Short Communication

Density of the Vulnerable Sunda clouded leopard *Neofelis diardi* in two commercial forest reserves in Sabah, Malaysian Borneo

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Abstract Recently the Sunda clouded leopard *Neofelis diardi* was recognized as a separate species distinct from the clouded leopard *Neofelis nebulosa* of mainland Asia. Both species are categorized as Vulnerable on the IUCN Red List. Little is known about the newly identified species and, in particular, information from forests outside protected areas is scarce. Here we present one of the first density estimates calculated with spatial capture–recapture models using camera-trap data. In two commercial forest reserves in Sabah (both certified for their sustainable management practices) the density of the Sunda clouded leopard was estimated to be c. 1 per 100 km^2 (0.84 ± SE 0.42 and 1.04 ± SE 0.58). The presence of the Sunda clouded leopard in such forests is encouraging for its conservation but additional studies from other areas, including protected forests, are needed to compare and evaluate these densities.

Keywords Camera trapping, density estimation, felid, Forest Stewardship Council, South-east Asia, spatial capture–recapture, sustainable forest management

This paper contains supplementary material that can be found online at http://journals.cambridge.org

Recently, the revision of the taxonomy of clouded leopards using molecular and morphological data has shown that Bornean and Sumatran clouded leopards form a distinct species, *Neofelis diardi,* and that each island is occupied by separate subspecies, *N. diardi diardi* in Sumatra and *N. diardi borneensis* in Borneo (Wilting et al., 2007, 2011). This revision was adopted by the IUCN Red List, with *N. diardi* categorized as Vulnerable and both subspecies as Endangered (Hearn et al., 2011).

Clouded leopards are the least known of the pantherine felids. Earlier density estimates were based on extremely scarce data (Davies & Payne, 1982; Wilting et al., 2006), raising concerns regarding reliability. Recently several intensive camera-trapping studies have been conducted in Sabah, Malyasian Borneo. Here we present rigorous density estimates for the Sunda clouded leopard from two commercially used forest reserves in this region.

We carried out camera-trap surveys in the 500 km^2 Tangkulap-Pinangah Forest Reserve and 572 km^2 Segaliud Lokan Forest Reserve, both in the lowlands of central Sabah. During the last 50 years both areas were repeatedly logged by conventional selective logging techniques. Consequently they are covered today with degraded secondary lowland dipterocarp forests. Logging ceased in Tangkulap-Pinangah Forest Reserve in 2001, and in June 2011 the Reserve received certification from the Forest Stewardship Council. In Segaliud Lokan Forest Reserve, which is privately managed by KTS-Plantations Sdn. Bhd, logging practices changed in 1998 to reduced impact logging, and the Reserve is certified by the Malaysian Timber Certification Scheme.

We set up 64 and 55 camera-trap stations, covering areas of 122 and 114 km^2 in Tangkulap-Pinangah and Segaliud Lokan Forest Reserves, respectively (Fig. 1). Stations were spaced c. 1.7 km apart, each comprising two camera traps (Cuddeback Expert & Capture, Non Typical Inc., Green Bay, USA) facing each other to capture both flanks of any passing animal. This permitted identification of individuals based on their unique spot patterns.

Because of our limited number of camera traps we divided Tangkulap-Pinangah Forest Reserve into three blocks and Segaliud Lokan Forest Reserve into two blocks and sampled blocks separately. Each block was sampled for 42 (Tangkulap-Pinangah Forest Reserve) or 48 (Segaliud Lokan Forest Reserve) consecutive days. Total sampling duration was approximately 4 months, a period within the range of durations used in similar studies to approximate a closed population (e.g. Kawanishi & Sunquist, 2004; Royle et al., 2011). Tangkulap-Pinangah Forest Reserve was

