Assessing the population of grey peacock-pheasant (*Polyplectron bicalcaratum*) in a Southeast Asian conservation landscape

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Abstract. The rate of biodiversity collapse in Southeast Asia is amongst the highest in the world, and averting species extinctions in the region is now a global priority. Here we estimate the density of the threatened grey peacock-pheasant (*Polyplectron bicalcaratum*) in the pristine sub-montane evergreen forest of Huai Kha Khaeng Wildlife Sanctuary, Western Thailand, where poaching is low. In our density assessments, we compared four commonly used survey methods: (a) triangulation using fixed listening posts; distance sampling using both (b) line transects and (c) point transects; and (d) camera trapping using the single season Royle-Nichols heterogeneity model, to assess which one is the most appropriate for population estimation in such a loud-calling terrestrial bird species. Species density was estimated between 14.69 and 22.97 birds km^{-2} depending on the method used. The use of auditory records to compensate for low visual detection of this cryptic species might explain the higher estimates when compared with those reported for other populations. When comparing different methods point transects and triangulation provided similar density estimates, with point transects appearing to be the most effective method due to their precision and the clear analysis protocol, while density estimates provided by triangulation depend on species specific knowledge, thereby hampering translation of detections into a population estimate. Line transects appeared to overestimate density and presented logistic difficulties in these mountainous locations, although its suitability for the survey of larger areas might render it appropriate in flat terrains. Camera trap analysis gave the widest confidence interval and suffered from complications in selecting models with realistic assumptions and delineation of the sampling area.

Key words. distance sampling, camera trap, triangulation, population estimation, Huai Kha Khaeng Wildlife Sanctuary

INTRODUCTION

The rate of biodiversity loss in Southeast Asia is perhaps the highest in the world (Sodhi et al., 2004; Sodhi et al., 2010) and it has been considered the global priority for averting vertebrate species extinctions (Duckworth et al., 2012). Extensive, well-protected landscapes offer the best, if not only, prospect of long-term survival for many medium and large vertebrates. Despite this, we know little about the population status of many species in such landscapes and, therefore, whether or not such landscapes are performing their conservation role. This is due to a range of inter-related reasons that include limited resources (including expertise), challenging field conditions, limited biological knowledge and uncertainty over the applicability of sampling design and field protocols in existing survey methods.

Reliable population estimates are fundamental to many aspects of species ecology and conservation (MacLeod et al., 2011; Ahumada et al., 2013; Höing et al., 2013; Borchers et al., 2015). For example, the ability to compare population densities of a species between places or habitats allows the exploration of factors that may influence species distributions (Hamard et al., 2010; Bernardo et al., 2011; Selvan et al., 2013; Lee et al., 2015). Population estimates are also central to the assessments of species conservation status, for example, where estimates of some aspect of a population (e.g., size) are compared over time to draw inferences about extinction probability (Mace et al., 2008; IUCN, 2012). With an increasing number of species considered to be at risk of extinction (IUCN, 2014) and the pressures on biodiversity increasing (Tittensor et al., 2014), the need for reliable population estimates is becoming ever more pressing. First, however, it is important to be able to determine population density reliably given prevailing field conditions (e.g., topography and habitat) that influence field protocols and existing knowledge of species biology and that shape how detections can be translated into density estimates.

Analytical developments, such as distance sampling (Buckland et al., 2008; Thomas et al., 2010) and camera trapping (Carbone et al., 2001; Mackenzie et al., 2002; Royle & Nichols, 2003; Royle, 2004; Rowcliffe et al., 2008), have seen a notable improvement in the range of conditions under which population estimates can be made (Lee & Marsden,

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2008). Winarni et al. (2009), for example, used occupancy analysis to estimate the proportion of occupied habitat and finite mixture models to estimate the abundance of great argus (*Argusianus argus*) (a cryptic, terrestrial forest bird) when individual identification is not possible (O'Brien & Kinnaird, 2008). At the same time there are long-standing approaches that have been used to record detections of certain species in the field because aspects of their behaviour make them easily detectable. For example, triangulation has been used with vocal species (Jiang et al., 2006; Hamard et al., 2010; Phoonjampa et al., 2011).

Huai Kha Khaeng Wildlife Sanctuary, located in the Thanon Thong Chai mountain complex of the Tenassarim range between Thailand and Myanmar, represents one of the best preserved forests in the region (Bhumpakphan, 2001). It was declared a protected area in 1972 and now lies at the eastern edge of the Western Forest Complex, an extensive mosaic of contiguous protected areas in Western Thailand. There is limited information on the population status of endangered vertebrate species in Huai Kha Khaeng such as banteng (*Bos javanicus*) (Prayurasiddhi, 1997), tigers (*Panthera tigris*) (Simcharoen et al., 2007), and sambar (*Rusa unicolor*) (Simcharoen et al., 2014)

Here we determine the status of a resident loud-calling forest ground bird that is solitary and inhabits mountainous habitat, the grey peacock-pheasant (*Polyplectron bicalcaratum*). Given the high level of protection for all species in the study area, population estimates will provide useful information when evaluating the status of populations inhabiting less well protected areas. We use four survey methods to make density estimates: triangulation of calling locations, line transect sampling, point transect sampling, and camera trap sampling (using the single season Royle- Nichols heterogeneity model). We then discuss practical aspects of using these methods in broad scale surveys and long term monitoring of loud calling bird species during the breeding season to understand their population and spatial distribution.

