Zoology and Ecology, 2023, Volume 33, Number 1
Online ISSN: 2165-8013
https://doi.org/10.35513/21658005.2023.1.6

POPULATION STATUS AND DENSITY ESTIMATE OF LEOPARD *PANTHERA PARDUS FUSCA* IN DRY THORN FORESTS OF SOUTHERN INDIA

Krishnakumar Nagarajan[a], Divya Ramesh[a], Durairaj Boominathan[a], Sanket Bhale[a], Pranav Chanchani[a] and Ramakrishnan Balasundaram[b*]

[a]WWF-India, 172-B Lodhi Estate, New Delhi-110003, India; [b]Department of Wildlife Biology, Government Arts College,Udhagamandalam-643002, the Nilgiris, Tamil Nadu, India
*Corresponding author. Email: ramkiwildlife2011@gmail.com

Krishnakumar N., Divya R., Boominathan D., Sanket B., Pranav C., Ramakrishnan B. 2023. Population status and density estimate of Leopard *Panthera pardus fusca* in dry thorn forests of southern India. *Zoology and Ecology* 33(1) 45–53. https://doi.org/10.35513/21658005.2023.1.6

Article history
Received: 31 March 2022; accepted 30 March 2023

Keywords:
Leopard; population density; camera trapping; human habitations; home range; activity pattern; multi-use landscape

Abstract. The study aims to assess the population status and density of the Leopard (*Panthera pardus fusca)* in the Erode Forest Division, Tamil Nadu. The Erode Forest division has numerous villages within its boundaries and is exposed to associated biotic pressures. In order to improve the management practices of the wildlife in the area and to enhance its conservation, it is relevant to assess its status. In 2018 and 2020, we estimated the population density of the leopard in the entire forest division using 2 km^2 sample grids and the camera trapping method. In each grid, we deployed a pair of camera traps, the cumulative number of trap-nights being 22983 (10732 trap nights in 2018 and 12251 in 2020). We analysed the obtained data using spatially explicit capture-recapture models (SECR). The surveys yielded 198 images of the leopard in 2018 and 272 images in 2020, of which 48 and 44 leopard individuals were identified in the respective years based on the rosette pattern. The density estimates were 5.16 (SE = ±0.89) and 4.00 (SE ± 0.72) individuals/100 km^2 in 2018 and 2020, respectively. We found that in some regions overlapping with the human-use area, leopard densities were high, indicating that the species successfully exploits areas near human habitation and highlighting its high potential for interaction with humans. This baseline estimate and insights will help prioritize management actions, strengthen large mammal conservation beyond the boundaries of protected areas (PA), and plan human-wildlife conflict mitigation measures to enable the persistence of large carnivores in multi-use forests.

INTRODUCTION

Large carnivores typically occur at low densities, thus making their counts quite challenging. Advancements in both field and analytical methods such as spatially-explicit capture-recapture models have enabled more precise estimates of these cryptic and highly mobile species (Burton et al. 2015). These estimates are fundamental in determining the conservation status of a particular species (Harihar et al. 2009). Although widely distributed, the South Asian subspecies of the Leopard (*Panthera pardus fusca*) has been the increased conservation concern lately. Both their distribution and population in India have declined in recent years, due to threats of habitat loss, prey depletion, and retaliatory killing (Jhala et al. 2021). The species receives the highest protection under Schedule I of the Wildlife (Protection) Act, 1972. It is also listed as Vulnerable by IUCN (Stein et al. 2020) and in Appendix I of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES).

The large geographic range of the leopard is partly due to its ability to use and occupy diverse habitats including degraded forests, agricultural fields and other human-use areas. These landscapes are often able to sustain leopard populations with domesticated animals forming a major prey base (Athreya et al. 2014). While this perhaps show cases the leopard's adaptability, it is also reflective of the diminishing of natural habitats that could sufficiently support leopard populations and consequently minimise human-leopard interactions. The subspecies has suffered a 70–72% historic range loss (Jacobson et al. 2016). The increasing habitat loss, among other factors, allows for increased conflict between humans and leopards, with significant costs to both. A key component in understanding the context and patterns of such a conflict is the availability of reliable population density estimates (Pawar et al. 2019).

