territorial calls that are especially conspicuous between August and January (Heather & Robertson 1996; Higgins & Peter 2002). Territorial calls are often answered by a neighbouring male, while the short high-pitched contact call is used by both sexes (Heather & Robertson 1996).

Tūi are a large (average weight: male: 120 g; female: 85 g), forest honeyeater (Higgins et al. 2001). Both sexes sing, and the song dialect varies geographically (Heather & Robertson 1996). Singing (especially in the early morning and late afternoon) increases when territories are being established in September–October (Heather & Robertson 1996). Tūi produce a distinctive noise in flight, and are known to travel considerable distances to reach food resources (Heather & Robertson 1996). Tūi will aggressively drive other species

from feeding sites at great speed and with noisy wing beats (Heather & Robertson 1996).

Study sites

Three study areas (Tapu, Kauaeranga and Golden Cross) were established in Coromandel Forest Park, New Zealand (Fig. 1). Study sites were established in kauri/lowland podocarp–hardwood forest on land administered by the Department of Conservation, with ready access. Vegetation at the study sites is dominated by tawa (*Beilschmiedia tawa*), hīnau (*Elaeocarpus dentatus*), māhoe (*Meliclytus ramiflorus*), five-finger (*Pseudopanax arboreus*) and towai (*Weinmannia silvicola*), with scattered kauri (*Agathis australis*), rimu (*Dacrydium cupressinum*), tōtara (*Podocarpus totara*) and miro (*Prumnopitys ferruginea*). (Plant names follow the New Zealand Plant Names Database; Allan Herbarium 1996–2011.) Areas of similar forest type were identified using Land Resource Information System spatial data layers in ArcGIS (Newsome et al. 2000). Areas immediately adjacent to waterways and steep gully systems were excluded from the study sites to avoid terrain that would be difficult for observers to traverse, or where the detection of birds might have been limited by background noise.

The Tapu study site (37°00' S 175°34' E) comprises an area of 422 ha within the larger Tapu River possum and ship rat control area (786 ha). The site ranges from 220 to 480 m above sea level. Possum and rat control was undertaken in 1999 and 2002, using 1080 in bait stations, and in 2006 and 2009, using an aerial 1080 application. The Kauaeranga study site (37°03' S 175°35' E) is approximately 10 km south of the Tapu site; it is approximately 532 ha and situated within the larger Kauaeranga/Te Puru possum and rat control area (12 854 ha). The site ranges from 500 to 620 m above sea level. The Kauaeranga site received possum and rat control in 2005 and 2008 using an aerial 1080 application. Golden Cross (37°19' S 175°48' E) is situated 30 km south of the Kauaeranga site. The 716-ha study site ranges from 300 to 540 m above sea level. Broad-scale possum and ship rat control has not been conducted at this site although occasional small-scale trapping of possums for the sale of their fur had occurred prior to the commencement of this study. The vegetation at Golden Cross is less dense and diverse than at the Tapu and Kauaeranga study sites (I Jacobs, pers. obs), which is likely to be a consequence of the long history of browsing impacts from possums and goats (*Capra hircus*).

Line-transect establishment

Distance sampling was undertaken using a line-transect approach (Buckland et al. 2001). Twelve line-transects were established at each study site. Line-transects were between 300 and 450 m in length (measured using a hip-chain) and at least 200 m apart. At Tapu, six line-transects were set up along existing rat monitoring lines and six along old possum bait station lines (Fig. 1). Start points of rat monitoring lines were chosen, but bearings were random. Monitoring was undertaken annually from 2006 to 2009. At Kauaeranga, 12 line-transects were established using random start points and bearings. The number of transects were equally divided over the two main catchments within the study site (Fig. 1). Monitoring occurred annually from 2007 to 2009. At Golden Cross, six line-transects were set up along existing rat monitoring lines (with chosen start points and random bearings) and six along a walking route (Fig. 1). Monitoring was conducted annually from 2006 to 2009.

