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Research Article

Melanistic Leopards Reveal Their Spots: Infrared Camera Traps Provide a Population Density Estimate of Leopards in Malaysia

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ABSTRACT To date, leopards (*Panthera pardus*) in Peninsular Malaysia have been overlooked by large carnivore researchers. This is in part due to the country's unique population of individuals that are almost all melanistic, which makes it nearly impossible to identify individuals using camera traps for estimating leopard density. We discovered a novel modification to infrared flash camera traps, which forces the camera into night mode, that allows us to consistently and clearly see the spots of a melanistic leopard. The aim of this project was 1) to determine the feasibility of identifying melanistic leopards with confidence using infrared flash camera traps, and 2) to establish a density estimate for the leopard population in a wildlife corridor in Malaysia using maximum likelihood and Bayesian spatially explicit capture-recapture (SECR) models. Both SECR approaches yielded a leopard density of approximately 3 individuals/100 km^2. Our estimates represent the first density estimate of leopards in Malaysia and arguably, the world's first successful attempt to estimate the population size of a species with melanistic phenotypes. Because we have demonstrated that melanistic leopards can be monitored with confidence using infrared cameras, future studies should employ our approach instead of relying on scars or body shape for identification. Ultimately, our approach can facilitate more accurate assessments of leopard population trends, particularly in regions where melanistic phenotypes largely occur. © 2015 The Wildlife Society.

KEY WORDS camera trap, corridor, density estimate, leopard, logged forest, mark-recapture, *Panthera pardus*, Peninsular Malaysia.

The population status of leopards (*Panthera pardus*) in Peninsular Malaysia requires urgent assessment because threats to their survival are becoming manifold. For example, leopards are increasingly threatened by poaching pressure; in recent years, carcasses of leopards showing signs of having been snared have been discovered locally (Lai 2013, TRAFFIC 2014). In addition, natural habitat for the leopard has declined substantially in Malaysia with the country losing 14% of its natural forest cover in the years 2000 to 2012 (Hansen et al. 2013). Furthermore, remaining forest blocks in the peninsula have been progressively fragmented by extensive networks of paved roads (Clements 2013, Clements et al. 2014) and the expansion of monoculture plantations (Clements et al. 2010, 2014). Roads can have multiple, detrimental effects on big cat populations by acting as barriers to movement (Conde et al. 2010, Colchero et al. 2011), by promoting collisions with vehicles (Kerley et al. 2002, Goodrich et al. 2005), or by facilitating undesirable land use change (Laurance et al. 2009).

In an effort to maintain ecological connectivity on the peninsula, the Malaysian federal government has devised a plan to connect 4 fragmented forest complexes via a network of 17 wildlife corridors or habitat linkages known as the Central Forest Spine Master Plan for Ecological Linkages

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(Department of Town and Country Planning [DTCP] and Department of Forestry [DOF] 2012). However, this federal plan does not convey any actual protection status to these regions because land use decisions are made at the state level (Jain et al. 2014). Furthermore, as these corridors largely consist of forest reserves, they may still be under threat from conversion to rubber plantations (Aziz et al. 2010, Jain et al. 2014). These pressures make it necessary to have accurate information on the population trends of the leopard populations in Peninsular Malaysia's forest complexes and wildlife corridors to assess the effectiveness of conservation management interventions. However, this has been impeded for leopards in Malaysia in the past, in part because of a unique phenotype in the population. Melanism in leopards appears to be most pronounced in one particular region of its distributional range, south of the Isthmus of Kra on mainland Southeast Asia encompassing Peninsular Malaysia and Southern Thailand. To date, almost all observations of leopards in this region have been of melanistic individuals (Kawanishi et al. 2010). Not only is this a unique phenomenon for leopards, it is also possibly the only place in the world where an entire animal population is almost completely composed of the melanistic form of a species. This peculiar circumstance may be the result of 1) a founder effect following a historical population crash, 2) natural selection driven by competition with tigers (*Panthera tigris*) and low light conditions caused by a dense forest canopy, or 3) random genetic drift (Kawanishi et al. 2010). The only other known populations where melanistic leopards may constitute a large proportion can be found in Java and central Thailand; however, in these areas, spotted leopards have been recorded at a greater frequency than in Malaysia (Pocock 1930; Gippoliti and Meijaard 2007; Steinmetz et al. 2007, 2009).