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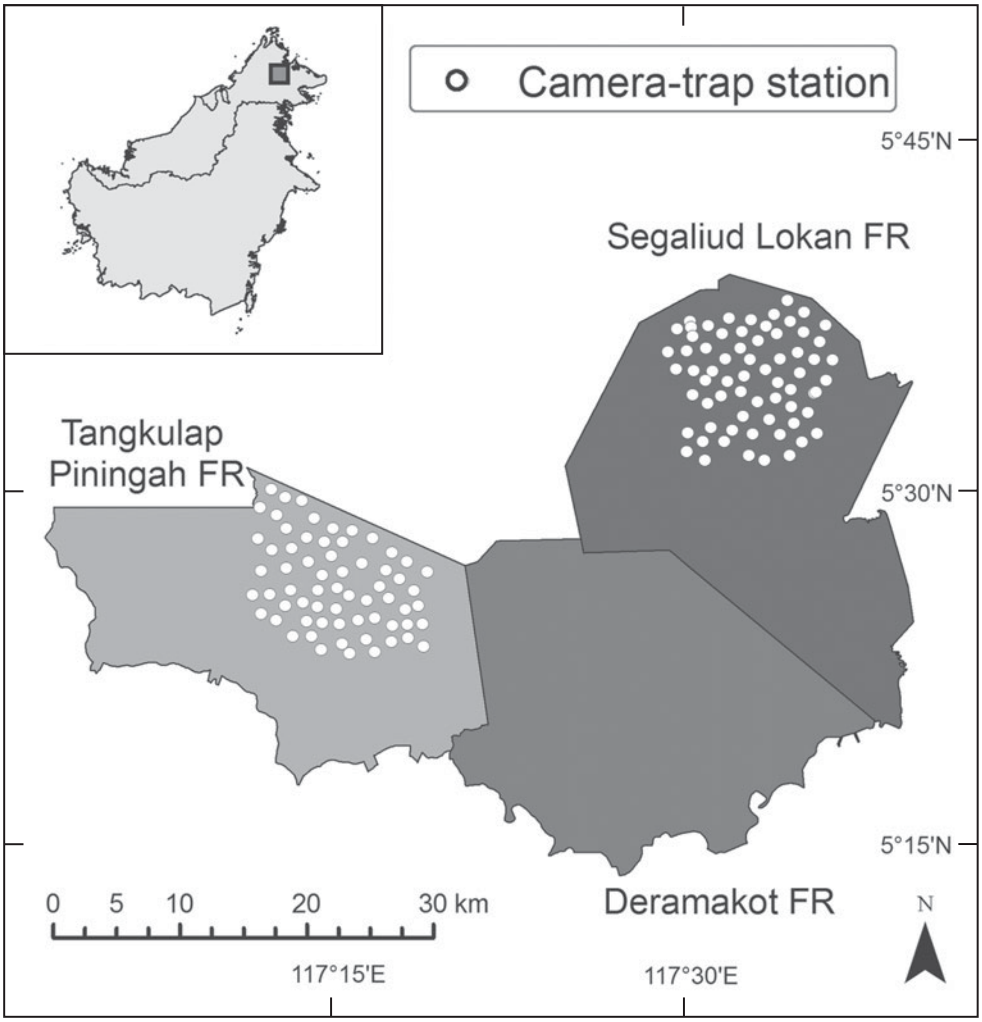

Fig. 1 Location of the camera-trap stations for the Sunda clouded leopard *Neofelis diardi* in Tangkulap-Pinangah and Segaliud Lokan Forest Reserves (FR). The rectangle on the inset shows the location of the main map in Sabah, Malaysian Borneo.

sampled during April–September 2009 and Segaliud Lokan Forest Reserve during January–April 2010.

For each study site we compiled the number of photographs of each individual at each camera-trap station (Appendix 1) and analysed the data using spatial capture–recapture models (Efford, 2004; Royle & Young, 2008). These models combine a model of individual movements with a model describing detection by camera traps. We adopted a model with a Poisson trap encounter process as described by Royle & Gardner (2011).

Because data at each site were sparse we coupled models from both sites and assumed that the parameter describing individual movements, σ, was constant across sites (i.e. σ is estimated from data generated at both sites). This reflects the assumption that individuals in the two reserves have similar-sized home ranges. We believe this is justified because the habitats in both study sites are similar (AW & AM, unpubl. data), suggesting that clouded leopards should have similar area requirements. Detection and density were estimated separately for each site.

In spatial capture–recapture models density is estimated as the number of individuals, N, occurring within the state space, an area encompassing the trapping grid large enough to contain all individuals that could have been exposed to trapping (Royle & Gardner, 2011). We defined the state space for each site by adding a 20-km buffer to the outermost coordinates of the two trapping grids.

We implemented the model in a Bayesian framework using *WinBUGS* (Gilks et al., 1994), accessed through *R v. 2.13.1* (R Development Core Team, 2011) using the package *R2WinBUGS* (Sturtz et al., 2005; see Appendix 2 for the WinBUGs code). We present results as means ± SE and the 2.5 and 97.5 percentiles of the posterior distributions. The latter characterize the 95% Bayesian credibility interval, analogous to a 95% confidence interval.

We obtained 29 (Tangkulap-Pinangah Forest Reserve) and 15 (Segaliud Lokan Forest Reserve) photographs of Sunda clouded leopards and in both areas we identified five individuals. The number of captures per individual was 1–17 and 1–9 in Tangkulap-Pinangah and Segaliud Lokan Forest Reserves, respectively. In both areas three individuals were males and two (Tangkulap-Pinangah Forest Reserve) and one (Segaliud Lokan Forest Reserve) were females; the sex of the remaining individual could not be determined. Baseline

TABLE 1 Parameter estimates (with SE and 95% Bayesian credibility interval, BCI) from spatial capture–recapture models of camera-trapping data of the Sunda clouded leopard *Neofelis diardi* in Tangkulap-Pinangah and Segaliud Lokan Forest Reserves (Fig. 1).

