Population size, distribution and status of the remote and Critically Endangered Bawean deer *Axis kuhlii*

Dede Aulia Rahman, Georges Gonzalez and Stéphane Aulagnier

Abstract Conservation of rare ungulates requires reliable population size estimates and distribution maps for prioritizing investments and assessing the effectiveness of conservation measures. We used both camera trapping and a random encounter model approach, and faecal pellet group counts, to update the range and population size of the Bawean deer *Axis kuhlii* in the Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia. We studied 2-month periods to fulfil the assumption of population closure. Both methods provided similar population density estimates (higher in the dry season) of c. 227–416 individuals. The estimated range of the species is significantly narrower than previously reported. The main threats (habitat loss as a result of illegal logging, and disturbance by dogs and hunters) are ongoing. Based on these results we suggest that the species should retain its Critically Endangered status on the IUCN Red List.

Keywords *Axis kuhlii*, Bawean deer, camera trapping, Cervidae, conservation, faecal pellet count, random encounter model

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Introduction

Reliable information on population size and range, and any trends in these parameters, is required to assess the conservation status of a species using the Red List criteria (IUCN, 2001). In the absence of such information, conservation management is often based on crude estimates, expert opinion or educated guesses, which may result in erroneous decisions that can be counter-productive (Akçakaya, 2002; Blake & Hedges, 2004; Murray et al., 2009). The Bawean deer *Axis kuhlii* (Temminck, 1836), the most isolated deer in the world and the only endemic deer species in Indonesian tropical rainforest, is categorized as Critically Endangered on the IUCN Red List (Semiadi et al., 2015). The Bawean deer is reported to range over a very small area restricted to the Bawean Island Nature Reserve and Wildlife Sanctuary and a peninsula on the north-west side of the island (Tanjung Cina; Lachenmeier & Melisch, 1996; Grubb, 2005). The protected area is relatively close to human settlements, and illegal logging is not uncommon in the forest habitat. Listed in Appendix I of CITES (2016), this taxon is legally protected and is one of 25 species prioritized for conservation by the Indonesian government on the basis of their threatened status (decree SK.180/IV-KKH/2015; Ministry of Environment and Forestry, 2015). Despite this status, and threats across its range, surprisingly little is known about the Bawean deer and no long-term monitoring has been implemented, partly because this is not a charismatic species.

Several methods have previously been used to study population trends and distribution in this species: faecal sampling (Blouch & Atmosoedirdjo, 1978; Blouch, 1980; LIPI & IPB, 1999; Semiadi, 2004; BBKSDA East Java, 2009), footprint (UGM & BBKSDA East Java, 2003) and call counts (BBKSDA East Java, 2009), and camera trap surveys (UGM & BBKSDA East Java, 2004). The latter study, in which 10 camera traps were installed at seven locations (Lang Pelem river, Lampeci river, Tambelang river, Mt Tinggi, Angsana block, Tanjung Putri block and Tanjung Cina) during 20 days, recorded no evidence of the Bawean deer, although this may be attributable to the short duration of the study and the placement of cameras in unsuitable locations.

Capture–recapture methods for estimating population size require individuals to be recognizable, either by rings or collars (e.g. Trolle et al., 2008; Oliveira-Santos et al., 2010) or by natural marks such as stripes, spots or scars (e.g. Kumbhar et al., 2013). They are not applicable to the many mammal species that lack distinctive marking, such as the Bawean deer, except when bucks are seasonally antlered.

The development of the random encounter model, a by-product of an ideal gas model (Hutchinson & Waser, 2007), has facilitated estimations of species densities from unmarked individuals with a known speed, and sensor detection parameters (Rowcliffe et al., 2008). The random encounter model has been implemented successfully for ungulate species by deploying cameras in systematic or fully randomized arrays (Rowcliffe et al., 2008; Rovero & Marshall, 2009; Zero et al., 2013; Carbajal-Borges et al., 2014).