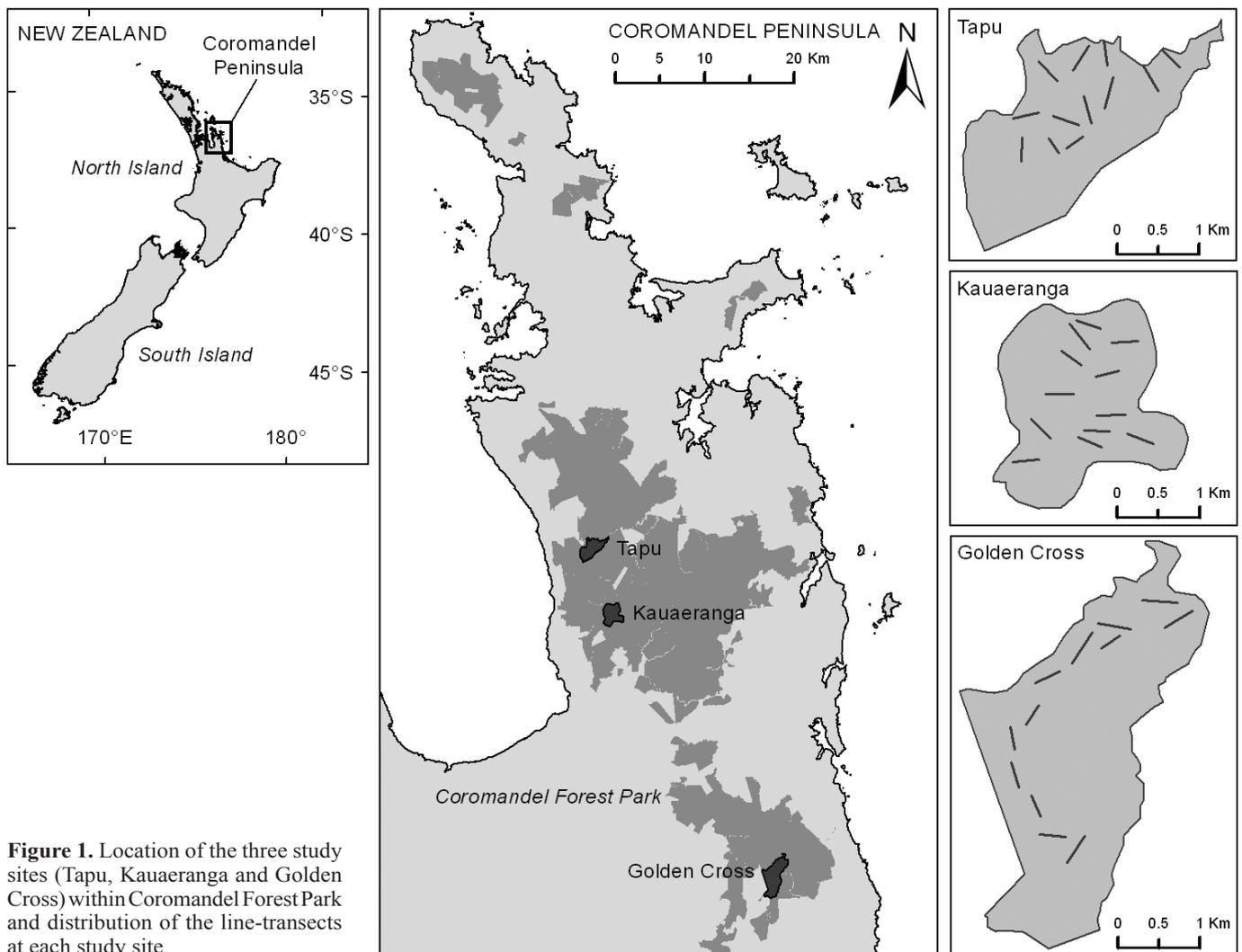


Figure 1. Location of the three study sites (Tapu, Kauaeranga and Golden Cross) within Coromandel Forest Park and distribution of the line-transects at each study site.

Distance sampling data collection

Monitoring was started in the second week of September and generally completed within 14 days. One observer was involved in data collection during all surveys (2006–2009) and provided field method training for other observers who assisted. Observers worked independently on different line-transects, between 0800 hours and 1400 hours, and only during fine weather (no rain or strong winds) to minimise bias and maximise the number of detections. Line-transects were generally traversed four times during each survey. Some transects at the Kauaeranga site were only traversed twice during the 2007 and 2009 surveys as long spells of bad weather prevented observers from re-entering the study site to complete the surveys within reasonable time frames. The total length of the line-transects sampled during each survey is presented in Table 1. Where possible, each line-transect was monitored at a different time of the day, in both directions and by different observers, to reduce any potential bias from both observers and temporal changes of bird behaviour during the monitoring periods.

Due to steep terrain and dense vegetation at the study sites, no birds were expected to be detected with accuracy from beyond 50 m of the line-transects. For this reason,

perpendicular, horizontal, distances from the line-transect to each bellbird, kererū, tomtit and tūī were recorded to the nearest metre within 50 m of either side of the line-transect, using a laser rangefinder (Bushnell Yardage Pro Sport 450). From 2008, laser rangefinders with built-in inclinometer function (Bushnell Yardage Pro Elite 1500 w/ARC and Bushnell Yardage Pro Scout 1000 w/ARC) allowed observers to more accurately measure horizontal distances to detected birds that were at higher or lower levels than the observer (e.g. on steep faces or in emergent trees). Accuracy of distances measured to birds that were seen was thought to be ± 1 m. Distances less than 5 m (minimum focal distance for a rangefinder) were estimated visually. Distances to those birds only heard, or not clearly seen, were estimated by measuring the distance to vegetation at an equivalent distance to the estimated position of the bird. Observers approached each line-transect with caution to avoid flushing undetected birds at or near the transect start point. Transects were walked at a slow and constant speed. Due to the steep and densely vegetated habitat, observers did not move away from the line-transect for more than a few metres to locate a heard bird. This was to ensure that birds on or near the line-transect were not missed. To prevent estimating distances from the same bird more than once, observers paid attention

Table 1. Total length of line-transects sampled during each survey, number of detections per survey, percentages of birds seen and total number of detections pooled across surveys for bellbird, kererū, tomtit and tūī at the Tapu, Kauaeranga and Golden Cross study sites in 2006–2009. The percentage of male tomtits singing a territorial song is also presented.

Site	Year	Total transect length (km)	Bellbird		Kererū		Tomtit		Tūī		
			<i>n</i>	% seen	<i>n</i>	% seen	<i>n</i>	% seen	% singing males	<i>n</i>	% seen
Tapu	2006	17.0	40	3	36	44	61	20	77	59	22
	2007	17.0	40	15	28	43	73	33	44	46	48
	2008	17.0	38	18	36	53	55	22	53	73	38
	2009	17.0	31	42	27	52	52	38	15	57	44
	Total	68.0	149	18	127	48	241	28	48	235	37
Kauaeranga	2007	18.0	97	5	21	48	131	34	42	21	43
	2008	19.5	34	21	12	50	133	17	62	26	35
	2009	17.0	21	24	7	57	158	29	33	35	28
	Total	54.5	152	19	40	53	422	27	45	82	33
Golden Cross	2006	19.8	6	33	19	21	63	27	52	14	14
	2007	19.8	32	6	10	40	105	22	50	12	17
	2008	19.8	20	5	10	70	67	16	49	6	17
	2009	19.8	2	0	7	29	60	15	45	7	71
	Total	79.2	60	8	46	37	295	20	49	39	26

to the movements of the birds seen. Particular attention was paid to ensure that distance estimates were made to their first position of detection. On occasions, birds were first detected by sound and then by sight when closer to the observer; in these cases distance estimates were made to the location where the bird was first heard. Birds that flew into or over the line-transect area were ignored to avoid overestimating densities. Where two or more birds were observed together, the distance to each individual bird was measured. Very few birds were found in clusters and the impact of clusters on density estimates was expected to be low (NZ Department of Conservation, unpubl. data).