Population studies for big cats in rainforests often rely upon the presence of individually identifiable characteristics on their pelage (Karanth 1995, Silver et al. 2004). This may explain why researchers in Malaysia have until now been unable to provide information on the density of melanistic leopards (though repeated presence-absence data could theoretically be used to asses population trends in individual landscapes; Royle and Nichols 2003, MacKenzie et al. 2005). A camera trapping method does exist to allow population density estimation of animals without individually unique markings by modeling the underlying process of encounter between animals and cameras (Rowcliffe et al. 2008). However, this approach may be unsuitable for large carnivores because of non-random movement of individuals (Foster and Harmsen 2012). Nevertheless, although leopards in Malaysia often appear uniformly black in camera trap photos, it is possible to see the more heavily pigmented rosette markings within their pelage under certain lighting conditions (Kawanishi et al. 2010, Schneider et al. 2012). The rosette markings are especially visible when viewed on images where an infrared flash has been used to illuminate the animal (Fig. 1). Because certain brands of camera trap use a flash of passive infrared light instead of full spectrum light, it may be possible for melanistic leopards to be individually identified and therefore monitored using such cameras.

Figure 1. Examples of photographs of melanistic leopards taken using (a) the daytime color mode (not from this study) and (b) with the camera forced into taking a photo using the infrared flash. Both photos were taken using RECONYX HC500 (RECONYX Inc., Holmen, WI) camera traps. We forced all cameras used in this study to use infrared flash.

In this study, we assessed 1) the feasibility of monitoring melanistic leopard populations through the use of infrared flash camera traps, and 2) for the first time estimate the density leopards in Peninsular Malaysia. We compared estimates from maximum likelihood and Bayesian spatially explicit capture-recapture (SECR) models (e.g., Darmaraj 2012). By facilitating the monitoring of leopard population trends, our results may also be used to support on-going efforts to designate the corridor as a protected area.

STUDY AREA

Situated in the northeastern state of Terengganu, the study area encompassed the habitat linkage Primary Linkage 7 (DTCP and DOF 2012) and part of a proposed larger wildlife corridor known as the Kenyir Wildlife Corridor (Clements 2013, Hedges et al. 2013). The study area consisted mostly of lowland-hill dipterocarp forest in the Tembat Forest Reserve (Fig. 2), which was selectively logged in the 1970s, and was more recently bisected by a 4-lane highway in the last decade. The borders of the study area were partially demarcated because of the presence of multiple boundaries: an artificial reservoir (Lake Kenyir constructed in 1985), rubber plantations, a region of clear felling for a new dam and a protected area, Taman Negara National Park (Fig. 2). Despite these boundaries, the corridor maintains connectivity with larger forest blocks on its southern (Taman Negara) and northern (Tembat) border. During the study period, active logging was being conducted along part of the northern border of the study site. No permanent human settlements existed within the area, however, signs of encroachment (camps and discarded materials) and physical