Dede Aulia Rahman* (Corresponding author), Georges Gonzalez and Stéphane Aulagnier Comportement et Ecologie de la Faune Sauvage, Institut National de la Recherche Agronomique, CS 52627, 31326 Castanet-Tolosan Cedex, France E-mail dede.auliarahman@gmail.com

*Also at: Faculty of Forestry, Department of Forest Resources Conservation and Ecotourism, Bogor Agricultural University, Bogor, Indonesia

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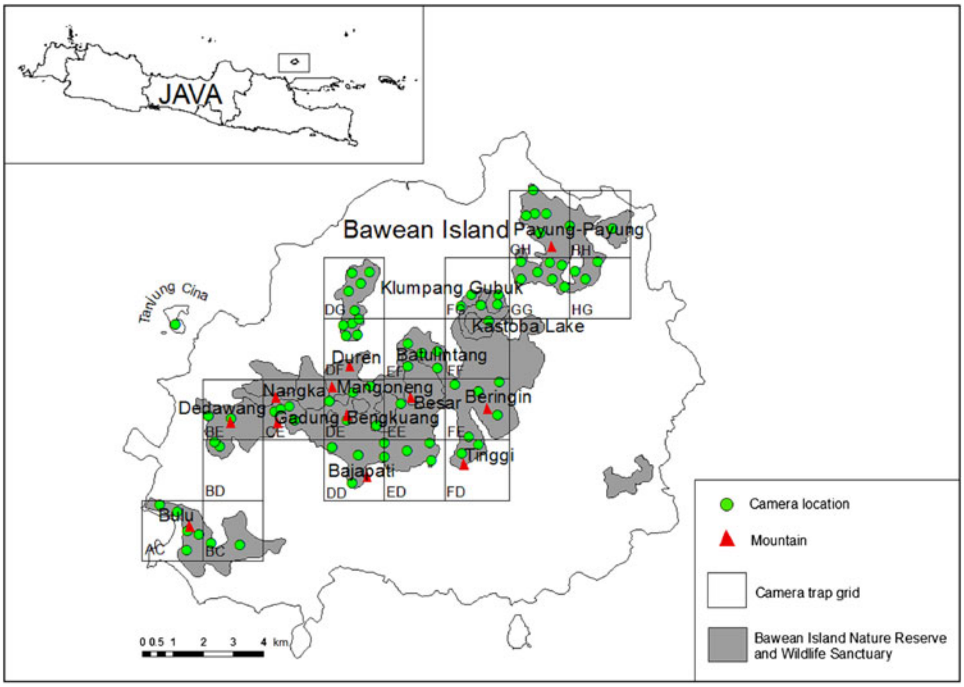

FIG. 1 Camera trap grid and camera locations in the Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia.

In this study we used two methods to estimate the abundance and map the range of the Bawean deer in the Bawean Island Nature Reserve and Wildlife Sanctuary, and assess its IUCN status. Density was estimated using both the random encounter model with camera trapping data and faecal pellet group counts; the latter technique was the most commonly used in previous studies.

Study area

Indonesia's Bawean Island (200 km²) is relatively isolated in the Java Sea (Fig. 1). Based on the classification of Smith and Ferguson, its climate is categorized as type C (Semiadi, 2004). Rainfall is abundant during the north-west monsoon, from the end of October until April, and reaches c. 2,500 mm on the southern coast. Temperature is almost uniform throughout the year, with mean maximum and minimum temperatures of 32 and 22°C, respectively (Semiadi, 2004). The study area encompasses 46.6 km² of the Bawean Island Nature Reserve and Wildlife Sanctuary, which is characterized by steep topography (with slopes > 60°) and a wide altitudinal gradient (up to 630 m). The main vegetation type is evergreen tropical forest, which covers 23% of the island. A mosaic of closed and open forest as well as permanently dry and seasonally flooded habitat types occur in the study area, including gallery forest, semi-deciduous forest with understorey, shrub and grassland, and teak *Tectona grandis* plantations (60% of the area), which are all globally threatened by deforestation and climate change. The remaining natural forests are confined to the steep sides and tops of the higher hills and mountains, often occurring as islands surrounded by teak (Semiadi, 2004).