Density estimation

Limited detections make estimation of a useful detection function difficult and may bias density estimates; for this reason data were analysed for each species only at sites where the total number of detections (pooled across surveys) was sufficient ($n > 60$; Table 1). As a result, data collected for kererū at the Kauaeranga site, and for bellbird, kererū and tūī at the Golden Cross site, were not analysed.

Data were analysed in Distance 6.0 (Thomas et al. 2009). No distinction was made between males and females or singing and non-singing birds. Data were not truncated more than the limit set in the field (50 m), as for most surveys the detection function at the 50-m point was less than 0.1 (Buckland et al. 2001), and truncation did not improve model fit. Data were generally not grouped into distance intervals for analysis; however, in a few cases where model fit was initially poor ($P < 0.05$), data were grouped into intervals to fit the detection function. Data were analysed independently for each species and site. Detection probability histograms were constructed for each survey.

Robust detection functions were fitted to the histograms based on guidelines in Buckland et al. (2001), and population density estimates were subsequently derived. To minimise potential bias in detection function between surveys, due to

limited sample size, data collected for bellbird and tūī at the Kauaeranga site, and kererū at the Tapu site (Table 1), were analysed using Conventional Distance Sampling (CDS) with a global detection function. The global detection function was derived by pooling the data from all surveys to maximise the sample size, followed by post-stratification to estimate population densities for each survey. For all other surveys, the precision of detection functions and derived density estimates were assessed in two ways: (1) data for each species and site were analysed using a global detection function followed by post-stratification, and (2) density estimates were derived using CDS with independent detection functions calculated for each species, survey, and site. The following details were compared for each analytical approach: Akaike's Information Criterion (AIC), visual inspection of the detection probability histograms, Q-Q plots, accuracy of calculated density estimates and corresponding confidence interval, Chi- P goodness of fit (GoF) statistics, and a version of the Cramér–von Mises (CvM) GoF statistic that weights lack of fit closer to the line-transect more heavily (Burnham et al. 2004). Once a preferred approach was selected, density estimates from competing models that provided good fits were averaged ($\Delta AIC < 2$; Burnham & Anderson 2002).

Results

Bellbird

A total of 149 bellbirds were detected at the Tapu site and 152 at the Kauaeranga site (Table 1). At these sites, the percentage of bellbirds seen was variable between surveys (range 3–42%; Table 1). Observers had noticed that bellbirds often flew away when being approached. Inspection of independent detection probability histograms highlighted a number of concerns for all but the 2009 survey at Tapu: (1) detection probabilities did not always decline with increased distances from the line-transect; (2) the detection function at the 50-m truncation point

