Short Communication

Bringing clarity to the clouded leopard *Neofelis diardi*: first density estimates from Sumatra

RAHEL SOLLMANN, MATTHEW LINKIE, IDING A. HAIDIR and DAVID W. MACDONALD

Abstract We use data from camera-trap surveys for tigers *Panthera tigris* in combination with spatial capture–recapture models to provide the first density estimates for the Sunda clouded leopard *Neofelis diardi* on Sumatra. Surveys took place during 2004–2007 in the Kerinci landscape. Densities were 0.385–1.278 per 100 km^2. We found no statistically significant differences in density among four study sites or between primary and mixed forest. Because the data sets are too small to account for differences in detection parameters between sexes, density is probably underestimated. Estimates are comparable to previous estimates of 1–2 per 100 km^2 from the lowlands of central Sabah, on Borneo. Data limitations suggest that camera-trap surveys for Sunda clouded leopards require traps spaced more closely, to increase the chance of recaptures at different traps. Nevertheless, these first density estimates for clouded leopards on Sumatra provide a benchmark for measuring future conservation impact on an island that is undergoing rapid forest loss.

Keywords Forest degradation, Indonesia, Kerinci Seblat, *Neofelis diardi*, population closure, spatial capture–recapture, Sunda clouded leopard

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

---

The Sunda clouded leopard *Neofelis diardi* occurs on the islands of Borneo and Sumatra, is categorized as Vulnerable on the IUCN Red List (IUCN, 2013), and is one of the least studied pantherine felids. Sunda clouded leopard populations have been studied in some areas of Malaysian Borneo (Brodie & Giordano, 2012; Wilting et al., 2012) but no density estimates are available for Sumatra.

As the Sunda clouded leopard can be individually distinguished from its pelt markings, spatial capture–recapture models based on camera-trap data can provide statistically sound density estimates (Royle et al., 2014). When spatial capture–recapture data from several surveys are available they can be combined to estimate shared model parameters to increase accuracy and precision (e.g. Wilting et al., 2012), which is particularly useful for the typically sparse data sets for elusive, rare species.

There are large amounts of incidental data for small Asian felids from camera-trap surveys implemented to collect data on the tiger *Panthera tigris*. These data can provide insights into the ecology of little-known species (e.g. Linkie et al., 2013). Because the spatial study design is generally tailored to the focal species it remains to be tested whether these surveys generate suitable data for estimating the population of smaller felids.

We use such incidental camera-trapping data to provide the first density estimates for the Sunda clouded leopard on Sumatra, for which such information was not previously available. Our analysis contributes to the scientific knowledge necessary for informed conservation, and provides a benchmark against which future population estimates can be evaluated. The study focuses on four camera-trap surveys that were conducted in rainforests with varying levels of disturbance. We explore possible differences in clouded leopard density and movement between forest types, using a spatial capture–recapture model that shares parameters across study sites. We further consider how future survey designs could increase detection of the clouded leopard by camera-traps.

Camera-trap surveys were conducted during 2004–2007 in four areas in the Kerinci landscape of Sumatra, Indonesia (Fig. 1): Renah Kayu Embun and Sipurak (primary forest in Kerinci Seblat National Park), and Bungo and Ipuh (primary/secondary forest predominantly within a former logging concession).

Camera-traps were placed predominantly on trails and spacing was 1.5–3.5 km (Table 1). We analysed the resulting data for the Sunda clouded leopard, using spatial capture–recapture models (Efford, 2004; Royle et al., 2014). Although the data were collected in the previous decade, they comprise the most comprehensive data set for Sunda clouded leopards on Sumatra, spanning several study areas and ecological circumstances. Because data were too sparse to estimate model parameters separately for each site, we constructed a combined spatial capture–recapture model with shared parameters across sites. Assuming that ecological

RAHEL SOLLMANN (Corresponding author) North Carolina State University, Department of Forestry and Environmental Resources, Raleigh, North Carolina, USA. E-mail rsollma@ncsu.edu

MATTHEW LINKIE Fauna & Flora International, Singapore

IDING A. HAIDIR Indonesian Ministry of Forestry, Jakarta, Indonesia

DAVID W. MACDONALD Wildlife Conservation Research Unit, Department of Zoology, Oxford University, Tubney, UK

Received 18 March 2014. Revision requested 2 May 2014.
Accepted 20 May 2014. First published online 14 July 2014.