Population estimates of the leopard are available for most protected areas in India. However, the forest habitats that are also functionally important occur outside the protected area network (Punjabi and Rao 2017). Leopards frequently use human-dominated landscapes, yet population estimates from these areas are sparse (Gubbi et al. 2019, 2021). These lands face intense pressures from human activities including livestock grazing and non-timber forest produce (NTFP) collection and are not explicitly managed for wildlife conservation. A longside initiatives towards improving human welfare and augmenting livelihoods in these areas, there is a need to monitor wildlife populations as well, given the many pressures on large carnivores globally.

This study aims to estimate the leopard population density in the Territorial Forest Division of Erode (EFD), Tamil Nadu, India. This division is a crucial part of the landscape connecting the Western and Eastern Ghats across the belt of multiple protected areas including the Bligiri Ranganathaswamy Temple (BRT) Tiger Reserve and the Malai Madeshwara (MM Hills) Wildlife Sanctuary, the Mudumalai Tiger Reserve and the Sathyamangalam Tiger Reserve. The study presents the first ever density estimates of the leopard in the area for the years 2018 and 2020,which were made using standard camera trap-based spatially explicit capture-recapture methods (Efford and Fewster 2013).

MATERIALS AND METHODS

Study area

The Erode Forest Division (EFD) is designated as a Reserved Forest in the Erode District of the Tamil Nadu State in south India (Figure 1). It covers an area of 821 km^2 with five administrative ranges, namely, Anthiyur, Bargur, Chennampatti, Erode and Thattakarai. The Mettur Stanley Reservoir in the North is a major geographical feature and a perennial water source for wildlife. The eastern and southern boundaries are surrounded by agricultural areas. The altitude ranges from 260 to 1546 m a.s.l. and the study area is arid for most of the year since it lies in a rain-shadow region. The average rainfall from both the southwest and northeast monsoons (Source: Forest Department) in the last decade was 725 mm. There are three major vegetation types including the Southern Thorn Forest, Southern Dry Mixed Deciduous Forests, and Phoenix Savannah Forest. The Southern Thorn Forest is dominated by *Anogeissus latifolia*, *Emblica officinalis*, *Pterolobium hexapetalum* and *Pterocarpus marsupium*; Southern Dry Mixed Deciduous Forests have *Dalbergia latifolia,*