METHODS

Study area. Huai Kha Khaeng Wildlife Sanctuary (15°00' to 15°48'N and 98°89'to 99°27'E) covers an area of 2780 km², 33% of which is hill evergreen and dry evergreen forest. The study was conducted near the Khoa Nang Rum Wildlife Research Station in the south-eastern part of the sanctuary (Fig. 1). The wet season is May to October during which the temperature ranges between 6 and 38°C and the dry season lasts from November to April with a temperature range of
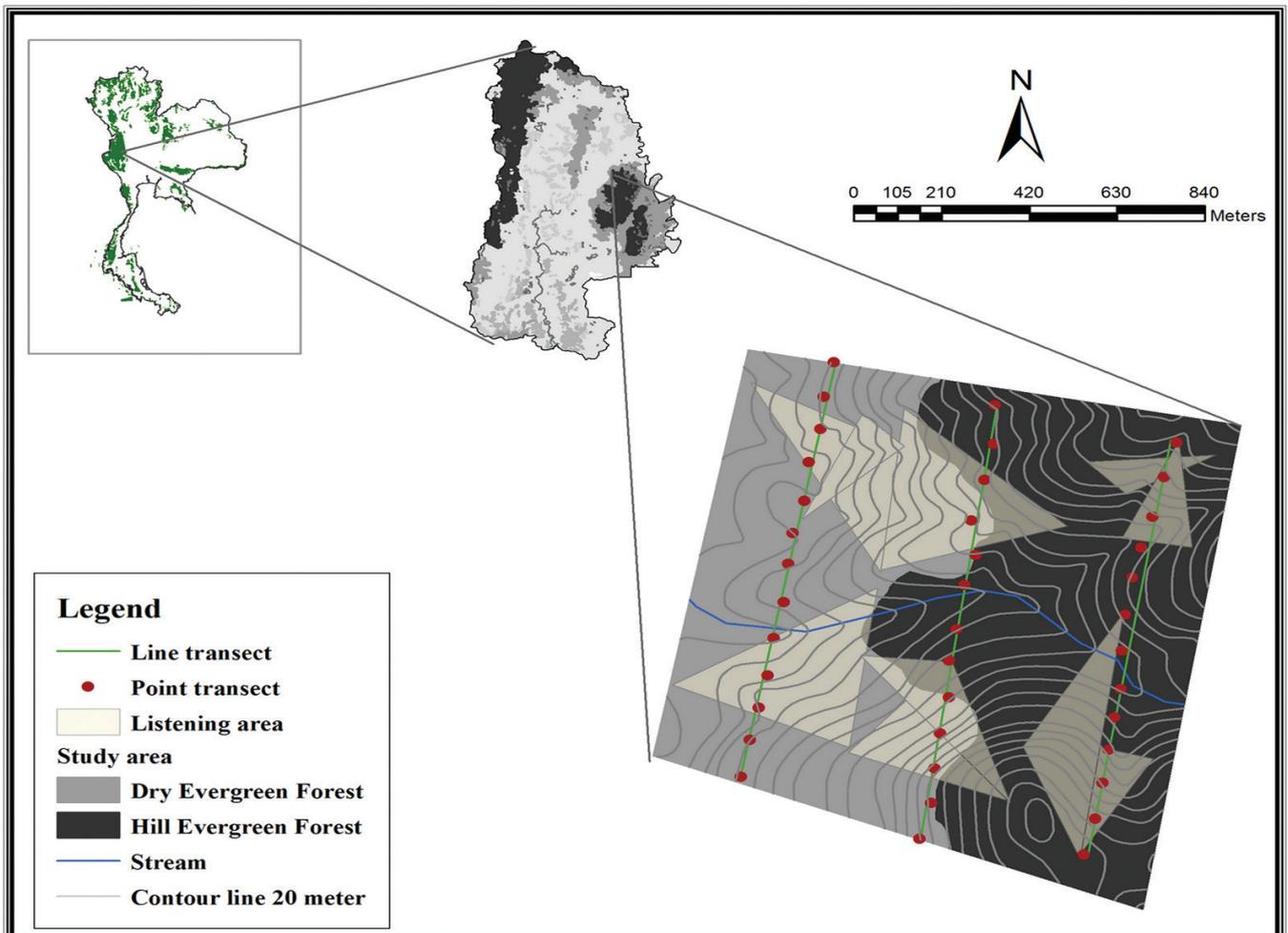

Fig. 1. Location of line and point transect, listening posts for triangulation, and area searched for display scrapes to spot mapping, Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani,Thailand

10 to 29°C (National Park Wildlife and Plant Conservation Department, 2014), within which there is a short cold, dry winter during December and January. Average rainfall is 1552 mm with the maximum rainfall in October (370 mm) (DNP, 2014).