Methods

Camera trapping

The Bawean Island Nature Reserve and Wildlife Sanctuary was divided into 20 4-km² grid cells using the geographical information system *ArcGIS 10.2.2* (ESRI, Redlands, USA). The camera trapping survey was conducted during both the wet (March–April and November 2014) and dry seasons (May–October 2014). Twenty Trophy Cam HD Max digital cameras (Bushnell Outdoor Products, Overland Park, USA) operating on passive infrared motion sensors were installed 30–50 cm above the ground, perpendicular to the ground, to record both small and large animals. Herbaceous vegetation in the vicinity of the cameras was cleared to avoid interference (Tobler et al., 2008; Team Network, 2011; Rovero et al., 2013). The cameras were set at 1 minute video mode with 1 minute intervals. The total survey effort was 5,500 trap days. Sampling precision was assessed as the coefficient of variation of trap rates with cumulative trapping effort (cameras × days). The sampling precision for the Bawean deer increased up to an optimum trapping effort of 520–560 camera days (Fig. 2). One camera trap per grid cell was deployed, in open and accessible locations, applying a buffer equivalent to half of the mean maximum distance moved, (1/2MMDM) to reduce the likelihood of capturing the same

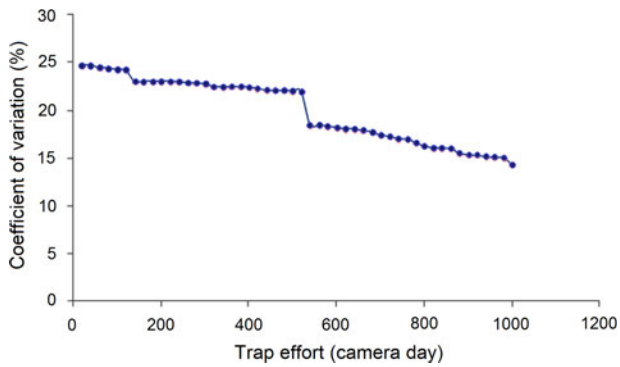

Fig. 2 Camera trap sampling precision expressed as the coefficient of variation of Bawean deer trapping rates with cumulative trap effort (number of cameras × trapping days).

individual twice (Karanth & Nichols, 1998; Soisalo & Cavalcanti, 2006).

Before installation we collected evidence of the presence of the Bawean deer (footprints, faeces, food remains, antler rubbing on trees) throughout the grid in the Bawean Island Nature Reserve and Wildlife Sanctuary and also in Tanjung Cina. We selected camera locations using the two following procedures. Firstly, we superimposed a grid of 100 × 100 m cells over the study area using the Fishnet and Clip tools in *ArcGIS 10.2.2* (ESRI, Redlands, USA). This generated 3,600 potential camera locations from which we randomly selected one for each 4 km^2 grid cell in the field. In general, cameras were not moved during the study; however, if a camera did not capture any mammal in 2–3 periods of checking we moved it 300–500 m from the original location within the same grid cell. Secondly, we selected locations where we found evidence of the presence of the Bawean deer. In practice, few camera traps were placed preferentially in this way (only 21 locations), as signs of the deer were difficult to find in the field. Moreover these cameras, which were expected to confirm the efficacy of the equipment, did not take significantly more photographs than randomly set cameras. In total, 75 locations were sampled during the survey period. Cameras were checked once every 28–31 days, and batteries and memory cards were replaced as necessary. Malfunctioning cameras were replaced to avoid loss of data.

Faecal pellet group count

Within each grid cell we counted faecal pellet groups in four plots (7 × 7 m) around the camera trap, spaced 10 m apart, according to Acevedo et al. (2010) and Alves et al. (2013). A total of 300 square plots (4 × 75 camera trap locations) were surveyed during the wet (February–March 2014) and dry seasons (August–September 2014). After the initial removal of all pellets present in each plot we calculated the faecal accumulation rate by recording the monthly deposition of pellets after the initial removal of all pellets present in the plot (deposition time of faecal groups). This method is appropriate for rapid surveys and when it is quite difficult to find a new group of faecal pellets in the field (Prugh & Krebs, 2004; St-Laurent & Ferron, 2008).