TABLE 1 Records of the Sunda clouded leopard *Neofelis diardi* from camera-trap surveys carried out during 2004–2007 in the Kerinci landscape, Sumatra (Fig. 1).

Area	No. of cameras	Area covered (km^2)	Mean spacing (km)	Total duration (days)	No. of camera-trap nights	No. of photos	No. of individuals (M/F/?)
Renah Kayu Embun	23	121	1.5	130	2,063	16	7 (6/1/0)
Sipurak	20	94	1.9	91	1,258	6	2 (2/0/0)
Bungo*	34	322	2.0	238	2,486	8	6 (5/1/0)
Ipuh*	38	706	3.5	222	3,563	17	7 (4/2/1)
Total	115			681	9,370	47	22 (17/4/1)

*Sub-divided into two surveys for analysis

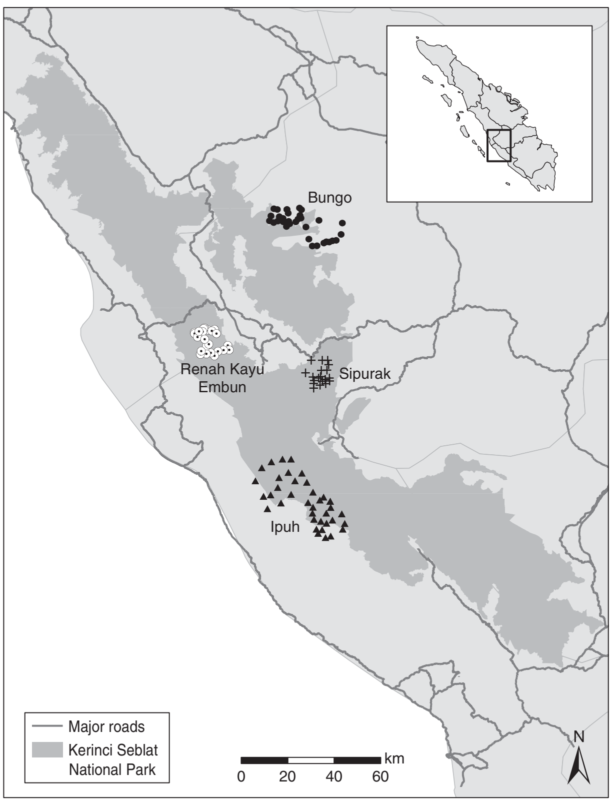

FIG. 1 The locations of camera-trap surveys for the tiger *Panthera tigris* during 2004–2007 in four areas (Table 1) in the Kerinci landscape (rectangle on the inset) on Sumatra, Indonesia.

circumstances should be comparable in the two primary forest and the two mixed forest areas, we estimate the baseline trap encounter rate λ_o and the movement-related parameter σ per forest type. Although gender can affect detection parameters in felids (e.g. Sollmann et al., 2011), modelling sex-specific detection parameters was not possible because of the low number of female recaptures.

Two surveys (at Bungo and Ipuh) lasted 8 and 7 months, respectively (Table 1). To approximate population closure we subdivided these surveys and considered the data sets for these shorter time intervals as independent. We assumed, however, that, density remained constant across these sub-surveys. This approach allows turnover in individuals without introducing an additional density parameter.

We implemented the model in a Bayesian framework using *JAGS* (Plummer, 2003), accessed through *R v. 3.0.1* (R Development Core Team, 2013). We report the posterior mean, standard deviation, mode and 2.5 and 97.5 quantiles. The quantiles comprise the 95% Bayesian credible interval (BCI). We consider parameters significantly different from each other if the 95% BCI of one does not include the mean of the other. Details of the model and its implementation are provided in Supplementary Material 1.

The four camera-trap surveys accumulated 9,370 trap nights and collected 47 records of 22 Sunda clouded leopards (Table 1). Of these individuals, one could not be sexed; of the remaining, 81% were male. Density at the four study sites was 0.385–1.278 individuals per 100 km^2. The 95% BCI for all density estimates largely overlapped and there was no apparent difference in density between primary (Renah Kayu Embun and Sipurak) and mixed forest sites (Bungo and Ipuh). The movement parameter σ was significantly larger in primary than in mixed forests (4.481 ± SD 1.561 km and 2.594 ± SD 0.527 km, respectively). Baseline encounter rate λ_o was lower in primary than in mixed forest (0.062 ± SD 0.027 and 0.101 ± SD 0.044, respectively) but 95% BCIs overlapped (Table 2).