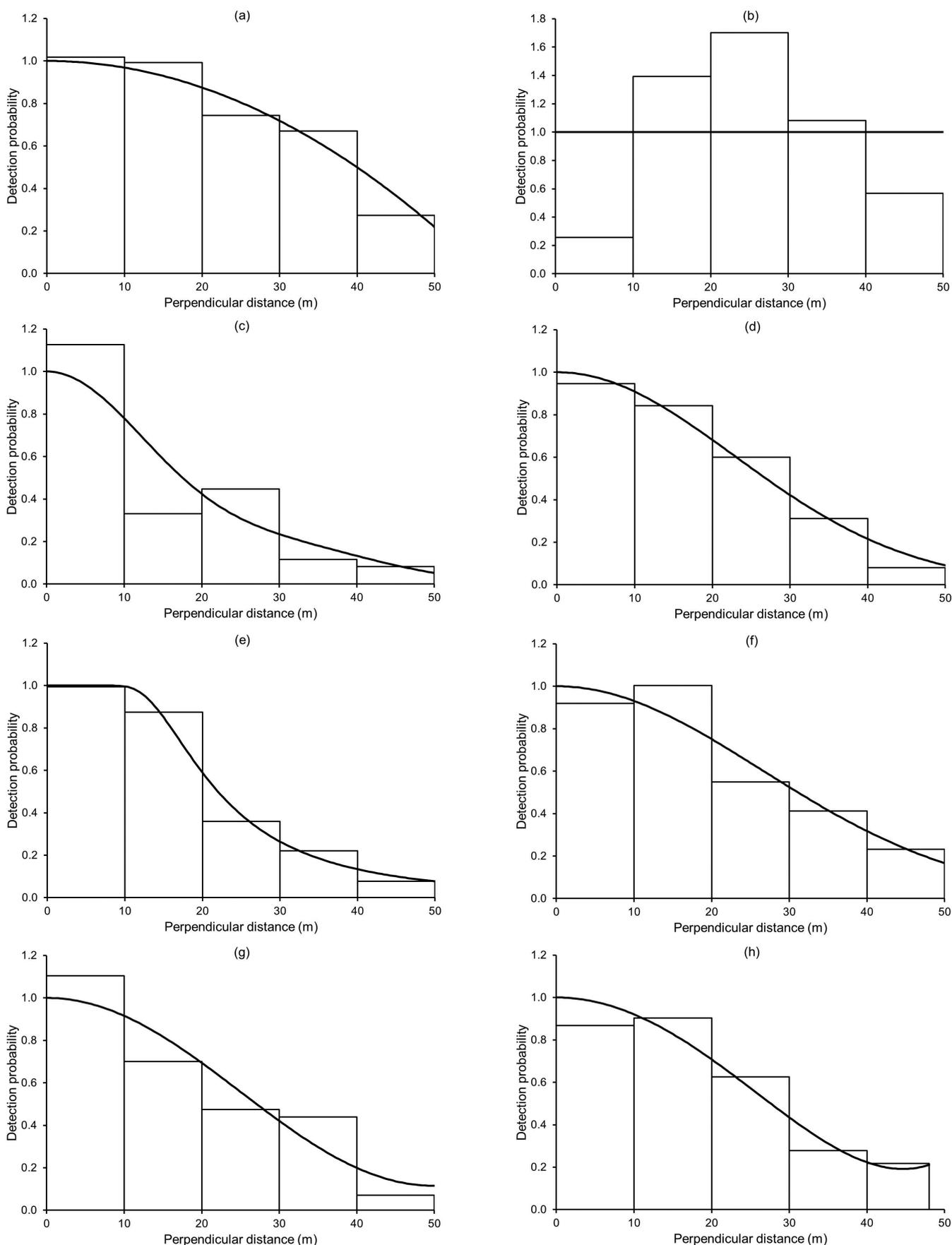


Figure 2. Global detection probability histograms for (a) bellbird at Tapu, (b) bellbird at Kauaeranga, (c) kererū at Tapu, (d) tomtit at Tapu, (e) tomtit at Kauaeranga, (f) tomtit at Golden Cross, (g) tūi at Tapu and (h) tūi at Kauaeranga. Detection functions (key function and adjustment term) fitted to the data are: (a) uniform simple polynomial, (b) uniform cosine, (c & d) half-normal cosine, (e) hazard-rate simple polynomial, (f) half-normal cosine and (g & h) uniform simple polynomial.

was sometimes greater than 0.1; (3) there was a tendency for detection distances to peak at 20–40 m; and (4) few bellbirds were detected close to the line-transect. Data from the 2009 survey at the Tapu site showed that the majority of bellbirds were seen within 15 m, and the detection probability declined with increased distances from the line-transect. A global detection probability histogram for distance data collected at the Tapu site is presented in Fig. 2a. A uniform detection function with a simple polynomial adjustment term fitted the pooled data well, which is likely related to the large number of detections made close to the line-transect during the 2009 survey. The sum of the AIC values calculated across individual surveys was lower than the AIC values from the pooled data, confirming that detectability was variable between surveys. Because of the rather large variation between the 2006–2008 surveys and the 2009 survey, density estimates derived from independent detection functions were preferred over those from the pooled data, and were used to estimate bellbird densities at the Tapu site (Table 2; Fig. 3a). The Cramér–von Mises GoF statistic, which weights lack of fit close to the line more heavily, indicated poor model fit when a detection function was fitted to the data from the 2006 survey ($P < 0.05$; Table 2). Grouping of the data into interval classes did not improve model fit. Data from the 2007 surveys initially also indicated poor model fit, but the fit improved ($P > 0.05$; Table 2) when distance data were pooled into four wide groups (0–15 m, 16–25 m, 26–35 m and 36–50 m). Data from the 2008 and 2009 surveys did not show any significant problems regarding model fit when detection functions were fitted ($P > 0.05$; Table 2). Because of low sample sizes (Table 1), estimated bellbird densities at the Kauaeranga site (Table 2; Fig. 3b) were derived from a global detection function. The global detection probability histogram (Fig. 2b) highlights the issues with the data as discussed previously, and model fit was poor. Both GoF statistics showed poor model fit when a global detection function was fitted to the data from the 2007 survey ($P < 0.05$; Table 2), and grouping of data did not result in an improved fit. Data from the 2008 and 2009 surveys provided better model fits ($P > 0.05$; Table 2). Without accurate models of the decline in detection probability with increased distance from the line-

transect, precise estimates of population densities could not be determined. With the exception of the 2009 survey at the Tapu site, bellbird density estimates (Table 2) are therefore not likely to reflect the actual population density or estimated density trends (Fig. 3a & b).

Kererū

Distances to 127 kererū were recorded at the Tapu site, of which 48% were detected by sight (Table 1). Most kererū were detected within 10 m of the line-transects, although there were slight peaks at detection distances of 20 m (2006 survey) and 25 m (2007 and 2009 surveys). The detection probability for kererū declined relatively rapidly and in a uniform fashion with increased distance from the line-transect, and very few kererū were detected beyond 30 m (Fig. 2c). Data were pooled across surveys and followed by post-stratification to estimate the population density for each survey (Table 3). To fit the detection function, distance data was pooled into four wide groups (0–15 m, 16–25 m, 26–35 m and 36–50 m). The Cramér–von Mises GoF statistic indicated poor model fit for data from the 2007 survey ($P < 0.05$). This is likely the result of a slight peak in detection distances between 0 and 2 m. No problems regarding model fit were found for the other surveys ($P > 0.05$; Table 3). Estimated kererū densities showed little variation over the period monitored (Table 3; Fig. 3c).

Tomtit

Distances to 241 tomtits were recorded at the Tapu site, 422 at the Kauaeranga site and 295 at the Golden Cross site (Table 1). The percentage of tomtits seen ranged from 15% to 38% for individual surveys (Table 1). Male territorial singing was variable; 15–77% of the tomtits detected during individual surveys were singing males (Table 1). At the Tapu and Kauaeranga sites, the majority of tomtits were detected within 15 m of the line-transect during all but one survey (Tapu 2006). However, at the Golden Cross site, tomtit detectability remained high up to 25 m from the line-transect. Detection probability declined in a slow uniform fashion with increasing distance from line-transects at all sites (Fig. 2d–f). For some

Table 2. Population density estimates (\hat{D}) for competing models ($\Delta\text{AIC} < 2$), and model averaged densities estimates (\hat{D}) for bellbird at the Tapu and Kauaeranga study sites in 2006–2009. Density estimates for the Tapu site were derived from independent detection functions for each survey and density estimates for the Kauaeranga site were based on a global detection function.

