

Abundance and density estimates for common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* in Manas National Park, Assam, India

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Abstract Effective conservation of rare carnivores requires reliable estimates of population density for prioritizing investments and assessing the effectiveness of conservation interventions. We used camera traps and capture–recapture analysis to provide the first reliable abundance and density estimates for the common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* in Manas National Park, India. In 57 days of camera trapping, with a total of 4,275 camera-trap days, we photo-captured 27 individually identified common leopards (11 males, 13 females and three unidentified), and 16 clouded leopards (four males, five females and seven unidentified). The abundance estimates using the M_h jackknife and Pledger model M_h were 47.0 and 35.6, respectively, for the common leopard, and 21.0 and 25.0, respectively, for the clouded leopard. Density estimates using maximum likelihood spatially-explicit capture–recapture were $3.4 \pm \text{SE } 0.82$ and $4.73 \pm \text{SE } 1.43$ per 100 km² for the common and clouded leopards, respectively. Spatially-explicit capture–recapture provided more realistic density estimates compared with those obtained from conventional methods. Our data indicates that camera trapping using a capture–recapture framework is an effective tool for assessing population sizes of cryptic and elusive carnivores such as the common and clouded leopards. The study has established a baseline for the long-term monitoring programme for large carnivores in Manas National Park.

Keywords Camera trap, capture–recapture, Manas National Park, *Neofelis nebulosa*, *Panthera pardus*, population, tiger

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Introduction

For effective management of mammals within protected areas knowledge of which species are present, and their relative abundance and distribution, is essential (Sheng et al., 2010). Well-designed monitoring programmes can obtain such information and provide robust data to wildlife managers for long-term monitoring (Pereira & Cooper, 2006; Marsh & Trenham, 2008). Monitoring is usually of specific species, ignoring sympatric species that may also be of conservation concern. Information on such sympatric species is, however, important for effective management (Gibbs et al., 1999). In the absence of species abundance information, conservation management decisions are often based on crude estimates, expert opinion or educated guesses, which may result in erroneous decisions that can be counterproductive for conservation (Blake & Hedges, 2004).

Large carnivores such as the tiger *Panthera tigris*, common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* may be sympatric, serve as umbrella species across a wide range of habitats and are functionally vital components of the ecosystems in which they occur. Tigers prefer relatively undisturbed habitats, where they feed on large prey (Karanth & Sunquist, 1995). The common leopard, in contrast, occurs across a wider range of ecosystems and feeds opportunistically on a variety of prey species (Bailey, 1993), whereas clouded leopards inhabit densely-vegetated habitats and remote areas, and prefer small prey (Grassman et al., 2005).

Mark–recapture has long been used to estimate biological populations (Otis et al., 1978). The method to estimate tiger populations using photographic capture–recapture analysis using camera traps was developed by Karanth (1995) and Karanth & Nichols (1998) in Nagarhole, India, following which it has been widely used to estimate populations of the tiger (Karanth & Nichols, 2000, 2002; Karanth et al., 2004; Jhala et al., 2008, 2011; Harihar et al., 2009b; Sharma et al., 2009) and common leopard (Chauhan et al., 2005; Edgaonkar, 2008; Sankar et al., 2008; Harihar et al., 2009a) in the Indian subcontinent, and the tiger (O'Brien et al., 2003; Kawanishi & Sunquist, 2004; Linkie et al., 2006; Wang & Macdonald, 2009; Wegge et al., 2009)