At c. 0.5–2.0 per 100 km^2, our estimates of Sunda clouded leopard density on Sumatra are comparable to previous estimates from spatial capture–recapture models of 1–2 per 100 km^2 for the lowlands of central Sabah, Borneo (Brodie & Giordano, 2012; Wilting et al., 2012). This does not support the hypothesis that, compared to Borneo, clouded leopard densities on Sumatra may be limited by interspecific competition from the larger tiger (e.g. Palomares & Caro, 1999), which occurs at densities of 1.5–3.3 per 100 km^2 in the Kerinci landscape (Linkie et al., 2006).

We found no statistical evidence for differences in density across the four study areas, nor between primary and mixed primary/secondary forest. We did, however, estimate significantly larger movement parameters in primary forest, indicating that clouded leopards have larger home ranges there. Populations of top predators are regulated by prey abundance, and certain prey species attain

https://doi.org/10.1017/S003060531400043X Published online by Cambridge University Press

Table 2 Summary statistics of spatial capture–recapture models fit to camera-trap data on the Sunda clouded leopard from four study sites in the Kerinci landscape, Sumatra (Fig. 1).

Parameter*	Mean	Mode	95% Bayesian credible interval (2.5–97.5)
D, Renah Kayu Embun	1.570 ± SD 0.696	1.172	0.578–3.273
D, Sipurak	0.767 ± SD 0.519	0.385	0.145–2.101
D, Bungo	1.618 ± SD 0.728	1.278	0.576–3.375
D, Ipuh	1.110 ± SD 0.472	0.893	0.417–2.239
λ_0, primary	0.062 ± SD 0.027	0.049	0.023–0.127
λ_0, secondary	0.101 ± SD 0.044	0.074	0.038–0.207
σ, primary	4.481 ± SD 1.561	3.700	2.835–8.097
σ, secondary	2.594 ± SD 0.527	2.374	1.832–3.857

*D, density (per 100 km^2); λ_0, baseline trap encounter rate (photographs per 10 days); σ, movement parameter (km)

higher densities in disturbed forests (Ross et al., 2013). It is conceivable that the mixed primary/secondary forests provide a similar prey base for clouded leopards as primary forests. We estimated a slightly higher baseline detection rate for mixed forest (Table 2). Impassable canopy gaps in these disturbed forests may cause this semi-arboreal species to descend, which in turn could increase its detection probability. Alternatively, the denser undergrowth typical of secondary forest might have focused Sunda clouded leopard movements along the roads where camera-traps were placed.

Female clouded leopards were camera-trapped less frequently than males, and no female was ever recorded at more than one trap. Without spatial recaptures it is impossible to estimate σ separately for males and females (Sollmann et al., 2012), although the home range of females is probably smaller than that of males, as is the case for many felids. Attempts to estimate separate baseline detection rates for the two sexes failed because of the sparse data. These factors probably result in an underestimate of overall density.

Our analysis shows that incidental photographic data from surveys designed to study tiger populations can be used to estimate density of the much smaller Sunda clouded leopard. The sparseness of the present data sets, however, indicates that a camera-trap survey designed for the tiger is not ideal for the Sunda clouded leopard. The application of spatial capture–recapture models requires spatially spread out recaptures and that sufficient individuals are exposed to the trapping array. Therefore, for a rare and wide ranging, partially arboreal species, a camera-trap array has to both cover a large area and consist of a denser network of cameras. If this is logistically infeasible, spreading clusters of camera-traps throughout the study area can provide a more efficient alternative (Efford & Fewster, 2013). Choice of camera-trap location should focus on natural breaks in the forest canopy, where the animals are more likely to descend from the trees.

Our study provides insights into Sunda clouded leopard populations in forests experiencing varying levels of anthropogenic pressure but also highlights a knowledge gap: the high rates of forest loss and degradation on Sumatra occur disproportionately at lower elevations (Uryu et al., 2010) and further research on the status of the Sunda clouded leopard across this gradient of habitat degradation is needed. Nevertheless, these first density estimates for the species on Sumatra provide a benchmark to assess its population status, and underscore the rarity of this restricted-range felid.

Acknowledgements

We thank Dedy Kiswayadi for preparation of GIS data sets and Yoan Dinata for help with field work. DWM acknowledges the support of the Robertson Foundation and the Recanati–Kaplan Foundation. Funding for this study was provided by the U.S. Fish and Wildlife Service, 21st Century Tiger, Rufford Small Grants for Nature, and the People's Trust for Endangered Species.