Site	Year	Model ¹ (key+adjust)	ΔAIC	GoF Chi- P	GoF CvM (cos) P	\hat{D}	\hat{D}	95% CI
Tapu	2006	Unif+cos	0.00	0.082	0.025	0.213		0.141–0.321
		Hnorm+cos	1.98	0.571	0.500	0.243		0.142–0.415
	2008	Hnorm+cos	0.36	0.124	0.300	0.309	0.290	0.167–0.413
		Hazrate+cos	1.06	0.113	0.400	0.292		
		Unif+cos	0.93	0.068	0.200	0.235		
		Unif+poly	0.00	0.148	0.300	0.307		
		Hnorm+cos	0.14	0.399	0.500	0.488	0.516	0.247–0.785
	2009	Hazrate+cos	0.07	0.397	0.900	0.565		
		Unif+cos	0.00	0.364	0.700	0.530		
Unif+poly		1.80	0.139	0.200	0.430			
Unif+cos		0.00	0.000	0.005	0.540		0.412–0.706	
Kauaeranga	2007	Unif+cos	0.00	0.000	0.005	0.540		0.412–0.706
	2008	Unif+cos	0.00	0.932	0.800	0.174		0.124–0.246
	2009	Unif+cos	0.00	0.416	0.400	0.124		0.071–0.216

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

Table 3. Population densities estimates (\hat{D}) for kererū at the Tapu study site in 2006–2009, based on a global detection function.

Year	Model ¹ (key+adjust)	GoF Chi- <i>P</i>	GoF CvM (cos) <i>P</i>	\hat{D}	95% CI
2006	Hnorm+cos	0.805	0.300	0.316	0.186–0.536
2007	Hnorm+cos	0.949	0.025	0.230	0.127–0.416
2008	Hnorm+cos	0.417	0.400	0.509	0.258–1.007
2009	Hnorm+cos	0.122	0.100	0.457	0.247–0.848

¹Half-normal model with a cosine adjustment term.

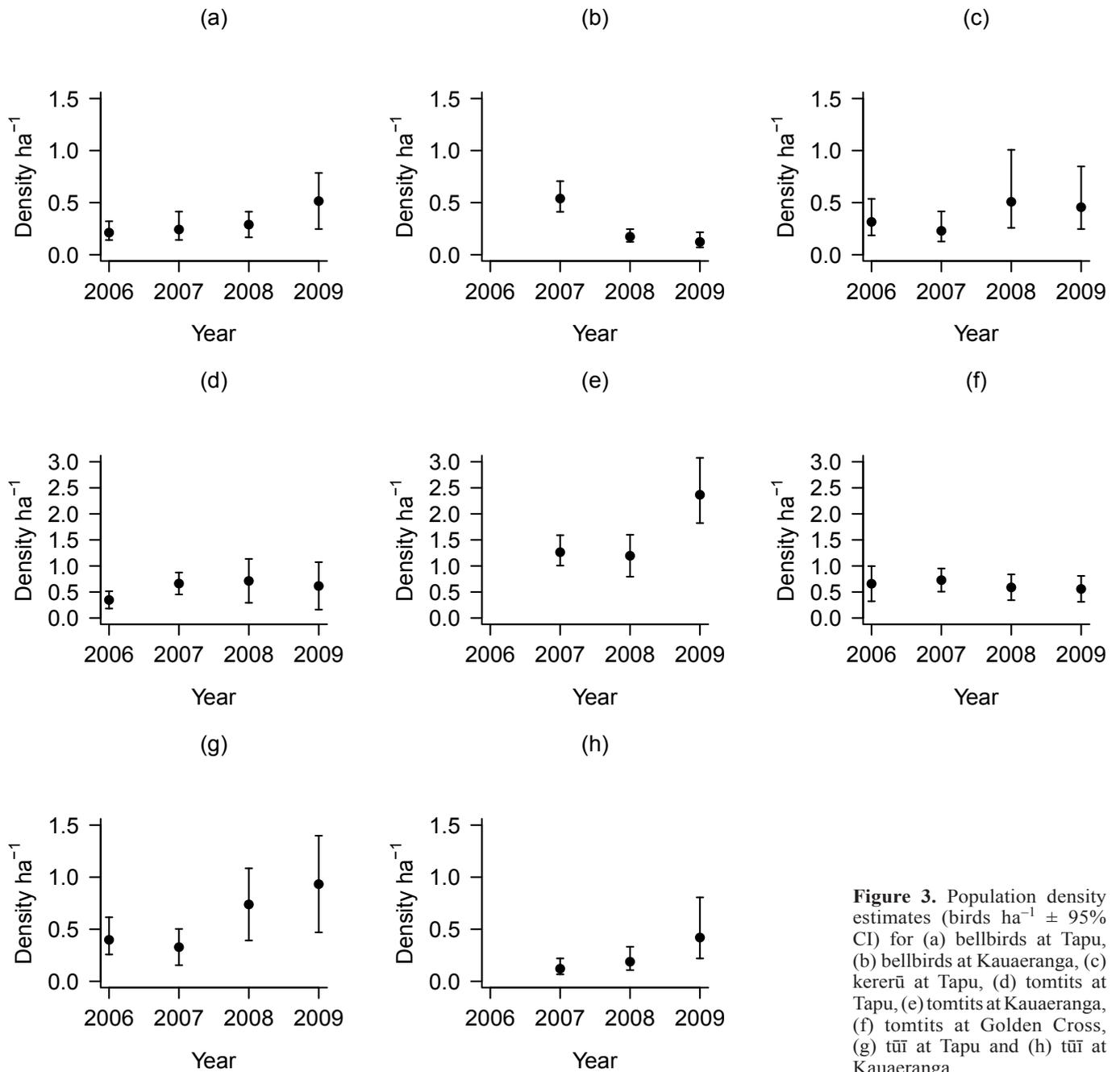


Figure 3. Population density estimates (birds ha⁻¹ ± 95% CI) for (a) bellbirds at Tapu, (b) bellbirds at Kauaeranga, (c) kererū at Tapu, (d) tomtits at Tapu, (e) tomtits at Kauaeranga, (f) tomtits at Golden Cross, (g) tūi at Tapu and (h) tūi at Kauaeranga.