Random encounter model

The random encounter model uses the rate of contact between moving animals and static camera traps to estimate species density. It requires estimation of species-specific camera trap detection (Carbone et al., 2001), along with a camera trap detection specified by radius and angle, and an estimated day range based on speed of movement and activity data (Rowcliffe et al., 2011, 2014). The model is based on three main assumptions: (1) animals conform adequately to the model used to describe the detection process (i.e. they behave like particles of an ideal gas, moving randomly and independently of one another), (2) photographs represent independent contacts between animals and cameras, and (3) the population is closed (Rowcliffe et al., 2008). To fulfil these assumptions, camera traps were set at least 300 m apart to reduce the likelihood of capturing the same individual twice, and increase independence of locations (Kays et al., 2009). We studied 2-month periods in the dry season (June–July and August–September) on the basis that in such short sampling times the probability of birth, death, migration or immigration events is low (Karanth & Nichols, 1998; Silver et al., 2004; Soria-Díaz & Monroy-Vilchis, 2015).

We used the following equation to obtain density estimates from camera trap encounter rates (Rowcliffe et al., 2008):

$$gD = \frac{y}{t}\frac{\pi}{vr(2+\theta)}$$

where y/t = trapping rate (number of independent photographic events per camera trap day), v = a species' mean daily speed of movement (km day^{-1}), r = radius of the camera trap detection zone (km) and θ = angle of the camera trap detection zone (radians). The outcome can then be multiplied by g (mean group size), as the independent unit recorded by the camera is the group rather than the individual (Rowcliffe et al., 2008; Zero et al., 2013).

Independent photographic events were defined as individuals entering and exiting the field of view (Cusack et al., 2015). An individual's mean daily speed of movement was calculated as the speed recorded from camera trap videos multiplied by the proportion of time spent active (Rowcliffe et al., 2014). The radius of the camera trap detection zone was calculated by measuring the distance from the camera to the location of deer at the first trigger, based upon marked locations in the field. The angle of the camera trap detection zone was obtained in the field by detecting a stick in six paired approaches perpendicular to the sensor beam at a distance of 4 m and using a compass placed on a flat surface directly below the camera. The angle of maximal detection was then converted to radians for calculations. We used mean values of r and θ from all cameras in the calculations. The mean group size for this mostly solitary species was influenced mainly by does and their young.

Faecal accumulation rate

Population density (D, individuals per km²) was estimated using the equation proposed by Eberhardt & Van Etten (1956): $D = (\mathrm{NP} \times D\mathrm{pg})/(T \times \mathrm{d}R)$, where NP = number of plots per km², Dpg = mean number of faecal pellet groups, T = deposition time of faecal pellet groups, and dR = defecation rate. In the absence of field data we used the observed defecation rate of captive Bawean deer (13 faecal pellet groups per individual per day; Blouch & Atmosoedirdjo, 1987). We extrapolated the calculated densities to the total protected area on Bawean island to estimate the population size. The standard error of the estimates was computed using the delta method (Seber, 1982).

Distribution

We mapped the distribution and abundance based on the random encounter model and the faecal pellet count (map source: Bakosurtanal, 2002) using *ArcGIS*.

Results

Random encounter model

We recorded 118 photographs of Bawean deer (2.15 individuals per 100 trap-days), none during March–April, 10 in May (but only two independent photographic events), 19 in June, 23 in July, 32 in August, 22 in September, 6 in October and 6 in November. Random encounter modelling was performed bimonthly for June–July and August–September, with 32 and 50 independent photographic events, respectively. All variables and estimates for preferentially set, randomly set and all cameras are summarized in Table 1. Obtaining similar estimates for both sets of cameras, estimations for all cameras were 4.87 ± SE 1.05 individuals per km² in June–July and 8.92 ± SE 1.17 in August–September, yielding population estimates of 227 ± SE 33 and 416 ± SE 55, respectively.

Faecal accumulation rate

We counted 30 and 50 faecal pellet groups after 60 days of accumulation in the wet and dry seasons, respectively. We estimated a density of 3.48 ± SE 2.61 individuals per km² in the wet season (February–March) and 5.18 ± SE 3.61 in the dry season (August–September). The population size over

TABLE 1 Results of random encounter modelling to estimate the population of Bawean deer *Axis kuhlii* in the Bawean Island Nature Reserve and Wildlife Sanctuary (Fig. 1), for preferentially set (at locations with signs of deer), randomly set, and all cameras.