Study species. Grey peacock-pheasant is categorised as Least Concern on the IUCN Red List (IUCN, 2014) and is a relatively common species when compared with other peacock-pheasants (Johnsgard, 1999). It is a loud calling ground-dwelling bird that inhabits dense forest over hilly terrain (Johnsgard, 1999). During the breeding season male grey peacock-pheasants defend their territories from other males and mostly call from display scrapes (Baker, 1930), which are patches of bare ground from which they clear all leaf litter (Johnsgard, 1999). The breeding season is January until May. The female usually does not call but responds to the calling of males by visiting display scrapes (pers. obs.). As yet there has been no assessment of home range size in grey peacock-pheasant. However, in this work we used the mean home range size (male = 2.95 ha ± 1.59; Liang & Zhang, 2011) of the Hainan peacock-pheasant (*Polyplectron katsumatae*), a closely related species previously considered a subspecies of grey peacock-pheasant (Chang et al., 2008; Collar, 2009; Chang et al., 2013), to determine distance between camera traps and the effective sampling area for camera trap sampling.

Survey methods. We derived density estimates for four survey methods for comparison. For triangulation and distance sampling using both line transects and point transects, we used only the distinctive loud vocalisations of male grey peacock-pheasant, as they are clearly recognisable in the field and can be detected from a relatively long distance. Data for each method were collected between January and April 2013. The study area was 1200 × 1200 m. All observers were trained together prior to the survey to identify grey peacock-pheasant vocalisations and to standardise estimates of distance so as to minimise inter-observer variability in identification and distance.

Triangulation. Male grey peacock-pheasant can be heard calling loudly from display scrapes. Camera trap video (unpublished data) confirmed that males do call at scrapes in the morning. We assume that males mostly restrict their calling activity to these areas in order to attract females. Twenty-seven listening posts were established in nine sampling areas in part of the study site and each of these areas was sampled for three days each month. Observers were stationed at three listening posts simultaneously between 0600–1130 hours ± 0.21 min and for each call heard they recorded time, direction and an estimate of distance. Records of birds heard at distances greater than 180 m were removed from analysis because beyond this distance the call was faint and the distance from the observer was difficult to estimate precisely.

The number of individuals was determined by mapping the calling locations obtained from triangulation onto a map using ArcGIS version 9.3 (ESRI, 2008). We mapped the calling males that were heard by drawing a straight line on a map in the distance and direction of detection. Based on daily maps, calling locations were located by triangulation at the intersection of the lines that were made from at least two listening posts from which calling was heard at the same time. To reduce double counting we considered calling locations ≤ 97 m apart to belong to the same individual, assumed to be the size of a grey peacock-pheasant territory based on the reported data for the closely related Hainan peacock-pheasant (Chang et al., 2008; Liang & Zhang, 2011). This was based on the assumption that the species is expected to remain relatively close to a display scrape during the mating season (Johnsgard, 1999). The density estimate of grey peacock-pheasant was calculated following Hamard et al. (2010) and Höing et al. (2013): (1) Density estimate: $D = n/[p(m) \times E]$; (2) correction factor (calling probability): $p(m) = 1-[1-p(1)]^m$, where n = the cumulative total number of bird heard in the effective listening area, $p(m)$ = the cumulative number of birds singing in m days, $p(1)$ = the mean of the proportion of birds heard calling, E = effective listening area.

We determined the effective listening area by assuming a constant maximum radius (following Brockelman et al., 2009; Hamard et al., 2010; Höing et al., 2013) for clearly heard calls of 180 m around each listening post, this being the area where a minimum of two listening posts could have heard grey peacock-pheasant calling.

Distance sampling. Three 1200 m north-south line transects were spaced 400 m apart (to avoid double counting of birds detectable at long range; Bibby et al., 2000) covering the entire study area (Fig 1). Each transect was walked by an observer between 0630–1130 hours ± 0.21 min at an average speed of 5 m per minute. Each line transect was walked once a month by each observer, so that all transects were walked by all observers each month. The total length of each transect that was walked was 14.4 km per month, making a total of 43.2 km. At each detection, the following was recorded: time, detection cue (male vocalisation, visual), number of individuals, sex (when possible), compass bearing and distance of each detection from the observer to detections. Perpendicular distance was calculated in ArcGIS 9.3 by using the compass bearing and estimated distance from observer. Time and compass bearing were used to further avoid double counting.