Table 4. Population density estimates (\hat{D}) for competing models ($\Delta\text{AIC} < 2$), and model averaged densities estimates ($\hat{\bar{D}}$) for tomtit at the Tapu, Kauaeranga and Golden Cross study sites using independent detection functions for each survey from 2006 to 2009.

Site	Year	Model ¹ (key+adjust)	ΔAIC	GoF Chi- <i>P</i>	GoF CvM (cos) <i>P</i>	\hat{D}	$\hat{\bar{D}}$	95% CI		
Tapu	2006	Hnorm+cos	1.78	0.082	0.300	0.364	0.349	0.183–0.514		
		Hazrate+cos	0.00	0.211	0.200	0.362				
		Unif+cos	0.47	0.110	0.400	0.324				
	2007	Hnorm+cos	0.00	0.183	0.600	0.670				
		Unif+cos	0.09	0.209	0.600	0.694				
		Unif+poly	0.58	0.121	0.500	0.617				
	2008	Hnorm+cos	1.48	0.203	0.400	0.691			0.714	0.293–1.135
		Hazrate+cos	0.00	0.183	0.400	0.688				
		Unif+cos	0.95	0.127	0.200	0.773				
	2009	Hnorm+cos	0.71	0.495	0.300	0.662			0.617	0.162–1.073
		Hazrate+cos	0.46	0.372	0.400	0.608				
		Unif+cos	0.41	0.490	0.400	0.593				
Kauaeranga	2007	Unif+poly	0.00	0.493	0.400	0.613	1.197	0.794–1.599		
		Hazrate+cos	0.00	0.148	0.050	1.265				
		Hnorm+cos	0.55	0.580	0.800	1.194				
	2008	Hazrate+cos	1.29	0.513	1.000	1.218				
		Unif+cos	0.00	0.533	0.800	1.191				
		Unif+poly	1.72	0.438	0.800	1.189				
2009	Hazrate+cos	0.00	0.174	0.025	2.368	1.823–3.075				
	Hnorm+cos	0.00	0.352	0.600	0.624	0.660	0.322–0.997			
	Hazrate+cos	1.21	0.293	0.800	0.681					
Golden Cross	2006	Hazrate+poly	1.80	0.237	0.700	0.729	0.729	0.507–0.951		
		Unif+cos	0.87	0.297	0.700	0.653				
		Hnorm+cos	0.31	0.212	0.400	0.727				
	2007	Unif+cos	0.00	0.206	0.300	0.759				
		Unif+poly	0.92	0.202	0.400	0.686				
		Hnorm+cos	0.33	0.733	0.300	0.598			0.590	0.343–0.838
	2008	Hazrate+cos	0.67	0.759	0.400	0.554				
		Unif+cos	0.00	0.728	0.200	0.608				
		Unif+poly	1.56	0.670	0.300	0.594				
	2009	Hnorm+herm	0.94	0.212	0.100	0.601			0.560	0.311–0.809
		Hazrate+cos	0.38	0.231	0.300	0.504				
		Unif+cos	0.00	0.251	0.100	0.612				
	Unif+poly	0.20	0.161	0.300	0.526					

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

surveys, in particular at the Golden Cross site, there was a peak of detection distances between 8 and 15 m (Fig. 2f). During the 2006 survey at the Tapu site, more singing males were recorded (Table 1), especially between 15 and 40 m from the line-transect, and the detection probability close to the line-transect was lower. The summed AIC values across independent surveys were consistently lower than the AIC values from the pooled data from the same period, confirming that detection probability varied between surveys. Estimated tomtit densities and corresponding 95% confidence intervals were similar for pooled and independent detection functions. The Cramér–von Mises GoF statistics indicated poor model fit close to the line-transect for data from the 2009 survey at the Kauaeranga site ($P < 0.05$; Table 4); however, GoF Chi-*P* did not show any significant problems ($P > 0.05$; Table 4). The poor model fit close to the line is likely to be related to a peak in detection distances between 8 and 15 m and less detection on or close to the line-transect. No problems regarding model fit were found for any of the other surveys ($P > 0.05$; Table 4). Based on lower AIC, independent detection functions were used to estimate population densities (Table 4). Estimated tomtit

density at the Tapu site (Fig. 3d) increased between 2006 and 2007 but did not vary much after this initial increase. Estimated tomtit densities at the Kauaeranga site (Fig. 3e) were very similar during the 2007 and the 2008 surveys, while density estimates significantly increased between 2008 and 2009. Density estimates and corresponding confidence intervals at the Golden Cross site showed little variation over the period monitored (Fig. 3f).

Tūi

Distances to a total of 235 tūi were recorded at the Tapu site with 37% identified by sight; at the Kauaeranga site a total of 82 tūi were recorded, of which 33% were seen (Table 1). Detection probability histograms were similar for all surveys conducted at the Tapu site, and the probability that a tūi was detected slowly declined in a uniform fashion with increasing distance from the line-transect (Fig. 2g & h). Detection distances showed some slight peaks during two of the seven surveys. The sum of the AIC values calculated across independent surveys was lower than the AIC values from the pooled data and estimated tūi densities were very similar for pooled and

independent detection functions. Based on lower AIC, density estimates for the Tapu site were calculated from independent detection functions (Table 5). To fit the detection function, distance data from the 2006 survey at Tapu were pooled into four equal interval classes of 12.5 m. Data from other survey at Tapu were left ungrouped. Density estimates for the Kauaeranga site were derived from the pooled data (Table 5), because of low sample sizes (Table 1). To fit the detection function, distance data were pooled into four wide groups (0–15 m, 16–25 m, 26–35 m and 36–50 m). GoF statistics did not indicate any significant problems regarding model fit ($P < 0.05$; Table 5). Tūi density estimates at the Tapu site (Fig. 3g) and the Kauaeranga site (Fig. 3h) showed little variation between consecutive surveys.