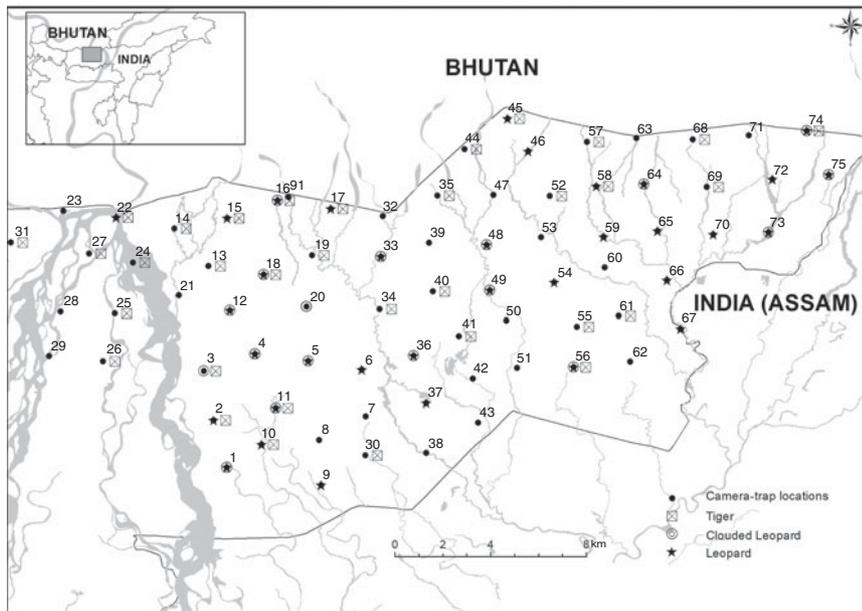


FIG. 1 Camera-trap locations in Manas National Park, indicating those at which tiger *Panthera tigris*, leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* were photo-captured. The shaded rectangle on the inset indicates the location of the main map in north-east India.

and common leopard in other countries (Balme et al., 2007; Henschel, 2008; Khorozyan et al., 2008; Gray & Prum, 2012). Little is known, however, about the status and behaviour of the clouded leopard (Wilting et al., 2006). Grassman et al. (2005) systematically surveyed a clouded leopard population but other available information on the ecology of the species is anecdotal (Banks, 1931; Pocock, 1939), based on local information (Rabinowitz et al., 1987; Rabinowitz, 1988) and sighting reports (Davies, 1990; Ghose, 2002). The clouded leopard has been reported in India from the north-eastern states of Assam, Meghalaya, Arunachal Pradesh, Tripura, Mizoram, Sikkim and northern parts of West Bengal (Katti et al., 1990; Choudhury, 1993; Ghose, 2002; Borah et al., 2010). A study of the Sunda clouded leopard *Neofelis diardi* using capture–recapture models has been carried out in Sabah, Malaysia (Wilting et al., 2006) and densities have been estimated from the same area (Brodie & Giordano, 2012; Wilting et al., 2012).

A camera-trapping study to determine the relative abundance of tigers and their prey in Manas National Park (Jhala et al., 2011; J. Borah et al., unpubl. data) also provided data on the occurrence of other large felids. Here we use these data to estimate the abundance and density of the common and clouded leopards, and establish baseline data for long-term monitoring programmes and for conservation planning in the Park. The camera trapping was conducted as a part of the All India Tiger Estimation programme of the Government of India in collaboration with the National Tiger Conservation Authority, Wildlife Institute of India and Assam Forest Department, and involved WWF–India, the Ashoka Trust for Research in Ecology and Environment, and Aaranyak as collaborative partners.

Study area

The 500 km² Manas National Park in the state of Assam, India, lies on the borders of the Indo–Gangetic and Indo–Malayan biogeographical realms. It lies on a gentle alluvial slope in the foothills of the Himalayas, where wooded hills give way to grasslands and tropical forest, and is home to a variety of important mammal species, including the tiger, pygmy hog *Porcula salvania*, hispid hare *Caprolagus hispidus* and Asian elephant *Elephas maximus*. The Park supports 22 of India's most threatened mammal species, as listed in Schedule-I of the Wildlife (Protection) Act of India (Deb Roy, 1991). Together with the Royal Manas National Park in Bhutan, the Park forms one of the largest areas for tiger conservation in South Asia, representing the full range of habitats from the subtropical plains to the alpine zone (Wang, 2001).

Methods

Camera trapping

We put camera traps (Cuddleback, Non Typical Inc., Wisconsin, USA; Trailmaster, Goodson & Associates, Kansas, USA; Panthera Camera Trap V3, Panthera, USA; CEDT, Indian Institute of Science, Bangalore, India) in 75 locations covering c. 300 km² across two ranges of the Manas National Park (Fig. 1) from November 2010 to February 2011. A pair of camera traps were placed in a 2 × 2 km cell; the distance between each camera location was 1.75–2.15 km. The camera traps were deployed in the best possible locations in each grid cell to ensure coverage of the entire sampling area and thus satisfy the assumption that no