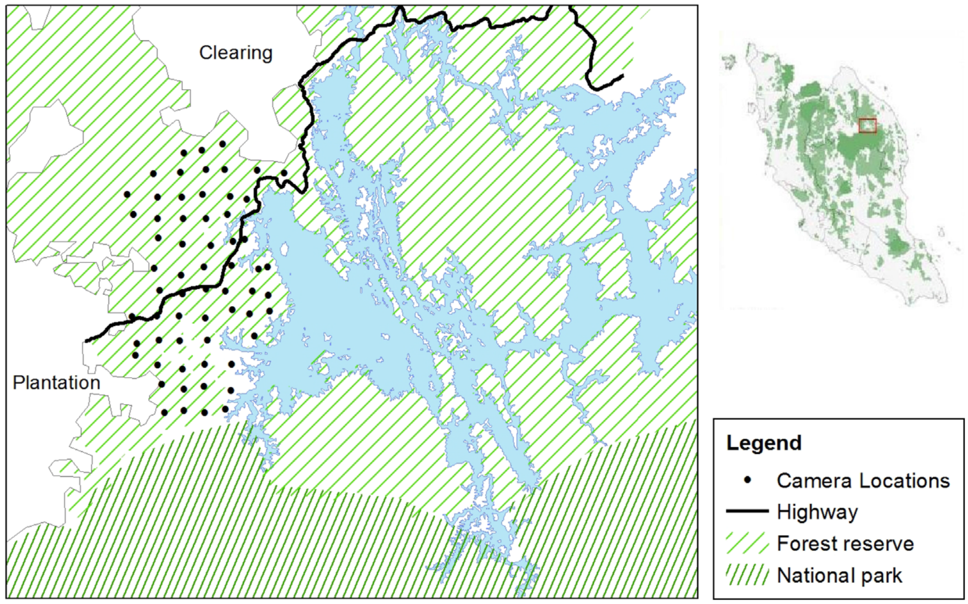

Figure 2. Overview of the study site and its location in Malaysia with respect to remaining forest, camera site locations, highway, current (2013) forest cover around the study site, and Taman Negara National Park.

encounters with poachers occurred during the study. The monsoon season, which generally occurs between January and March, had almost no overlap with the study.

METHODS

Camera Trapping

We deployed camera traps (Model HC500; RECONYX Inc., Holmen, WI) across 62 stations, encompassing an area of approximately 150 km^2 (Fig. 2), for a period of approximately 6 months between May and December 2013. Each station comprised 2 camera traps on opposite sides of the trail to each other, with all stations operating continuously at the same time once we finished deployment in June to retrieval beginning in November. To maximize detection probability for large carnivores, we situated cameras on an animal trail, ridgeline, or old logging road, and placed them approximately 45 cm above the ground in the trail center and 2–5 m from the middle of the trail. Leopard and other large cat movements are likely to be funneled by these features (as indicated by leopard signs; e.g., Karanth 1995, Gray and Prum 2012). Each station was located within a 1.7×1.7-km (2.89 km^2) cell, and was situated as close to the center of each cell as possible to avoid clumping of stations, while not compromising the suitability of the location. We chose the size of each cell to increase the likelihood that all individual animals were camera trapped, based on home range data from radio collaring studies conducted on leopards in Thailand (8.8–45.7 km^2; Rabinowitz 1989, Grassman 1999, Simcharoen et al. 2008). The spacing between cameras was roughly half the diameter of the lowest estimate of a leopard's home range (8.8 km^2). Tobler and Powell (2012) found inter-camera trap distances using this rule to be the maximum spacing resulting in accurate results when performing simulations with data on jaguars (*Panthera onca*). This spacing combined with the number of camera traps available allowed an area of approximately 180 km^2 to be camera trapped, which theoretically allowed for the inclusion of several male home ranges (assumed to be larger than female ranges; Odden and Wegge 2005) to fall inside the trapping area. Expanding the trapping grid farther was not feasible because of forest edge and national park boundaries. We visited stations every 2 months to change batteries and memory cards. In most cases, we used the same location for each station throughout the study; however, we relocated some stations 20–200 m from the original location if we had few detections of large mammals, defined as any species with a body mass > 20 kg (Morrison et al. 2007). We set cameras to high sensitivity for motion and took 3 photos in rapid succession upon each trigger. We forced each camera into night mode, whereby the infrared flash operated for each picture taken, by applying semi-adhesive stickers (Tack-it^{TM}; Faber-Castell, Stein, Germany) over the light sensor of the camera. We covered the light sensors because we found the spot pattern on the coat of melanistic leopards to be more visible in infrared illuminated photos compared with color photos taken using the same camera model (Fig. 1).