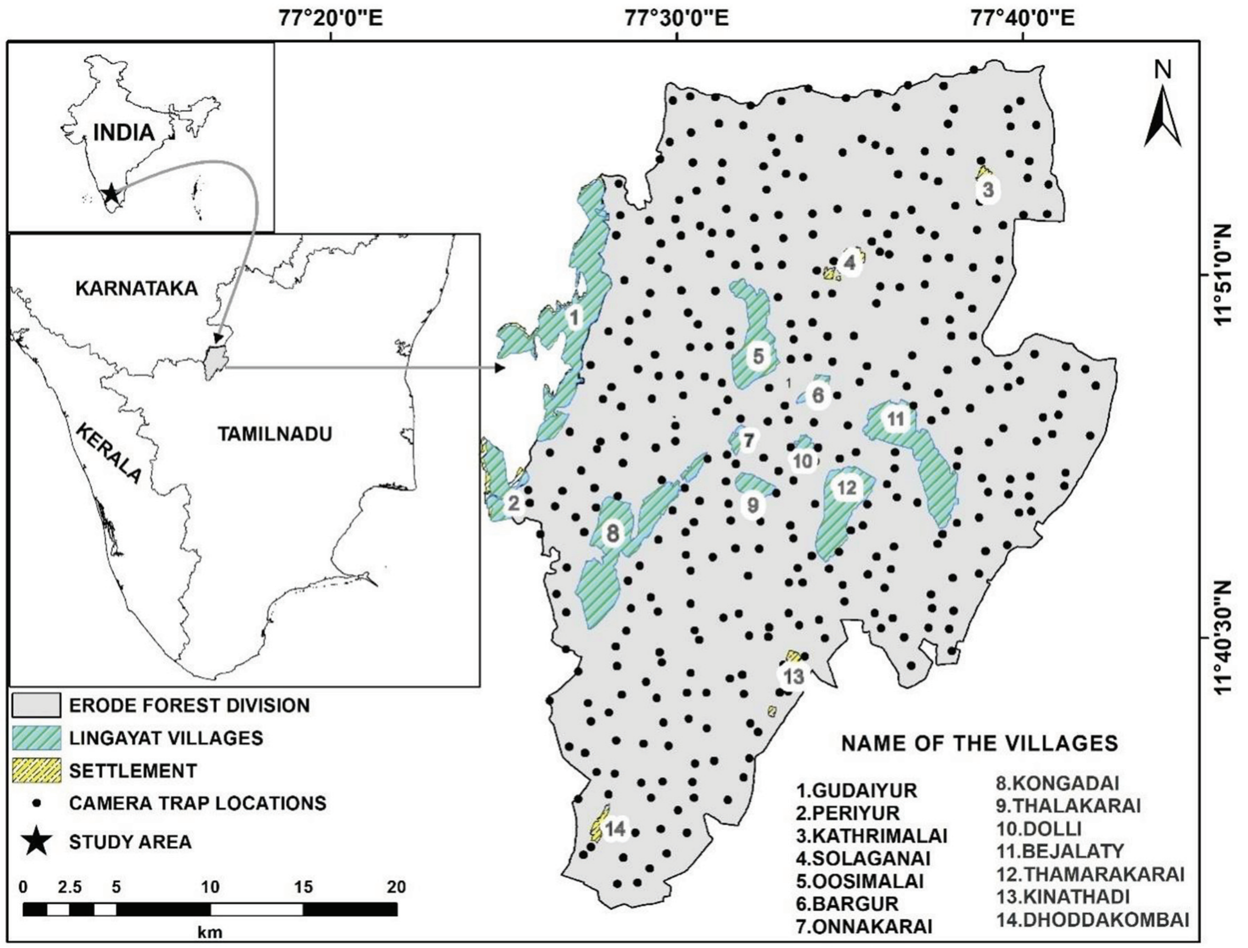

Figure 1. Map of the study area along with the location of villages and camera traps (n = 367 and 379 respectively in 2018 and 2020) in the Erode Forest Division.

Terminalia tomentosa, Albizzia amara, Cassia fistula, Hardwickia binata and *Santalum album*, and the Phoenix Savannah Forest is dominated by *Phoenix sylvestris* associated with *Butea monosperma, Capparis spinosa* and *Vetiveria zizanioides* (Champion and Seth 1968).

There are 40 villages including 6 forest settlements (Thottakombai, Sholaganai, Kaakayanur, Kinathadi, Sundapur and Kathrimalai) located in 13 enclaves inside the forest and numerous villages on the periphery of the Erode Forest Division. The total human population is 13,799 (male 7144 and female 6655) in 4015 households (WWF-Baseline Data-2019 – unpublished). Most people are from Lingayat community (62%). The estimated number of cattle (cow, buffalo, and ox) individuals grazing inside the forest area is 11,375, and that of goats and sheep is 4339. These groups are mainly involved in the collection of agricultural (major cultivation of *Sorghum bicolor* and *Manihot esculenta*) and non-timber forest products (including *Phoenix sylvestris* and *Emblica officinalis*).

METHODS

We created a 2 km^2 grid array and overlaid this on a map of the study area to guide our survey effort and camera trap placement, following the guidelines of the National Tiger Conservation Authority (NTCA). We created a total of 488 grids in the Erode Forest Division, of which we sampled 367 and 379 grids in 2018 and 2020, respectively.

Prior to the camera trapping study, we conducted wildlife sign occupancy surveys in each grid. Within each grid, we surveyed animal trails, streams, other water sources and paths. We recorded carnivore signs such as pugmarks, scat, scrapes, rake marks and prey species signs of hoof marks, pellets, and dung. We mapped these using GIS to select locations where animal captures on camera traps could be maximized. Subsequently, we conducted camera trapping from Aug–Nov 2018 and Jul–Sept 2020, with a total of 10,732 and 12,250 trap-nights respectively (Table 1).