Point transect data were collected at 39 points: 13 points located every 100 m along each of the three line transects (Fig. 1). Points were visited by three observers 3 days per month for four months. Observers surveyed 39 points per day and spent 5 minutes at each point: as the calling frequency during the breeding season was very high, we reduced the count period to 5 minutes to limit the risk of double counting animals as noted elsewhere (Norvel et al., 2003; Howell et al., 2004, Lee & Marsden, 2008). We collected data between 0630–1130 hours ± 0.21 min. Each point was visited 12 times in total over the four-month survey period. At each detection, the following was recorded: time, detection cue (male vocalisation, visual) number of individuals, sex
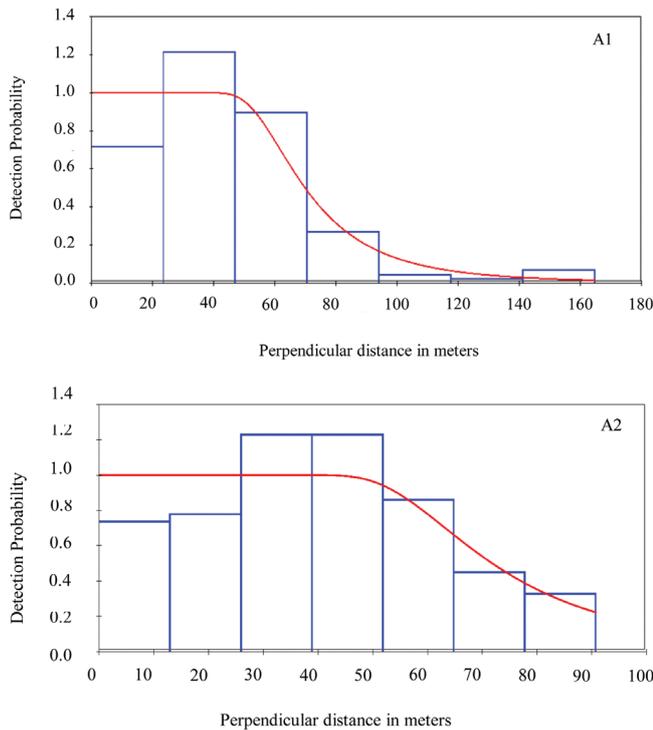
Fig. 2. Histograms of perpendicular distances of ungrouped grey peacock-pheasant detections and estimated detection functions derived from DISTANCE software for line transects: (A1) not truncated (A2) truncated by eye at 90 m
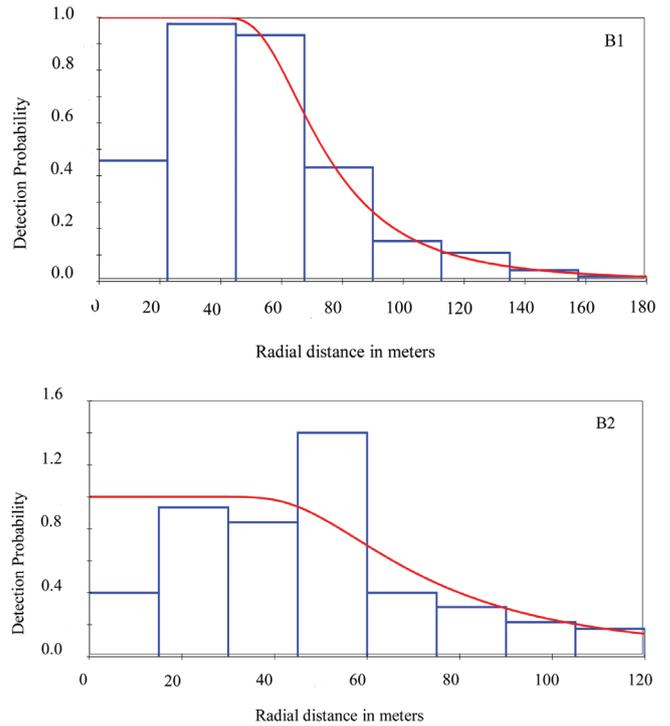
Fig. 3. Histograms of distances and estimated detection functions derived from DISTANCE software for point transects: (B1) not truncated (B2) truncated by eye at 120 m

(when possible) and compass bearing from the observer to each detection. To avoid double counting arising from birds moving during the sampling period, all calling and visual detections were plotted on the GIS map so that cross-checks could be performed and detections excluded. We considered distance, time and direction between detections, and a detection was excluded when: i) it was in the same position as; or ii) it was within a 200 m diameter of the existing detection.

We analysed density and detection probability of males detected by calls for both line and point transects using DISTANCE Version 6.0 (Thomas et al., 2010). Following Buckland et al. (2001), Gale et al. (2009), and Winarni et al. (2009), we examined a variety of models to increase the likelihood of finding the best-fitting models. We tested ungrouped data with uniform, half normal, and hazard rate key functions followed by parameter adjustments, either cosine or polynomial. We also employed a variety of truncation distances to improve the shape of detections; truncation was done by eye usually at approximately 90 m for line transects, and 120 m for point transects (Fig. 2, Fig. 3) (following Buckland, 2001; Thomas et al., 2010). We selected the best model based on Akaike's Information Criterion (AIC) (Arnold, 2010). However, it is important to note that AIC can only be used to assess competing models' fit to the same data set (Rosenstock et al., 2002). In addition, we also considered a smaller coefficient of variation to compare among truncated and untruncated datasets (Buckland et al., 2001).