Density Estimation

We performed a maximum likelihood spatially explicit capture-recapture (SECR) analysis to estimate the population density of leopards in the study area. We used the SECR package (Efford 2011) in the statistical software program R (version 3.0.2, www.R-project.org, accessed 01 Nov 2013). For each detection, the same 2 researchers identified individual animals from the spot pattern on their coats. We included leopard detections in the analysis only if both researchers were in agreement that a leopard could unequivocally be identified from its spot pattern. We constructed a capture matrix (i.e., the detection history of individuals) according to whether they were photographed during an occasion, lasting 24 hours, or not. We entered camera trap functionality into a trap matrix according to whether 1 or both cameras at a site were active. We accounted for missing data caused by malfunction, damage by elephants, or interference by humans in the trap matrix. We used a half-normal detection function using a Poisson distribution with constant default models. To satisfy the closure assumption and to minimize the likelihood of activity centers changing considerably, we chose a 93-day (3 m) window from the data set following Darmaraj (2012) and Linkie et al. (2008), commencing when all cameras had been set in the forest. We directly accounted for sex-specific variation in capture probability (λ_0) and animal movement (σ) by incorporating the sex of leopards as a covariate into a model. We then assessed the suitability of this model against the null model by comparing Akaike's Information Criterion (AIC) statistics. In addition, we investigated the effects of varying sample size lengths on density estimates, precision, and closure by performing additional analyses using a 45-, 61-, and 123-day window. We tested for closure by performing a closure test (Otis et al. 1978) within the SECR package.

We created a habitat mask to allow suitable habitat outside the study area to be incorporated into the SECR model. We classed non-habitat as lake, region of clear felling, or mixed plantation (rubber, fruit tree, and oil palm). We considered clear felling and mixed plantation non-habitat because evidence suggests that some large cat species are not able to persist in these habitat types (Maddox et al. 2007, McShea et al. 2009, Sunarto et al. 2012). We calculated the buffer area for the mask following Efford (2004) as 4 times the root pooled spatial variance (RPSV), which is the overall distance between camera locations an animal was detected at during the study. This resulted in a buffer width of 11.28 km^2. We then used the program ArcMap (version 10.1, Environmental Systems Research Institute, Redland, CA) to construct the mask. We overlaid a Landsat 8 image of the study site (scene path/row: 127/56; United States Geological Society, glovis.usgs.gov, accessed 22 Apr 3013) with a polygon of the study area and buffer zone, and obtained *x*–*y* coordinates for the center of each pixel that represented suitable habitat (using a 580 m × 580 m cell size following Royle et al. 2009*a, b*).

In addition to the maximum likelihood analysis, we also implemented SECR within a Bayesian framework, using the program JAGS (Plummer 2003) accessed through package jagsUI (Kelner 2014) in program R (code available in Supplementary Information). We then compared the variance in results obtained from maximum likelihood and Bayesian methods. We followed the model developed by Sollmann et al. (2011), which also allowed for us to account for sex-specific variation in λ_0 and σ. We adapted the model to allow for variable camera trap operation and to differentiate between suitable and non-suitable habitat in the state space (the habitat matrix used in the analysis). This modeling approach used data augmentation with a zero-inflated binomial mixture (Royle et al. 2007), where M (100) was an arbitrary figure much larger than the actual possible population size in the study area, with prior distributions of individuals being uniform over the area. We ran 7 Markov chain Monte Carlo (MCMC) chains using 255,000 iterations with a burn-in rate of 5,000 and a thinning rate of 10. We assessed chain convergence using the Gelman–Rubin statistic *R*-hat with a value of below 1.1 indicating convergence (Gelman and Hill 2006).