	Preferentially set cameras		Randomly set cameras		All cameras	
	June–July (8 cameras)	Aug.–Sep. (9 cameras)	June–July (12 cameras)	Aug.–Sep. (11 cameras)	June–July (20 cameras)	Aug.–Sep. (20 cameras)
Trapping rate (captures per day)	0.0533	0.0984	0.0519	0.0686	0.0525	0.0820
Detection distance (km)	0.0083 ± 0.0005	0.0076 ± 0.0004	0.0081 ± 0.0005	0.0072 ± 0.0004	0.0082 ± 0.0003	0.0074 ± 0.0003
Detection arc (radians)	0.3410 ± 0.0088	0.3462 ± 0.0044	0.3332 ± 0.0070	0.3266 ± 0.0037	0.3366 ± 0.0054	0.3379 ± 0.0032
Group size (no. of individuals)	1.25 ± 0.11	1.24 ± 0.07	1.24 ± 0.10	1.11 ± 0.06	1.24 ± 0.07	1.17 ± 0.05
Speed (km day^{-1})	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484
Model estimate (95% CI)	4.83 (3.80–5.86)	9.80 (8.23–11.37)	4.88 (3.89–5.87)	8.12 (6.82–9.42)	4.87 (4.18–5.56)	8.92 (7.77–10.07)
Population size	177–273	384–530	181–274	318–439	195–259	362–469