References

Brodie, J. & Giordano, A.J. (2012) Density of the Vulnerable Sunda clouded leopard *Neofelis diardi* in a protected area in Sabah, Malaysian Borneo. *Oryx*, 46, 427–430.

Efford, M. (2004) Density estimation in live-trapping studies. *Oikos*, 106, 598–610.

Efford, M.G. & Fewster, R.M. (2013) Estimating population size by spatially explicit capture–recapture. *Oikos*, 122, 918–928.

Gelman, A., Carlin, J.B., Stern, H.S. & Rubin, D.B. (2004) *Bayesian Data Analysis*. 2nd edition. Chapman & Hall/CRC, Boca Raton, USA.

IUCN (2013) *IUCN Red List of Threatened Species v. 2013.2*. Http://www.iucnredlist.org [accessed 24 February 2014].

Linkie, M., Chapron, G., Martyr, D.J., Holden, J. & Leader-Williams, N. (2006) Assessing the viability of tiger subpopulations in a fragmented landscape. *Journal of Applied Ecology*, 43, 576–586.

Linkie, M., Guillera-Arroita, G., Smith, J., Ario, A., Bertagnolio, G., Cheong, F. et al. (2013) Cryptic mammals caught on camera: Assessing the utility of range wide camera trap data for conserving the endangered Asian tapir. *Biological Conservation*, 162, 107–115.

Palomares, F. & Caro, T.M. (1999) Interspecific killing among mammalian carnivores. *The American Naturalist*, 153, 492–508.

Plummer, M. (2003) JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. In *Proceedings of the 3rd International Workshop on Distributed Statistical Computing* (eds K. Hornik, F. Leisch & A. Zeileis), pp. 20–22. Technische Universität Wien, Vienna, Austria.

R Development Core Team (2013) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Ross, J., Hearn, A.J., Johnson, P.J. & Macdonald, D.W. (2013) Activity patterns and temporal avoidance by prey in response to

Sunda clouded leopard predation risk. *Journal of Zoology*, 290, 96–106.
Royle, J.A., Chandler, R.B., Sollmann, R. & Gardner, B. (2014) *Spatial Capture–Recapture*. Academic Press, Waltham, USA.
Royle, J.A. & Dorazio, R.M. (2012) Parameter-expanded data augmentation for Bayesian analysis of capture–recapture models. *Journal of Ornithology*, 152, 521–537.
Sollmann, R., Furtado, M.M., Gardner, B., Hofer, H., Jacomo, A.T.A., Tôrres, N.M. & Silveira, L. (2011) Improving density estimates for elusive carnivores: accounting for sex-specific detection and movements using spatial capture–recapture models for jaguars in central Brazil. *Biological Conservation*, 144, 1017–1024.
Sollmann, R., Gardner, B. & Belant, J.L. (2012) How does spatial study design influence density estimates from spatial capture–recapture models? *PLoS ONE*, 7(4), e34575.
Uryu, Y., Purastuti, E., Laumonier, Y., Sunarto, Setiabudi, Budiman, A. et al. (2010) *Sumatra's Forests, their Wildlife and the Climate—Windows in Time: 1985, 1990, 2000 and 2009*. WWF–Indonesia Report, Jakarta, Indonesia.
Wilting, A., Mohamed, A., Ambu, L.N., Lagan, P., Mannan, S., Hofer, H. & Sollmann, R. (2012) Density of the Vulnerable Sunda clouded leopard *Neofelis diardi* in two commercial forest reserves in Sabah, Malaysian Borneo. *Oryx*, 46, 423–426.

Biographical sketches

Rahel Sollmann is a quantitative ecologist with a focus on stochastic population modelling. Her work concentrates on the ecology and conservation of terrestrial mammals, particularly carnivores, and the non-invasive methods used to study these species. Matthew Linkie's research interests primarily focus on evaluating the performance of conservation strategies, especially for managing protected areas and threatened mammals in the tropics, as well as seeking ways that science can influence on-the-ground conservation. Iding Haidir's interests lie in carnivore conservation and protected areas management. In the last decade he has been working for Indonesia's national parks management in central Sumatra, focusing on forest and wildlife conservation. David Macdonald's research focuses on applying ideas from behavioural ecology, in an interdisciplinary framework, to finding practical solutions to problems in wildlife conservation. He works with mammals, and in particular with carnivores.