Discussion

Due to the high vegetation density and complexity of the Coromandel forests, difficulties in meeting the first distance sampling assumption (subjects on the line or point are detected with certainty) were anticipated. Considerable effort was made to minimise violation of this assumption, by undertaking surveys during the season and times of day when selected study species were most conspicuous. Bellbird conspicuousness, however, was variable and bellbirds were rarely seen during some surveys. The detection probability for bellbirds on the line-transects was less than 1 during most surveys; it is therefore likely that not all bellbirds on the line-transect were detected – a violation of the first distance sampling assumption. Kererū, tomtit and tūi were found to be very vocal during the times surveys were conducted. Kererū and tūi were often detected by the distinctive sound of their wing beats, and tomtits were usually present in the sub-canopy, which made them easily detectable. The data suggest that the detection probability for kererū and tūi on the line-transect was approximately 1 during most surveys. This indicates that most kererū and tūi on line-transects were detected in proportion to birds detected

at increased distance from the line-transect. Tomtit distance observations peaked between 8 and 15 m during some surveys, which could have been the result of tomtits avoiding observers. However, tomtits did not appear to move to great extents and observers were confident that they detected almost all tomtits on or near the line-transect. The peak in tomtit detections was higher at the Golden Cross site than at the Tapu and Kauaeranga sites. Six of the 12 line-transects at this site were following a walking route, and while the canopy above the route was closed, the sub-canopy (in which tomtits are often found) was not as dense as elsewhere in the forest. Consequently, tomtit presence on and within a couple of metres from the line-transect was lower. With the data collected it is not possible to determine whether the first distance sampling assumption was met for kererū, tomtit and tui, but it is likely that potential violation of this assumption was minimised.

Bellbirds were often observed moving away from the line-transect when being approached by an observer, and given that bellbirds were rarely seen during some surveys and the detection probability was less than 1 during most surveys, it is likely that some bellbirds might have departed prior to being detected by observers. This violates the second distance sampling assumption (subjects are detected at their initial location, before any movement in response to the observer has occurred). Kererū and tūi showed little response when approached by observers. They sometimes flew away when an observer was within a few metres from the birds, but their movement was often noted due to the distinctive sound of their wing beat, and observers thought that the location they had departed from could usually be accurately determined. Observers also thought that undetected movement, particularly when in close proximity to an observer, was likely to be rare. It is therefore likely that the second distance sampling assumption was met for kererū and tūi. Tomtits are known to move towards observers (due to disturbance of invertebrates), which can result in overestimation of density. Field observers took considerable effort to ensure that all tomtits were detected at their initial locations prior to any movement in response to the

Table 5. Population density estimates (\hat{D}) for competing models ($\Delta\text{AIC} < 2$), and model-averaged population densities estimates (\bar{D}) for tūi at the Tapu and Kauaeranga study sites from 2006 to 2009. Density estimates for the Tapu site were derived from independent detection functions for each survey and density estimates for the Kauaeranga site were based on a global detection function.

Site	Year	Model ¹ (key+adjust)	ΔAIC	GoF Chi- P	GoF CvM (cos) P	\hat{D}	\bar{D}	95% CI
Tapu	2006	Hnorm+herm	0.39	0.062	0.150	0.399	0.329	0.258–0.615
		Hnorm+cos	0.31	0.591	0.700	0.341		
	Hazrate+cos	0.30	0.866	1.000	0.300			
	2008	Unif+cos	0.97	0.489	0.500	0.356	0.739	0.392–1.085
		Unif+poly	0.00	0.706	0.800	0.328		
		Hnorm+cos	0.17	0.561	0.500	0.743		
	2009	Unif+cos	0.00	0.566	0.500	0.770	0.934	0.470–1.398
		Unif+poly	1.22	0.457	0.300	0.674		
		Hnorm+cos	1.30	0.571	0.300	0.880		
Unif+cos		0.00	0.694	0.600	1.007			
Kauaeranga	2007	Unif+poly	1.52	0.388	0.200	0.838	0.067–0.220	
		Unif+poly	0.00	0.741	0.900	0.122		
		Unif+poly	0.00	0.739	0.400	0.189		
2008	Unif+poly	0.00	0.585	0.100	0.421	0.108–0.332		
	Unif+poly	0.00	0.585	0.100	0.421			
2009	Unif+poly	0.00	0.585	0.100	0.421	0.220–0.806		
	Unif+poly	0.00	0.585	0.100	0.421			

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

presence of observers, and subsequent inspection of detection probability histograms showed that potential movement of tomtits towards observers was minimal. Some data, however, did indicate a slight peak in detection distances between 8 and 15 m from the line-transect that may be the result of tomtits avoiding observers. However, such peaks were not seen during all surveys, and some tomtits did not appear to have moved at all when observers approached. In addition, the distances they moved were never thought to be great and violation of the second distance sampling assumption was thus likely minimal.