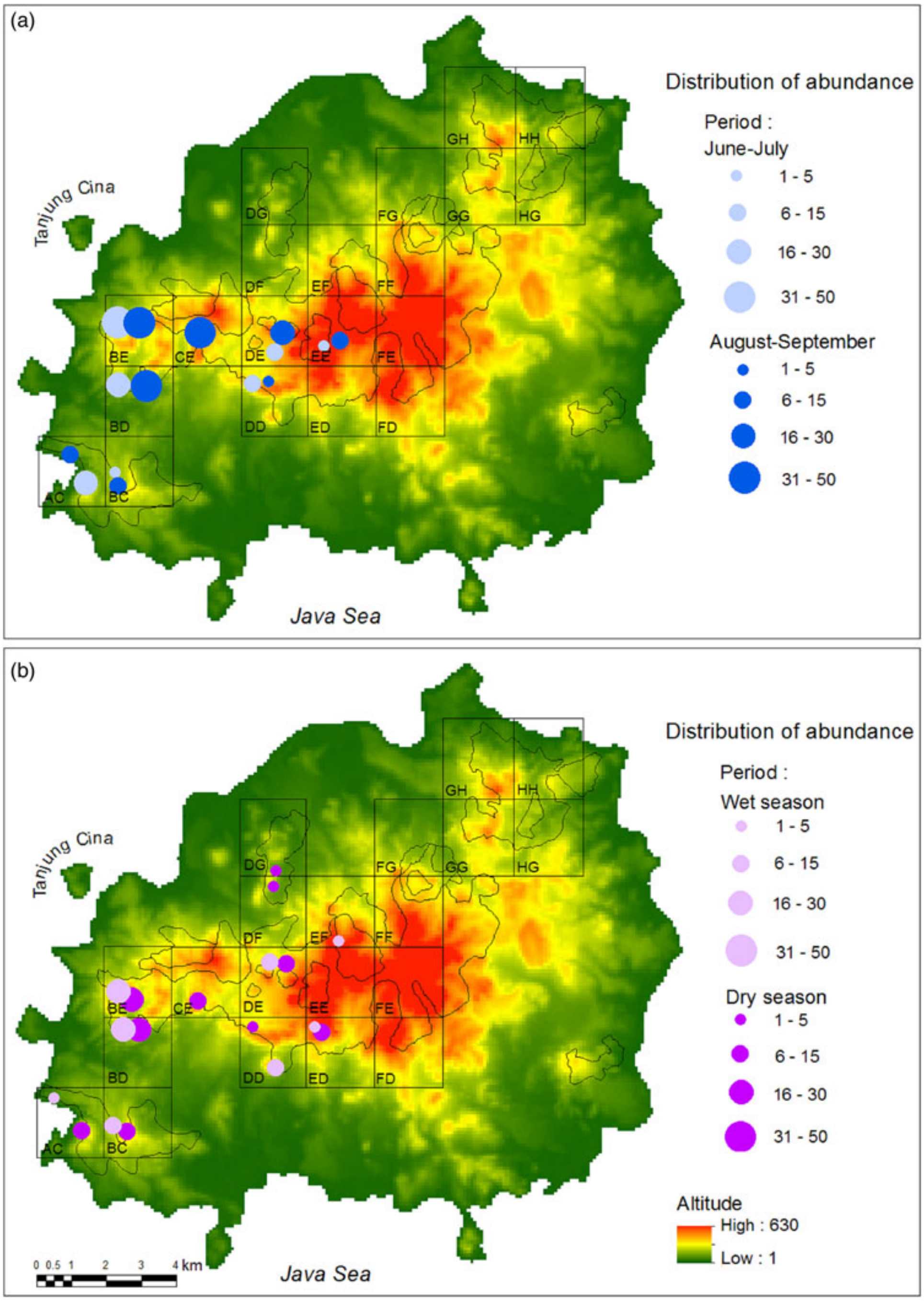

FIG. 3 Seasonal distribution of abundance (individuals per km²) of Bawean deer in the Bawean Island Nature Reserve and Wildlife Sanctuary (Fig. 1) based on (a) camera trapping and random encounter modelling and (b) faecal pellet counts and faecal accumulation rates.

the sampled area was estimated to be 162 ± SE 122 and 242 ± SE 168 in the wet and dry seasons, respectively.

Distribution

The presence of Bawean deer was recorded in eight and 11 grid cells using camera traps and faecal pellet counts, respectively, including seven grid cells by both techniques (Fig. 3). The recorded range of the species was restricted to the south-western part of the Bawean Island Nature Reserve and Wildlife Sanctuary, from Mount Bulu to Mount Bengkuang, at 34–320 m elevation. Only old faecal pellets were found at Mount Tinggi and Mount Besar. No deer were recorded in Tanjung Cina or in the north-east of the island by these techniques, nor did we find any footprints or other sign of presence at Mount Tinggi, Mount Beringin, Kastoba Lake or Mount Payung-Payung. The highest estimated abundance was in the vicinity of Mount Dedawang (36.8 and 28.3 individuals per km² by random encounter modelling and faecal accumulation rate, respectively). Abundance was lower at Mount Duren (1.1 individuals per km² by faecal accumulation rate) and Mount Besar (3.4 and 3.3 individuals per km² by random encounter modelling and faecal accumulation rate, respectively), and also around Mount Bajapati (4.1 and 2.2 individuals per km²). It was intermediate in the mixed secondary and teak forest of Mount Bulu (21.5 and 7.9 individuals per km²).

Discussion

Density estimates

We successfully tested the suitability of camera trapping and random encounter modelling for monitoring the status of the Bawean deer in its tropical forest habitat. The absence of photographs during the first 2 months (March–April) may be related to the presence of a high number of researchers at the beginning of the survey period, unsuitable locations of cameras, and lower activity of the species in the wet season. The trapping rate and density estimate increased during the dry season, peaking in August. As most deer were photographed when feeding, this could be related to the availability of food plants, which can become more scarce during the dry season, even in tropical habitats (Pontes & Chivers, 2007), leading to wider movements.

Estimates obtained with the random encounter model were more precise (narrower confidence intervals) and higher than those obtained using faecal pellet counts. This discrepancy may be attributable to the decay of faeces, and the approximate values of some parameters, such as the speed of deer movement, and the camera detection zone used in random encounter modelling. All parameters, even those that are hard to obtain (Rowcliffe et al., 2012), should be measured more accurately for the Bawean deer in the future. The combination of camera trapping and global positioning system telemetry could improve the accuracy of estimates, not only for performing random encounter modelling but also for analysing how species' home ranges can affect the required size of the area sampled. Such a study could also test the assumption of random distributions of cameras and wildlife (Cusack et al., 2015). The camera detection zone should also be investigated in different habitats and seasons; for example, we measured a lower detection radius in the wet season, although the difference was too weak to explain the absence of deer detection in that season.