Camera trapping. Camera trapping was conducted during the breeding season of 2013 (January to April). We used Scout Guard SG565F-8M, a digital scouting camera that was programmed to take pictures 24 hours per day. Camera traps were attached to a suitable tree at a height of 40–50 cm above the ground in order to determine the best angle with the depression about 5–10°. Thirty-nine camera traps were arranged systematically along 100 m long transects (13 cameras per line) separated by 400 m for 30 consecutive days. Cameras were then moved in the same grid formation 100 m to the east, as suggested by several authors (e.g., O'Brien et al., 2003; Soisalo & Cavalcanti, 2006; Karanth et al., 2011; Foster & Harmsen, 2011). For a territorial species it is recommended that cameras be spaced such that coverage is approximately one camera per territory (Maffei et al., 2004; Dillon & Kelly, 2007; Karanth et al., 2011). The spacing of camera traps was based on the estimated male home range of Hainan peacock-pheasant, 2.95 ha (±1.59) (Liang & Zhang, 2011), which is an average radius of 96.88 m (85.92–165.32 m). Cameras were, therefore, set 200 × 200 m apart so as to avoid gaps between camera traps. Photographs were identified by location, date, time and sex of the detected animal. Photographs were considered as independent events at 1 hour intervals to avoid double counting of individual animals lingering in front of the camera (Mugerwa et al., 2012). The dataset from 5 consecutive days was pooled for each 30 trap-days sampling period yielding six sampling replicates to increase detection probability (Rovero et al., 2010).

Density was estimated using two step processes: (1) We started by estimating abundance, using two techniques for

Table 1. Male grey peacock-pheasant density estimates using spot mapping, line transect, point transect, triangulation and camera traps.

Method	n	E	μ	P	D	SE	% CV	95% CI
Line transect	144	43.2	72.74	0.80	21.80	1.95	8.90	17.67–26.90
Point count	158	468	85.52	0.23	14.69	1.57	10.70	11.90–18.14
Camera trap	–	–	–	0.20	22.97	8.37	35.88	6.56–39.38
Triangulation	–	–	–	–	16.85	0.97	–	15.23–18.57

n = number of detections; E= effort of survey (kilometre for line transect and time to visit for point count); μ = the effective strip half-width (m); P = detection probability; D= estimate density of males km-2;SE = Standard Error; CV = the coefficient of variance; CI = confidence interval.

which individual recognition is not needed: (a) photographic rate data using the number of photographs/number of trap days as an abundance index (Rowcliffe et al., 2008; Rovero & Marshall, 2009; Liu et al., 2013): these models assume that the number of photographs obtained is a positive function of the abundance of the animals (O'Brien & Kinnaird, 2008); and (b) detction – non detetion data using the single season Royle-Nichols heterogeneity model (Royle & Nichols, 2003; Suwanrat et al., 2015) in the program PRESENCE, Version 6.1 (Mackenzie et al., 2002; MacKenzie et al., 2006): these models assume that the probability of detecting animals at a site is independent of the detection of birds at other sites. These detection/non detection data are used to estimate abundance across the entire area (Royle & Nichols, 2003; Royle, 2004) and can be used with count data (O'Brien & Kinnaird, 2008; Linkie et al., 2013). (2) We then converted the estimated abundance of male grey peacock-pheasants to density by dividing the estimated abundance (N) from the single season Royle–Nichols heterogeneity model by the effective sampling area of the camera traps (O'Brain & Kinnaird, 2008; Suwanrat et al., 2015).

We did not use the random encounter model (REM) to convert photographic rate to density because it has not been tested on birds (O'Brien & Kinnaird, 2008), although Rowcliffe et al. (2008) have demonstrated the potential of this method to convert abundance to density for mammals. REMs are based on an analytical model which requires (1) the species encounter rate, which is dependent on information about the distance and angle at which the camera trap sensor detects the animal, and (2) the average speed of the target species (Rowcliffe et al., 2008; Foster & Harmsen, 2011; Cusack et al., 2015), which is difficult to estimate without radio telemetry data. Although, Rowcliffe et al. (2012) suggested that many of these factors may not be a problem, REMs may be most effective for species that are relatively wide ranging (≥1 km/day) (Rowcliffe et al., 2008), such as female lions (*Panthera leo*) (Cusack et al., 2015), whereas grey peacock-pheasants are highly territorial and have a narrow ranging pattern for daily movement.