RESULTS

The entire 6-month study yielded data from 10,850 camera trap nights. During this time, we detected 9 leopard individuals. In general, we detected male leopards at greater frequency than females (5 males:4 females, *n* detections per male = 18, 17, 8, 8, 6; per female = 7, 6, 4, 4; total detections = 78). Only 5 detections of leopards did not lead to positive identification of individuals (6% of the total number of leopard detections) giving a 94% success rate at identifying individual animals.

To estimate the density of the leopard population, we used a 93-day subset of the data spanning 5,601 trap nights collected from the entire study. During this period, we recorded 51 capture events of 9 leopard (5 male and 4 female) individuals, with a mean number of captures of 5.7 (range 2–10) per individual. We rejected 2 additional leopard capture occasions from the analysis because we were not able to identify the individuals captured because of their positions in relation to the cameras.

The closure test in the secr package supported the notion that the population was closed during the sample period ($Z = -0.22$, $P = 0.41$). Model selection results for the maximum likelihood analysis indicated (from comparing the AIC values) that the model incorporating sex as a covariate was best selected. We estimated the density of leopards at 3.00/100 $km^2 \pm$ SE 1.02 (maximum likelihood) and 3.06/100 $km^2 \pm$ SE 0.91 (Bayesian). The coefficients of variation were 0.34 and 0.30, respectively. In the maximum

Table 1. Density estimates ($\hat{D}$; individuals/100 km^2) And results for closure from maximum likelihood spatially explicit capture-recapture (SECR) analysis for leopards in malaysia in 2013 when using variable sample period lengths.

Sample period length (days)	$\hat{D}$	SE	CV	Z (closure)	*P* (closure)
45	3.30	1.28	0.39	−1.12	0.13
65	3.31	1.14	0.34	1.93	0.97
93	3.00	1.02	0.34	−0.22	0.41
123	2.92	0.99	0.34	0.03	0.51

likelihood analysis, the probability of capture at activity center (λ_0) was 0.014 (males) and 0.0039 (females) and the function of movement (σ) was estimated at 2,249 m (males) and 2,699 m (females). For the Bayesian analysis, λ_0 was 0.014 (males) and 0.0036 (females) and σ was 4,016 m (males) and 5,950 m (females).

By conducting a sensitivity analysis for different sampling period durations, increasing the sample period lengths for SECR analysis from 45 days to 123 days caused density estimates for leopards to decrease from 3.30 to 2.92 individuals/100 km^2 (Table 1; Fig. 3). The level of precision of the density estimates remained stable when using 61–123-day sample periods (CV = 0.34). Closure was not violated when using all sample period lengths (Table 1).

DISCUSSION

Our study has demonstrated that it is possible to use infrared flash camera traps to monitor melanistic leopards with confidence. Because reliable population monitoring relies upon accurately identifying most individuals in a study area, our 94% identification success rate supports this. Given that identification was based solely on spot patterns of leopards, and both researchers were in agreement for all matches, we believe that the recognition process of individuals was accurate. Population surveys often result in a proportion of detections that must be discarded from the analysis because of an inability to positively identify the individual animal (e.g., 21% and 35% of leopard photos were rejected by Steinmetz et al. 2009 and Gray and Prum 2012, respectively). Therefore, the rate of positive identification in this study appears to be sufficient for the purpose of conducting SECR analysis. This is supported by the coefficient of variation of our density estimate, which is within the range of what has been achieved for other, non-melanistic leopard density estimates (Table 2).

A likely reason as to why it was possible to view the rosette markings in melanistic leopards is because of the physical properties of the pigment eumelanin. As the wavelength of a light source increases, so does the transmission coefficient (a measure of how much of an electromagnetic wave [e.g., light] can pass through an object) of eumelanin (Meredith and Sarna 2006, Nielsen et al. 2008). Because near infrared light (as used in infrared flash photography) has a longer wavelength than visible light, eumelanin in the less heavily pigmented background of a melanistic leopard's pelage appears less opaque when illuminated by an infrared flash revealing the more heavily pigmented spotted pattern. This demonstrates how using infrared illumination allowed consistently accurate identification of leopard individuals in this study. In addition, other species of mammals with varying degrees of eumelanin deposition in their coat could reveal individual markings if photographed with an infrared flash. This phenomenon warrants consideration by researchers wishing to individually identify species that may have these characteristics.