animal had a zero probability of being photographed. The survey was thus designed to cover the study area homogeneously, to maximize the chance of photographing all animals present in the area (Karanth & Nichols, 1998). Most of the camera traps were positioned on paths or animal trails, based on a sign survey carried out prior to camera trapping, to maximize the chances of photographing carnivores. The time delay between photographs was set to minimize the possibility of missing any animals. All cameras were operational for 24 hours per day for 57 days, except in cases of malfunction, or damage caused by elephants. Each day was defined as a sampling occasion (Otis et al., 1978). Fifty-seven days was adequate for assuming demographic closure (Otis et al., 1978) of the study population as previous studies of large felids have indicated that trapping periods of 2–3 months ensure that no population change occurs during a study (Karanth, 1995; Karanth & Nichols, 1998; Silver et al., 2004). All camera units were mounted on trees, on poles or in steel cages, 3–4 m on either side of a path or trail, with the sensor 20–40 cm from the ground, and were checked daily. Although the same camera locations were generally maintained throughout the study, we moved the cameras by 100–200 m from the original location whenever signs of trap shyness were observed. We identified individual common leopards by the spot pattern of their pelage and clouded leopards by their distinctive cloud-like pelage pattern.

Abundance estimation

We developed individual capture histories for common and clouded leopards in a standard X matrix (Otis et al., 1978; Nichols, 1992). These were analysed, using models developed for closed populations, in *CAPTURE* (Rexstad & Burnham, 1991) and *MARK* (White, 2008). We assumed that the sampled population was demographically closed, as common and clouded leopards are long-lived animals (Otis et al., 1978; Smith, 1993; Karanth, 1995; Srivastav & Nigam, 2009) and our sampling period was relatively short. We formally tested for population closure using *CloseTest* (Stanley & Burnham, 1999) and open Pradel models implemented in *MARK*. In the Pradel models we compared the Akaike information criteria corrected for small sample size (AICc) scores between a model in which recruitment and survival were constrained to 0 and 1, respectively (representing population closure), and an open model in which these parameters were estimated based on observed data. The parameters recruitment and survival correspond to immigration and fidelity, respectively, assuming a population is demographically closed (Boulanger & McLellan, 2001; Harihar et al., 2009a).

The jackknife estimator (Otis et al., 1978) has been used in photographic-capture studies (Karanth, 1995; Karanth &

Nichols, 1998; Karanth et al., 2004; Maffei et al., 2004; Simcharoen et al., 2007; Wang & Macdonald, 2009) to estimate capture probabilities and population size. We generated parameter estimates under the M_h model, which was the best-fit model for our data, in *CAPTURE*. We also used closed population Pledger models (Pledger, 2000) in *MARK*, where heterogeneity is handled using a finite number of mixtures. Compared to simpler models in *CAPTURE*, Pledger models are able to deal better with heterogeneity in capture probabilities (Boulanger et al., 2002). We ran the null model with all capture and recapture probabilities equal (M_o), the heterogeneity model with two mixtures of identical capture and recapture probabilities (M_h), the behavioural model with different capture and recapture probabilities (M_b) and the behaviour and heterogeneity model with two mixtures of capture and recapture probabilities and a behavioural response (M_{bh}). We model-averaged abundance estimates (Burnham & Anderson, 2002), using AICc, across the models.

Density estimation

We estimated common and clouded leopard densities by dividing the population size based on our abundance estimates with the effective sampled area. The effective sampled area was computed following the approach developed by Wilson & Anderson (1985), using half the mean of maximum distance moved (HMMDM) method, in which a buffer of HMMDM for all individuals captured at more than one camera-trap location is added to the trapping grid polygon (Karanth & Nichols, 1998). We also obtained density estimates using full maximum likelihood spatially-explicit capture–recapture using *DENSITY v. 4.4* (Efford, 2009), which did not rely upon closed population estimates from *CAPTURE* or *MARK*. The buffer width around the trapping grid was set to 10 km and we assumed a half-normal spatial capture probability function and a Poisson distribution of home-range centres for estimating density.