We determined the effective sampling area of camera traps based on average home range size (Maffei et al., 2004; Cuellar et al., 2006; Soisalo & Cavalcani, 2006; Foster& Harmsen, 2011). We used the home range size of Hainan peacock-pheasant as a proxy for the home range size of grey peacock-pheasant and calculated the effective sampling area
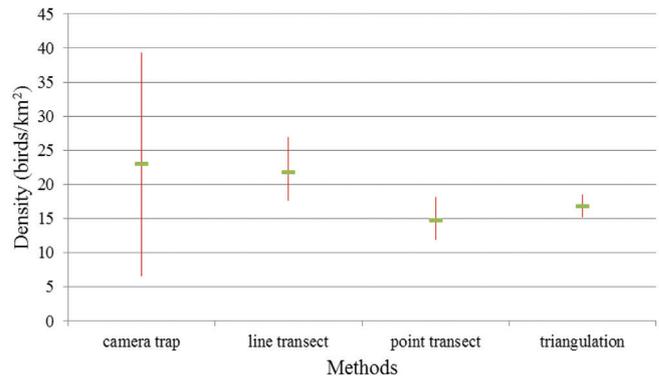

Fig. 4. The estimated density and standard error of Grey Peacock-pheasant by four survey techniques in the 1200 × 1200 m study area at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani, Thailand

using a circular buffer around each camera trap location with the home range radius (96.88 m; Liang & Zhang, 2011), and then merging all buffered areas in ArcGIS version 9.3 to produce a total effective trap area.

RESULTS

Male grey peacock-pheasant density estimates in Huai Kha Khaeng Wildlife Sanctuary ranged from 14.69 to 22.97 birds km-2 (Fig. 4). Density estimates for point transects and triangulation were broadly similar (14.69 birds km-2, 95% CI [11.90, 18.14]; 16.85 birds km-2, 95% CI [15.23, 18.57]). Density estimates of line transects and camera traps were slightly higher (21.80 birds km-2, 95% CI [17.67, 26.90]; 22.97 birds km2, 95% CI [6.55, 39.38]) (Table 1).

Triangulation. Over the four months of sampling we detected nine calling males from at least two listening posts in an effective listening area of 0.43 km2. The correction factor (calling probability) was 0.97 and the estimated density of males was 16.85 birds km-2 (±0.97SE), 95 % CI [15.23, 18.57] (Table 1).

Distance sampling. We obtained a total of 171 detections from line transects, including male auditory detections and visual detections of both males and females. However, as our study was focused on male density and probability of detection, we only used male auditory detections (144 detections, 84.2 % of the total detections). The model with the lowest AIC value was the hazard rate key function with truncation at 90 m giving a smaller coefficient of variation

Table 2. The minimum AIC values of two data sets: a) untruncated datasets; b) truncated datasets by eye at 90 m for line transects, and 120 m for point transects. Datasets were tested with uniform, half normal, and hazard rate key functions followed by cosine or polynomial series expansions. The lowest AIC was indicated by asterisks.

Dataset	Key Function	Adjust Term	AIC	%CV	D	P
Line transect						
a) Untruncated	Hazard rate	–	1341.12*	9.55	21.92	0.46
	Hazard rate	cosine	1343.21	9.55	21.92	0.46
b) Truncated at 90 m	Hazard	–	1221.56*	8.90	21.80	0.80
	Hazard rate	cosine	1223.74	8.90	21.80	0.80
Point transect						
a) Untruncated	Hazard rate	–	1533.15*	10.71	14.69	0.23
	Hazard rate	cosine	1535.23	10.71	14.69	0.23
b) Truncated at 120 m	Hazard rate	–	1370.01*	15.00	15.10	0.45
	Hazard rate	cosine	1371.50	15.00	15.10	0.45

(Table 2). The detection probability of calling males was 0.80 ($\pm$0.049SE), 95 % CI [0.71, 0.90] and the effective strip width was 72.74 m ($\pm$4.46SE). Male density was estimated at 21.80 birds km^{-2} ($\pm$1.95 SE), 95 % CI [17.67, 26.90], CV = 8.93 (Table 1).

We obtained a total of 178 detections from point transects. As with the line transects, both the density and detection probability were calculated only for males, using the entire detection sample and only the auditory detections (158 detections, 88.76 % of the total dataset). The model with the lowest AIC value was the hazard rate key function with untruncated data giving a smaller coefficient of variation (Table 2). The detection probability of calling males was 0.23 ($\pm$0.024 SE), 95% CI [0.18, 0.29] and the effective strip width was 85.5 m ($\pm$ 4.6SE). The male density estimate was 14.69 birds km^{-2} ($\pm$1.57 SE), 95 % CI [15.23, 18.57], CV = 10.71% (Table 1).

Camera trapping. A total of 184 photographs of grey peacock- pheasants were taken during 3215 trap days at 156 camera locations, which gave 112 (60.87%) detections of single males, 60 (32.61%) detections of single females, seven (3.80%) detections of both male and female, four (2.17%) detections of a female and chick and one (0.54%) detection of a male and chick. The ratio of single male: single females in photographs were 2:1 (112:60). Birds were detected throughout the day, with most male activity (number of photographs hour^{-1}) at 0600–0700 hours and 0800–0900 hours (12 photographs hour^{-1}) and most female activity at 0700–0800 hours (10 photographs hour^{-1}) (Fig 1S). The mean photographic rate of male grey peacock-pheasant (no. of photographs per 100 days) $\pm$ SE was 3.83/100 trap days ($\pm$0.0007).