Our findings suggest that random encounter modelling may yield accurate density estimates for elusive, rare and unmarked species, unlike photographic capture–recapture techniques, which require both unique markings and high-quality photographs for recognition of individuals (Soria-Díaz & Monroy-Vilchis, 2015). Moreover, random encounter modelling is continually being improved (Rowcliffe et al., 2011). Both methods estimated the highest density in the dry season, as previously reported (Blouch & Atmosoedirdjo, 1978), which supports the hypothesis that there is less movement in the wet season. The size of the Bawean deer population was estimated to be 242 individuals by the faecal pellet count method and 416 by random encounter modelling, which, compared to the previous estimate (250–300, by faecal pellet count; Semiadi, 2004), suggests stability.

Distribution and conservation status

Our records indicate that the range of the Bawean deer has narrowed significantly. Camera trapping and faecal pellet counts proved to be complementary, with presence at Klumpang Gubuk recorded only by the latter technique. Unlike Blouch & Atmosoedirdjo (1987) and Semiadi (2004), we found Bawean deer only in the central mountain range and in the south-west of the Bawean Island Nature Reserve and Wildlife Sanctuary, around Mount Bulu. We assume that the deer is no longer present in Tanjung Cina, where a density of 11.8 individuals per km² during the wet season was reported previously (Semiadi, 2004). No sign of presence was recorded at Mount Tinggi, Mount Beringin, Kastoba Lake or Mount Payung-Payung. Records by Sitwell (1970), Blower (1975), Blouch & Atmosoedirdjo (1978) and Blouch (1980) may indicate the existence of transient or survivor individuals rather than a stable population, possibly associated with increased habitat quality in some protected areas where routine patrol activities have reduced human disturbance and damage to vegetation.

The highest densities of Bawean deer were reported in secondary forests around Mount Dedawang, Mount Nangka, Mount Gadung, Mount Duren, Mount Mangoneng, Mount Bengkuang and Batulintang, a small area around Mount Bulu. The lowest densities were estimated in primary forests at Mount Besar, Mount Bajapati and Klumpang Gubuk. The population was centred around Mount Dedawang (cf. Blouch & Atmosoedirdjo, 1987), with activity concentrated at low altitudes (< 300 m), where food and water are abundant.

Hunting activity was recorded at six of 20 camera trap locations (Rahman et al., 2016), and one snare was found in Batu Gebang block (the south-eastern part of Mount Dedawang), close to semi-open cultivated areas used by wild boar for foraging, and with the highest density of Bawean deer. Although wild boar were the poachers' main target, deer could also be trapped, and die from stress-related causes (BBKSDA East Java, 2009). Furthermore, the Bawean Island Nature Reserve and Wildlife Sanctuary is close to human settlements, and some areas have been damaged by illegal logging. The continued presence of Bawean deer in harvested forests suggests some degree of tolerance to selective logging. The deer are attracted to settlements by agricultural crops (Semiadi, 2004), which places them at risk from feral dogs (Blouch & Atmosoedirdjo, 1978). We photographed feral dogs in 12 grid cells (Rahman et al., 2016) and recorded two cases of Bawean deer killed by feral dogs close to settlements. Although such events are rarer now than previously (Blouch & Atmosoedirdjo, 1987), the threat should be taken seriously as feral dogs are the main predators of several deer species in South America (Weber & Gonzalez, 2003).

The Bawean deer has survived a decade of social turmoil, in which food scarcity triggered high levels of hunting and illegal logging (Semiadi, 2004). Despite a stable population size, the species should retain its Critically Endangered status under criterion B1ab(ii, iii) and not C2a(ii) (which suggests a population decline) as in the most recent assessment (Semiadi et al., 2015). The extent of occurrence is < 100 km^2, the area of occupancy is declining and the habitat is fragmented. Further study is needed, including a long-term monitoring scheme. A captive-breeding programme was established in 2006 with a founder population of two stags and five hinds, and this population had increased to 35 individuals by 2014 (Meijaard et al., 2014).

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Author contributions

DAR, GG and SA conceived and designed the study. DAR collected the field data and analysed the camera trap data. DAR, GG and SA wrote the manuscript.

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Biographical sketches

Dede Aulia Rahman specializes in the ecology of deer species in tropical rainforest, and is working to develop the use of camera trapping and remote sensing in ungulate conservation projects in Indonesia. Georges Gonzalez studies the behaviour, management and conservation of ungulates in Western Europe, particularly in protected or managed areas. Stéphane Aulagnier's main area of interest is the evolutionary biology and conservation of Palaearctic mammals.