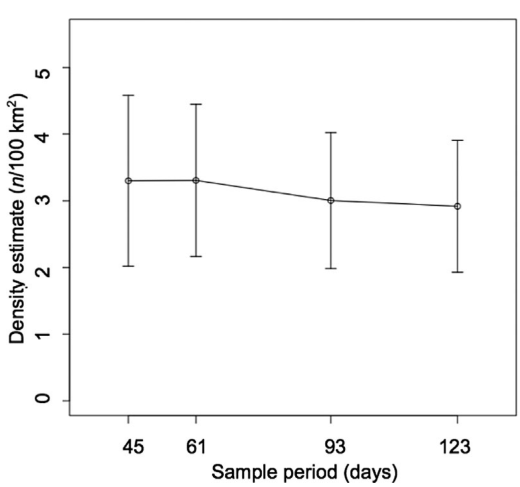

Figure 3. Density estimates from spatially explicit capture-recapture (SECR) analysis with standard error for leopards in Malaysia in 2013 using sample periods of 45, 61, 93, and 123 days.

Our study has provided the first density estimate for leopards in Malaysia, and arguably the world's first population density estimate of a melanistic phenotype of a species. Not only is this information valuable for guiding future conservation management actions, it has shown that melanistic populations of leopards in Malaysia, and elsewhere, can be monitored with confidence. This could influence leopard research using camera traps elsewhere in Southeast Asia, especially in Java and Thailand. In Java, the critically endangered Javan leopard (*Panthera pardus melas*; Ario et al. 2008) has a substantial proportion of melanistic individuals in the population (Pocock 1930, Ario and Supian 2009). However, previous population studies (e.g., Ario 2006, 2007; Ario and Supian 2009) have based individual identification partly on body size and shape—this technique has since been shown to be unreliable (Tobler and Powell 2012). In Southern Thailand, where melanism in leopards is also common (Steinmetz et al. 2007), Steinmetz et al. (2009) included melanistic individuals within a capture-recapture analysis, partly by using scars to identify individuals. However, this technique would not have been feasible for this study, where most individuals had no obvious scars by which to identify individuals or in some cases were not visible where previous or subsequent photos showed obvious scarring. Therefore, using infrared flash illuminated camera trap pictures to identify individuals based on their spotted patterns should be seen as a more reliable method to estimate population densities.

Estimates of Population Density

Both maximum likelihood and Bayesian analyses gave very similar density estimates and levels of precision. We chose the sample period length for analysis (93 days) in consideration of assuming population closure and avoiding the probability of activity centers of individuals changing considerably, while maximizing the chance of re-detections of individuals. Choosing a longer or shorter sample period did not substantially affect the density estimates or level of precision (Fig. 3). Thus, we can be relatively confident that a 93-day sample period was appropriate in this circumstance.

Table 2. Density estimates ($\hat{D}$) for leopards (individuals/100 km^2) from other camera trapping studies in mainland South/southeast Asia. We also present method of analysis (SECR = spatially Explicit Capture-recapture, CC = conventional Closed Capture-Recapture), Effort (number of Trap Nights), Number Individuals Captured (n), and Coefficient of Variation, Which Reflects the Level of Precision of the Results. WC = wildlife Corridor, WS = wildlife Sanctuary, NP = national Park, PF = protected Forest, TR = tiger Reserve.