The estimated abundance of male grey peacock-pheasant from the single season Royle-Nichols heterogeneity model was 27.84 $\pm$ 9.99SE birds (95% confidence interval 8.25–47.55 and detection probability was 0.20 $\pm$ 0.07SE). We obtained the density by buffering camera locations with the radius of male home range as 96.88 m (see Methods) giving a total effective sampling area of the camera traps 1.21 km^2 and a density of male grey peacock-pheasant of 22.97 birds km^{-2} ($\pm$8.37SE), 95% CI [6.55, 39.38] (Table 1).

DISCUSSION

Density estimates of calling grey peacock-pheasant males were obtained in mixed hill and dry evergreen forest in western Thailand using four methods. Three of them relied on detections of calling birds (triangulation, point transects and line transects), at least in part, and one did not (camera trapping). We showed that density estimates ($\pm$SE) derived using these methods were 16.85 $\pm$ 0.97, 14.69 $\pm$ 1.57, 21.80 $\pm$ 1.95 and 22.97 $\pm$ 8.37 birds km^{-2} respectively.

The density estimates that we obtained were much higher than those reported elsewhere for grey peacock-pheasant and the closely related Hainan island form, now recognised as a separate species. Selvan et al. (2013) estimated that the density of grey peacock-pheasant in the Eastern Himalayan lowland tropical forest of Arunachal Pradesh, India was 4.02 birds km^{-2} ($\pm$ 0.7SE), and Gao (1999) estimated the density of Hainan peacock-pheasant on Hainan Island, China to be 3.75 birds km^{-2}. These differences probably lie in the methodological approach, with both of these earlier studies relying on visual detections only, whereas we used a wider range of detection cues across all methods. Furthermore, we concentrated our study in the breeding season, when calling was highest, as did Gao (1999), while Selvan et al. (2013) covered a 16 month period from September 2009–January 2011. Finally, there are differences in the habitats studied. Selvan et al. (2013) surveyed lowland forest that is not the primary habitat for grey peacock-pheasant, and Gao (1999) surveyed both upland and hill forest, which vary in their importance for Hainan peacock-pheasant. In contrast, we surveyed only upland evergreen forest, considered the main habitat of grey peacock-pheasant and in an area where poaching is very limited because of the SMART (Spatial Monitoring And Reporting Tool) patrol system (Linkie et al.,

Table 3. Summary of key features of line transect, point transect, triangulation and camera trap methods used to estimate the density of male grey peacock-pheasant in Huai Kha Khaeng Wildlife Sanctuary, Thailand.

Method/ Detail	Line Transect	Point Transect	Triangulation	Camera Trap
Time of day	3 days/month 0600–1130hrs ±0.21min	3 days/month 0600–1130hrs ±0.21min	2 days/month 0600–1130hrs ±0.21min	Set camera trap and collect = 7 days/month 0830–1630hrs Get data 30 days/month 24 hours
Effort	43.2 km	12 times	9 listening areas	878 trap days
Effective area	0.5473 km^2	0.5851 km^2	0.4309 km^2	1.21 km^2
Person days/ month (cost)	9(87.79US$),	9(87.79US$)	6(58.52US$)	10(97.55US$)
Equipment cost	3 compass = 25US$	3 compass = 25US$	3 compass =25US$	39 camera trap & boxes = 9750US$
Analysis	Distance 6.0 Arc GIS 9.3	Distance 6.0 Arc GIS 9.3	Distance V6.0 Arc GIS 9.3	Presence 6.1 Arc GIS 9.3
Sampling	1.2 km interval 400 meters Total = 3 line transects	13 points interval 100 m were set on each transect Total = 39 points	27 listening posts	Set 200 × 200 m = 42 locations
Pre-field work preparation	Set line transect (1.2 km.) /1 day /3 manpower = 3 day	Set point count 13 points (1.2 km) /1 day/3 manpower = 3 days	Set point on map	Set point on map
Special need for training	Identification of calls and estimation of distance	Identification of calls and estimation of distance	Identification of calls and estimation of distance	Understanding of each camera model and how best to set them

2015; Hötte et al., 2016), a system that combines more science technology and management to increase the effectiveness of law enforcement in order to protect wildlife and its habitat in protected areas, it is used extensively throughout the sanctuary (WCS Thailand, 2015).

In contrast to these two studies, Mallari et al. (2011) designed their field protocol to suit their chosen analytical approach (Distance Sampling) and, therefore, used line transects to estimate densities of the congeneric Palawan peacock-pheasant in four habitats of varying human disturbance. The highest density of 20.3 birds km^{-2} (±64CV) was found in old growth forest and was similar to the estimates we obtained using our different methods. The similarity between our findings and those of Mallari et al. (2011), and the reasons that they differ so much from those of Selvan et al. (2013) and Gao (1999) suggest that density estimation must carefully consider the relationship between sampling design, field protocol and analysis to produce robust estimates.