Parameter*	Units	Mean ± SE	95% BCI
Both			
σ	Km	6.490 ± 1.531	4.445–10.420
Tangkulap-Pinangah Forest Reserve			
	State space = 2,842 km^2		
λ_o	Photographs per occasion	0.076 ± 0.025	0.041–0.136
N		23.79 ± 11.95	7–52
D	Individuals per 100 km^2	0.837 ± 0.420	0.246–1.830
Segaliud Lokan Forest Reserve			
	State space = 2,782 km^2		
λ_o	Photographs per occasion	0.059 ± 0.058	0.015–0.219
N		28.87 ± 16.20	8–71
D	Individuals per 100 km^2	1.038 ± 0.582	0.288–2.552

*σ = movement parameter, related to home range radius; λ_o = baseline trap encounter rate, the detection parameter of the spatial capture–recapture model; N = number of individuals in state space; D = density

trap encounter rates λ_o were similar in both reserves and Sunda clouded leopards showed large movements (σ = 6.5 km). With 0.84 ± SE 0.42 and 1.04 ± SE 0.58 individuals per 100 km^2, density was similar in both sites (Table 1).

As these are among the first density estimates for the Sunda clouded leopard using spatial–recapture modelling comparison with most existing estimates is difficult. The provisional estimates of 25 individuals (Davies & Payne, 1982) and 8 individuals per 100 km^2 (Wilting et al., 2006) were based on scarce data. Densities obtained with non-spatial capture–recapture models in two study areas in Sabah (both previously selectively logged but with different forestry management strategies and histories) were 4.8–7.3 individuals per 100 km^2 (A.J. Hearn, J. Ross, D. Pamin, H. Bernard, L. Hunter & D.W. Macdonald, unpubl. data). Although these estimates could indicate higher numbers of Sunda clouded leopards in these areas, the differences in densities could also be a methodological artifact, as non-spatial capture–recapture modelling often leads to higher density estimates (e.g. Sharma et al., 2010). In contrast, Brodie & Giordano (2012) estimated the density of the Sunda clouded leopard in a protected area in Sabah, using spatial capture–recapture models, to be similar to those we report.

We recorded more males than females and individual males were photographed almost four times more often. Similarly, in other pantherine species male cats move over larger areas than females and are more readily detected by camera traps (e.g. Sollmann et al., 2011). Furthermore, female clouded leopards may also spend more time in trees than males: because of their lower weight they may be more agile and better climbers. Thus females may be detected less often in ground-based camera traps. Unfortunately, data were too sparse to model movement and detection separately for both sexes. Assuming a lower probability of detection and smaller movements for females, the density estimates could increase if differences in movements by sex were accounted for (Sollmann et al., 2011).

Even for a large cat a density of c. 1 individual per 100 km^2 is low. This raises several conservation concerns. Firstly, studying clouded leopards is difficult. Even our large and narrow-spaced trapping grid did not result in sufficient data to incorporate potentially important covariates in the model (sex, on/off road camera placement), and density estimates had large standard errors, as did the estimates of Brodie & Giordano (2012). To obtain more precise estimates and to monitor populations over time, substantial field monitoring will be required. Secondly, areas to protect clouded leopards need to be very large to ensure stable populations, probably several thousand km^2. Consequently, few existing protected areas are large enough to ensure the long-term viability of any Sunda clouded leopard population. Thirdly, therefore, forests beyond the borders of protected areas, such as timber concessions, are important for the survival of the species. This requires sustainable management of these areas because it is unknown to what extent Sunda clouded leopards can survive in highly degraded forests. The danger is that overexploited non-certified forests are often transformed into oil palm plantations, which are unlikely to support resident clouded leopards. To address these concerns further research should focus on timber concessions, to foster our understanding of habitat and space requirements of the Sunda clouded leopard in these altered environments.

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Appendices 1–2

The appendices for this article are available online at http://journals.cambridge.org

Biographical sketches

ANDREAS WILTING focuses on the ecology and evolution of mammals, particularly carnivores, in the Sunda Shelf. He integrates results from field research, distribution modelling and phylogenetic approaches to gain insights into the past and current distribution of these species. He and all the other authors have a strong interest in the study and conservation of tropical carnivores, their prey, and their interactions with humans. AZLAN MOHAMED uses camera-trapping to study mammals in Peninsular Malaysia. LAURENTIUS N. AMBU'S main interest lies in sustainable management of wildlife populations, and PETER LAGAN and SAM MANNAN focus on sustainable forest management in Sabah, Malaysian Borneo. HERIBERT HOFER'S focus is on integrating the behavioural ecology, conservation biology and evolutionary epidemiology of predominantly African carnivores and their pathogens. RAHEL SOLLMANN studies carnivores in Brazil and is currently working on the application of non-invasive methods and related statistical modelling techniques to this group of species.