Results

We photo captured 27 individually identified common leopards (11 males, 13 females and three unidentified) and 16 individually identified clouded leopards (four males, five females and seven unidentified) during the total of 4,275 camera-trap nights. Capture frequencies were 1–8 for common leopards and 1–7 for clouded leopards. *CloseTest* supported the assumption of population closure for the 57-day sampling period for common leopards but not for clouded leopards (Table 1). However, in *MARK*, the open Pradel model estimated survivorship (θ) to be $0.96 \pm \text{SE } 0.01$ and recruitment (f) to be $0.06 \pm \text{SE } 0.01$ for the clouded leopard population. The constrained Pradel model, in which

TABLE 1 The results of tests of population closure using *CloseTest* and open Pradel models (see text for further details) for camera-trap data of the common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* in Manas National Park, Assam, India (Fig. 1).

Species	<i>CloseTest</i>		Pradel model	
	χ^2	P	Open model (ΔAICc)	Constrained model (ΔAICc)
Leopard <i>Panthera pardus</i>	25.5	0.92		
Clouded leopard <i>Neofelis nebulosa</i>	41.5	0.01	41.07	13.80

θ was set at 1.0 and f at 0.0 (the closed model), was better supported than the open model (Table 1). The clouded leopard population was therefore considered closed and analysis was done using a closed capture–recapture framework.

Abundance

For the common leopard, tests for heterogeneity in trapping probabilities ($\chi^2 = 9.42$, $df = 1$, $P = 0.009$) and the affect of a behavioural response ($\chi^2 = 7.11$, $df = 1$, $P = 0.007$) supported the suitability of these models in *CAPTURE*. The overall model selection test ranked M_h (incorporating individual heterogeneity in capture probabilities) as the best model (Criteria rated 1). The probability of detecting an individual on at least one sampling occasion (mean \hat{P}) was 0.01. The population estimate using M_h with the jackknife estimator was $47.00 \pm SE 11.30$. Using *MARK* the estimates of abundance were 27–35 ($\pm SE 5.60$). The Pledger model M_h was the most strongly supported, based on AICc , with a model-averaged estimate of common leopard abundance of $35.60 \pm SE 5.50$. Model-averaged initial capture probability was $0.02 \pm SE 0.06$ and recapture probability $0.11 \pm SE 0.02$.

For the clouded leopard the overall model selection test ranked M_h as the best model, using *CAPTURE*. The probability of detecting an individual on at least one sampling occasion was 0.02. The population estimate using M_h with the jackknife estimator was $21.00 \pm SE 6.60$. Using *MARK* the estimates of abundance were 16–25 ($\pm SE 6.90$). The Pledger model M_h was the most strongly supported, based on AICc score, with a model-averaged clouded leopard abundance estimate of $25.03 \pm SE 6.80$. Model-averaged initial capture probability was $0.02 \pm SE 0.006$ and recapture probability $0.12 \pm SE 0.03$.

Density

For the common leopard the maximum distance moved by recaptured individuals between captures was 1.6–13.1 km (mean $3.4 \pm SE 1.9$). Based on HMMDM the total sampling area was estimated to be $414.2 \pm SE 36.3 \text{ km}^2$. Density estimates based on model M_h (jackknife), using *CAPTURE*, were $11.30 \pm SE 2.90$ per 100 km^2 , and $8.40 \pm SE 1.40$ per 100 km^2 based on model-averaged abundance estimates

using *MARK*. In spatially-explicit capture–recapture analysis using *DENSITY*, density was estimated to be $3.40 \pm SE 0.82$ per 100 km^2 . Capture probability at home-range centre (g_0) was estimated to be $0.54 \pm SE 0.13$ and σ (a function of movement) was $4,210 \pm SE 489 \text{ m}$.

For the clouded leopard the maximum distance moved by recaptured individuals between captures was 2.0–13.6 km (mean $2.5 \pm SE 1.6 \text{ km}$). Based on HMMDM the total sampling area was estimated to be $382.6 \pm SE 35.2 \text{ km}^2$. Density estimates based on model M_h (jackknife), using *CAPTURE*, were $5.50 \pm SE 1.80$ per 100 km^2 , and $6.53 \pm SE 1.88$ per 100 km^2 based on model-averaged abundance estimates using *MARK*. Based on spatially-explicit capture–recapture analysis using *DENSITY*, density was estimated to be $4.73 \pm SE 1.43$ per 100 km^2 . Capture probability at home-range centre (g_0) was estimated to be $0.86 \pm SE 0.34$ and σ was $1,602 \pm SE 246 \text{ m}$.