Which method to use? Triangulation requires confidence that heard vocalisations can be assigned to an individual or a group (Brockelman & Srikosamatara, 1993). This method is used where individuals occur in groups, often widely dispersed, with at least one loud calling individual, such as gibbons (Brockelman et al., 2009). The challenge with grey peacock-pheasant is that calling males have a clumped distribution that results, in our case, in more than one male calling within 200 m of each other, making it difficult for observers to allocate calls to particular individuals. As noted above, the relationship between calling locations and the density of territories or individuals is not known. Furthermore, where calls are not heard over substantial distances, such as more than 500 m, it requires a greater effort to cover the study area adequately so that each call is heard by at least two observers. The combination of a lack of confidence in translating calls into a density estimate and the field effort required to adequately sample and locate all calls heard, suggests that triangulation is of limited value at present in surveying peacock-pheasants.

Point transects resulted in a slightly more precise estimate of density compared with that derived from line transects. In contrast, previous research on communities of birds demonstrated that line transects produce more precise estimates than point counts (Buckland, 2006; Gale et al., 2009). In grey peacock-pheasants, the detectability of vocalisations over large distances is problematic in mountainous areas because the ability of observers to detect and record birds whilst walking a line transect is limited (Howell et al., 2004). However, this method should be considered in areas where the topography is less rough

as it will allow observers to cover a larger area efficiently (Mallari et al., 2011; Sukumal et al., 2015).

Estimates of density from camera trapping had the widest standard error. In our study, the number of photographs per camera trap location is very small and this may be because male grey peacock-pheasants are relatively sedentary, particularly during breeding season (Johnsgard, 1999). The other methods that we used in this study were specifically comparing the density of calling males only, whereas the density estimate resulting from camera trapping was for all males making those estimates of density not directly comparable. Camera trapping may, however, prove useful to obtain other data, such as sex ratios, distribution and density of non-calling individuals of the species, and other species including potential predators (Li et al., 2010; Suwanrat et al., 2014). Camera trapping is labour intensive and the analysis complex, as demonstrated in studies of the non-loud calling and non- territorial Siamese fireback (*Lophura diardi*) (Suwanrat et al., 2015), and the loud calling, territorial great argus (O'Brien & Kinnaird, 2008; Winarni et al., 2009). Our data adds to the weight of evidence that camera trapping is not well suited for small study areas (Cueller et al., 2006; Jackson et al., 2006; Dillon & Kelly, 2007; Foster, 2008; Maffei & Noss, 2008) or for estimating abundance/ density of species which are highly territorial (Foster & Harmsen, 2011).

Our study suggests that the data generated by two methods (point transect and triangulation) could be used for density estimates of the grey peacock-pheasants and probably other peacock-pheasants with loud calls such as the Endangered Hainan peacock-pheasant, Vulnerable Malaysian peacock-pheasant (*P. malacense*) and Near Threatened Germain's peacock-pheasant (*P. germaini*). Triangulation is, however, less suitable than point transects, because of the field effort required and the lack of knowledge of the species' breeding system, which makes translating detections into density estimates very difficult. These uncertainties include whether males call only from display scrapes, whether they defend scrapes from each other and what proportion of males make and maintain scrapes. In contrast, point transects are more suitable because the assumptions of the method are statistical rather than biological and are explicitly stated so that they can be considered and satisfied when gathering data. The field protocol is practical in a range of challenging conditions, such as in mountainous areas and dense vegetation and is appropriate for broad scale surveys. The data are analysed using a well-defined and robust analytical procedure.

Some of the field protocols that we did not test included (a) call playback, and (b) spot mapping. Call playback was used by, for example, Jakob et al. (2010) for red-legged partridge (*Alectoris rufa*), but, given our lack of knowledge of the breeding behaviour of grey peacock-pheasants we considered it inappropriate to try this method here. Once the functions of calls are better understood in this species it will be possible to identify which call(s) can be used to elicit responses of grey peacock-pheasant to playback. For spot mapping, which was used by Suwanrat et al. (2015)

for Siamese fireback with radio telemetry, individual ranges could be identified and mapped accurately. Also Gale et al. (2009) used spot-mapping for a tropical forest bird community, with colour ringing to mark and map individuals, however here we considered it unreliable in the absence of individual recognition.

We conclude, therefore, that grey peacock-pheasant in Huai Kha Khaeng Wildlife Sanctuary, Thailand are surveyed most effectively using point transects. This method is the most precise, resource effective and has a clear analytical protocol.

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SUPPLEMENTARY MATERIAL

Fig. 1S. Number of camera trap photographs of males and females in each time period. Dark bars = male photographs and lighter bars = female.