Bellbird and tūī were easily detected from their calls up to 50 m or more from the line-transects, requiring observers to estimate large distances (with reduced accuracy at this range; Alldredge et al. 2007). Calls from birds that face towards the line-transect are likely to be louder and may therefore seem closer than calls from birds that are facing away from the line-transect (Alldredge et al. 2007). This directional influence is likely to have led to errors in distance estimation in some instances. Bellbirds were seen less frequently than any of the other study species, and the majority of bellbirds were detected by sound only (Table 1). Bellbirds were usually heard further from the line-transect, which meant that distance estimation to those birds was likely to be less accurate. Tūī were more frequently detected by sight than were bellbirds (Table 1) and were often detected in closer proximity to the line-transect, allowing for more accurate distance estimation. Considering the peaks in detection distance data for bellbirds, it is likely that distance estimation was not always accurate, violating the third distance sampling assumption (distances from the line or point to the subject are measured accurately). There were some small peaks in tūī detections during some surveys, but none were of great concern because they did not alter the ability to fit detection functions to the data. Kererū were more often detected by sight than any of the other study species (Table 1) with the majority detected within 10 m of line-transects, and therefore distance estimation was expected to be accurate. There were occasional peaks in detection distances to kererū at 20 m and 25 m during some surveys, which could have been caused by observers rounding to favoured distances. Few kererū were detected beyond 35 m from the line-transect, and considering that the call of the kererū is not loud, distance estimation error as a result of the directional calls (as experienced for bellbirds) was unlikely to have biased distance estimation to kererū. Most tomtits were detected in close proximity to the line-transect (within 15 m at Tapu and Kauaeranga and within 25 m at Golden Cross) and distance estimation to these birds was likely to be accurate. Increased detectability at Golden Cross is likely related to the less densely vegetated forest at this site that allowed observers to identify tomtits further from the line-transect. Distance estimation to singing males detected further from line-transects may have been less accurate, but detection probability histograms did not indicate any obvious problems. Violation of the third distance sampling assumption was thus likely to have been minimised for kererū, tomtit and tūī; however, limited distance estimation error may have biased density estimates.

Unexplainable anomalies in kererū, tomtit and tūī density estimates were not encountered in the surveys. Kererū and tūī densities remained constant during the monitoring period. Tomtit densities increased following pest control at the Tapu and Kauaeranga sites, which is likely to be the result of increased breeding success following a season of low possum and ship rat numbers (I Jacobs 2010, unpubl. report). The suitability of the line-transect distance sampling method to estimate tomtit

densities supports previous research conducted by Westbrooke et al. (2003). Distance sampling of tomtits at other times of year may be less successful due to changes in the behaviour of birds (when in moult, establishing territories, or nesting) and the dispersal of fledglings. One potential issue that this study does not address, however, is the influence of local and seasonal fluctuations of food resource availability that may significantly affect local conspicuousness, abundance and immigration of species such as kererū and tūī within and between sites at certain times of year.

In this study, multi-species surveys appeared to be a cost-effective approach for estimating population densities of three common forest bird species. Population density estimates of kererū, tomtits and tūī were obtained for little additional cost than a single-species survey. Using species that represent important forest ecosystem guilds may be more informative than single-species monitoring programmes when assessments of forest health and the effectiveness of pest control operations are required. The concurrent collection of data for four species did not appear to compromise the quality of the data collected on any of the selected species when using trained and experienced observers who were familiar with the distance sampling methodology and knowledgeable about the species monitored. Data quality and the ability to focus on multiple species may vary, however, if less experienced observers are used. In addition, estimated population densities of species monitored during this study were moderate to low, meaning observers had sufficient time to focus on detecting birds and accurately measuring and estimating distances. In areas where birds are present in high densities (such as on pest-free islands), a multi-species approach may not be practical.

Detection probability histograms suggest that kererū and tūī behaviour did not change considerably between surveys; however, tomtit detectability was slightly variable. Tomtits were likely to have moved in response to observers during some surveys, but not during others. Male territorial singing was also considerably higher during some surveys than others. While data were collected at the same time of year where possible, the onset of breeding is likely to have varied between surveys. During years where birds were observed to breed earlier, female tomtits were less detectable, displaying furtive behaviour typically associated with breeding, and were perhaps more cautious of observers. On the other hand, male territorial calls increased closer to the breeding season, and their loud calls could be heard further from the line-transects, resulting in higher detection probability at increased distances. Differences in tomtit behaviour between surveys are likely to be reflected in variations of detection functions. This is the major advantage of distance sampling over count or relative index methods where all other variables need to be equal in order to reliably measure changes in bird abundance between surveys. For this reason, distance sampling appears to be an attractive tool for monitoring over multiple years.

Without knowledge of the actual population densities of bellbird, kererū, tomtit at tūī at the three study sites, it is not possible to use a more objective approach to assess the distance sampling method. Results from this study do suggest, however, that there is potential for further development of multi-species distance sampling as a tool to monitor New Zealand forest birds, and further research is encouraged. The applied study design was limited by the following factors, which should be taken into consideration when similar distance sampling studies are designed: (1) the number of detections for some species was low; in order to generate reliable density estimates,

sufficient sightings of birds must be made, and a minimum of 60 detections is recommended (Buckland et al. 2001); and (2) rather than sampling each line-transect multiple times, increasing the number of line-transects to provide better representation of study sites is recommended. Sufficient detections would allow for estimation of population densities using independent detection functions rather than global detection functions. Independent detection functions may better account for variation in survey timing, differences between observers, and any change in bird behaviour and detectability between surveys. A larger number of observations may also allow for multiple covariate distance sampling (MCDS) analysis to be performed (Marques et al. 2007). MCDS analysis can potentially further address issues surrounding variable detectability, such as differences between observers and survey timing (Marques et al. 2007). Better representation of study sites can also be achieved by using a systematic sampling design (with a random start point; Buckland et al. 2001) or a completely random sampling design for establishing line-transects. Improved study design would involve increased costs when line-transects are being established; however, once in place, the cost of repeating monitoring sessions is unlikely to be substantially greater.

The line-transect distance sampling approach applied in this study did not appear to be suitable for estimating densities of bellbird. Further investigation may determine whether surveys at other times of year, when bellbird behaviour is more conducive to meeting the assumptions of the distance sampling method, may provide useful data. Continued monitoring of kererū, tomtit and tūi at the Tapu and Kauaeranga sites would provide further data to assess the long-term effectiveness of pest management programmes. Monitoring of kererū and tūi densities at the Golden Cross site should be reviewed as the number of detections for these two species is currently too low to estimate population densities reliably. If further monitoring at the Golden Cross site is desired, the sampling effort should be increased sufficiently.

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