Discussion

Our results provide the first reliable abundance and density estimates for the clouded leopard in Manas National Park, and India, and baseline estimates for the common leopard in the Park. We estimated density using several approaches but the estimates were bounded by wide confidence intervals, as in the studies of the Sunda clouded leopard (Brodie & Giordano, 2012; Wilting et al., 2012). The broad confidence intervals are probably because of the low number of recaptures of both common and clouded leopards, and highlight the fact that when using camera traps for surveying rare elusive large carnivores, maximizing both individual capture and recapture probabilities, and the sample size, are important (Gray & Prum, 2012). As our study was specifically designed to maximize the photographic-capture of tigers we believe that increasing the density of camera traps, and a reduced grid size, would maximize individual capture and recapture probabilities for common and clouded leopards.

The density of the common leopard has been reported to be 1.0–25.5 per 100 km^2 in the Indian subcontinent (Ramesh, 2010) and that of the clouded leopard in South-east Asia has been reported to be 9–25 per 100 km^2 (Wilting et al., 2006) and 0.8–1.9 per 100 km^2 (Brodie & Giordano, 2012; Wilting et al., 2012). Our density estimate for the common leopard in

Manas National Park is thus comparable to estimates from elsewhere. In the same survey the density of the tiger was estimated to be $1.8 \pm SE 1.1$ and $0.8 \pm SE 0.3$ based on HMMDM and maximum likelihood spatially-explicit capture–recapture, respectively (Jhala et al., 2011). Manas National Park is recuperating from the aftermath of ethnic violence but, with recent support from Government agencies, including the forest department, and involvement of various NGOs and local communities, wildlife populations, including those of carnivores, are now showing signs of recovery (Boojh et al., 2011). The low densities of the common and clouded leopards could be attributed to the presence of other predators, including tigers and dholes *Cuon alpinus*. The influence of competitive interactions between sympatric carnivores on their abundance and distribution is well known (Linnell & Strand, 2000). We recommend that future studies in Manas National Park examine intra-guild competition among these top predators.

Photographic capture–recapture analysis has been used previously for estimating individually identifiable cryptic animals such as tigers (Karanth & Nichols, 1998, 2000, 2002; Karanth et al. 2004) and common leopards (Chauhan et al., 2005; Edgaonkar, 2008; Sankar et al., 2008; Harihar et al., 2009a). We recommend exploring data using models in which individual covariates can be included to determine factors affecting capture and recapture probabilities. Estimating densities from abundance estimates in closed population capture–recapture models is largely based on observed animal movements (Borchers & Efford, 2008; Karanth & Nichols, 2010). The best approach is to use the spatial capture histories of camera traps in a likelihood-based density estimation framework (Borchers & Efford, 2008; Efford et al., 2009). As this method does not require the addition of a buffer to the trapping polygon for estimating effective trapping area, the resultant estimates are less biased by trap layout and density (Efford, 2004).

For monitoring the success of conservation activities baseline estimates of abundance and density are critical. However, low sample size and low probabilities of capture and recapture may lead to uncertainty, particularly when monitoring large rare carnivores such as tigers and common and clouded leopards. Data on intra-guild relations among sympatric carnivores are therefore essential for planning conservation interventions (Bangs & Fritts, 1996). Our research has provided evidence that in Manas National Park tigers and other carnivores have survived a decade of social turmoil in the region. Previous studies of sympatric large carnivores have examined behavioural factors and patterns of prey selection to infer the mechanisms facilitating coexistence (Karanth & Sunquist, 1995, 2000; Wang & Macdonald, 2009; Wegge et al., 2009; Harihar et al., 2011). Similar studies in Manas National Park would facilitate a better understanding of the ecology of the large carnivore

assemblage. Although there has been considerable conservation investment in recovering tiger populations (Walston et al., 2010), such efforts rarely take into account the possible cascading effects on sympatric carnivores such as the common and clouded leopard.

Our study has provided baseline density estimates for the common and clouded leopards in Manas National Park, and annual population monitoring is now being carried out to examine the population dynamics and trends of these species and the sympatric tiger. The densities of prey species are also being estimated. Future research and conservation initiatives will be able to use these baselines for management planning.

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