Study area	Method/effort	*n*	$\hat{D}$ ± SE	CV	Reference
Kenyir WC, Malaysia	SECR/5,601	9	3.00 ± 1.02	0.34	This study
Huai Kha Kaeng WS, Thailand	CCR/824	10	4.86 ± 2.56	0.53	Simcharoen and Duangchantrasiri 2008
Kuiburi NP, Thailand	CCR/1,055	5	3.3 ± 2.4	0.72	Steinmetz et al. 2007
Kuiburi NP, Thailand	CCR/1,458	9	4.8 ± 2.8	0.53	Steinmetz et al. 2009
Mondulkiri PF, Cambodia[a]	SECR/3,738	12	3.6–3.9 ± 1.0–2.9	0.28–0.74	Gray and Prum 2012
Manas NP, India	SECR/4,275	27	3.4 ± 0.82	0.24	Borah et al. 2014
Rajaji NP, India[b]	SECR/1,800	16	2.1 ± 1.63	0.78	Harihar et al. 2011
Mudumalai TR, India	SECR/2,000	29	13.17 ± 3.15	0.24	Kalle et al. 2011
Sariska TR, India[b]	CCR/3,400	8	3.1 ± 0.4	0.13	Mondal et al. 2012
Jigme Singye Wangchuck NP, Bhutan	CCR/4,050	13	1.04 ± 0.01	0.01	Wang and Macdonald 2009

[a] This study used different models within SECR but did not state which result was likely to be the most accurate.

[b] These estimates are following the recovery of a tiger population, where in previous years leopards had up to $\hat{D}$ = 7.88 ± 5.82, 9.76 ± 3.50 SE, and $\hat{D}$ = 7.6 ± 0.6 SE, respectively.

There were reasonable sex-specific differences in the detection of leopards. In general, male leopards were redetected with greater frequency than females and were 3.5–3.7 times more likely to be captured (according to the figures for detection probability. There may be 2 possible explanations for this. Firstly, Gray and Prum (2012), attribute sex-specific capture probability differences to female leopards naturally avoiding the types of trails camera traps are often set on. Another possible reason is that male leopards need to constantly traverse and maintain large home ranges, which may lead to a greater number of encounters with a camera station (Odden and Wegge 2005, Sollmann et al. 2013, Efford and Mowat 2014). The larger results of σ actually imply that female leopards in our study had larger home ranges than males. Thus, the increased proximity of male activity centers to a camera station may have additionally resulted in more recaptures (Efford and Mowat 2014). However our small sample size (5 males and 4 females) means our results for σ may be unreflective of actual home range size differences.

Two caveats have to be acknowledged for our population density estimate. First, at least 2 leopard individuals were translocated by wildlife authorities to the camera trapping area during the study. It is unknown whether these individuals were detected by the camera traps because no photographs were taken of the individuals at the time of translocation. However, leopards are territorial and are capable of dispersing large distances as transient migrants (Sunquist and Sunquist 2002), and studies have shown that most translocated leopard individuals exit the region of release (Linnell et al. 1997, Athreya et al. 2011). Therefore, it is possible that these individuals may have quickly left the study area to avoid conflict with resident leopards after being released. Second, it is also possible that the habitat clearance for a nearby dam (Tembat) could have led to an influx of leopards into our trapping area. Keeping in mind that specific site variables may have influenced the density estimate, our density estimate for leopards in Malaysia still falls within the range found by studies in protected areas across India, Cambodia, and Thailand (Table 2) even though our study was conducted in an unprotected and threatened wildlife corridor.

MANAGEMENT IMPLICATIONS

Using our approach, where camera traps are modified to only take photos in night mode, we are now able to monitor population trends of leopards to evaluate the impact of management interventions (e.g., anti-poaching patrols) in areas where melanistic phenotypes of this species occur (e.g., Malaysia, Thailand, and Java). Our technique can also provide greater insight into the interactions of leopards with other sympatric carnivores such as tigers (e.g., Harihar et al. 2011, Darmaraj 2012). Given the downward trajectory of the latter species in the region (e.g., Clements et al. 2010, Lynam 2010), a better understanding of factors influencing the population dynamics of both carnivores is urgently needed to facilitate the design of appropriate management interventions. We recommend that researchers consider using Bayesian analysis to estimate population density where possible, due to its ability to produce graphics illustrating activity centers, which can facilitate long-term monitoring.

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