We used camera models Cuddeback-Attack, Professional and C-1 camera traps with conventional 'white flashes', and motion sensor camera traps secured with a metal case and attached to the tree at a height of 30–50 cm above ground level at a distance of 4–6 m from the edge of animal trails and forest roads. At each survey location, we placed a pair of camera traps facing each other. We downloaded the data from each camera trap at 5–7day intervals, while the cameras were operational for a minimum of 29 and maximum of 32 days. We identified individual leopards based on their unique rosette patterns (Kalle et al. 2011), their identities being confirmed by two independent observers. Only those identified as adults were included in further analysis, while the cubs and sub-adults captured with mothers were excluded.

We used spatially explicit capture recapture (SECR) models, implemented in the package *secr* in R (version 3.4.0) to estimate leopard density. SECR methods have been widely used in large carnivore population estimations (Thapa et al. 2014; Rather et al. 2021). We used a 15 km habitat mask around the trapping block that comprised an evenly spaced mesh of potential activity within the habitat areas. We excluded non-habitat areas beyond forest boundaries, including revenue areas, settlements, agricultural fields, and built-up areas. Mesh spacing was 580 m, so each activity centre represented 0.34 km^2 of leopard habitat (Thapa et al. 2014). We used the g_0 (.) σ (.) formulation to model detection parameters, where g_0 is the baseline encounter probability and σ is a distance scale parameter describing animal movement around home range centres. The latter was modelled using the half-normal function. Then we assessed the support for an alternate model g_0 (b) σ (.) to examine behaviour-related heterogeneity in the detection process. Finally, we estimated leopard density for the entire forest division, using estimation methods described in (Efford and Fewster 2013). We used the same methods to generate density estimates for 2018 and 2020 separately. We generated density maps for the study area for both 2018 and 2020 using Arc GIS v.10.8.

We also used the time of capture from camera trap images to examine activity patterns of leopards, and calculated minimum convex polygons (MCP) to obtain the minimum movement area. This was done only for the individuals which were re-captured at more than three locations (Kumbhojkar et al. 2020). Due to the small sample size, to examine difference between male and female minimum movement area, we pooled individuals from 2018 and 2020 and performed a two-sample *t*-test (assuming unequal variances). This was performed in Microsoft Excel.

Table 1. Camera trap sampling effort in the Erode Forest Division in 2018 and 2020.

Sampling year	No. of camera trap stations	Camera trapping period	No. of active trap nights	Mean inter-trap spacing (m)
2018	367	28 August 2018 – 11 November 2018	10732	1033.33
2020	379	27 July 2020 – 20 September 2020	12251	1024.85

RESULTS

The number of unique leopard captures in 2018 and 2020 is comparable, as is the age-sex distribution of the captured individuals (Table 2). The overall recapture rate was 46% and 41% in 2018 and 2020, respectively. Out of the 48 individuals captured in 2018, only eight (16%) were re-captured in 2020, of which two were male, four female and the remaining two were unclassified. However, 36 new individuals were captured in 2020. The number of individuals re-captured more than five times during the sampling period was six in 2018 and 11 in 2020. In 2018, the highest number of re-captures was 12, attributed to the leopard ID 'EDL01'. In 2020, the highest number of re-captures was 23 of the leopard ID 'EDL20'.

Five competing models were tested and reported based on the lowest AICc values (Table 3). The same method was performed in both sampling years, which included individual behaviour responses model. The best supporting model estimated the density of leopards to be 5.16 (SE = 0.89) individuals/100 km^2 in 2018 and 4 (SE = 0.72) individuals/100 km^2 in 2020 (Table 4).

There was a considerable spatial variation in leopard occupancy in the Erode Forest Division, particularly around human settlements (Figure 2). There was a 7% reduction in high density (darker) grids from 2018 to 2020 with a corresponding increase in low density (lighter) grids.

There was an activity peak at dusk (1700–1900 hrs) and two smaller peaks around dawn (0200–0400 hrs and 0700–0900 hrs) (Figure 3), determined from the time of photo-captures. This pattern was observed in both sampling years and both for males and females (Figure 4).

The number of male and female leopards, for which

Table 2. Capture summary from the Erode Forest Division in 2018 and 2020.

Sampling year	Total no. of images	No. of unique individuals					
		Adults	Sub-adults	Total	Female	Male	Unidentified
2018	198	40	8	48	28	9	11
2020	321	36	8	44	24	12	8

Table 3. Models tested for leopard population estimation in the Erode Forest Division in 2018 and 2020, with a corresponding number of parameters (K), log likelihood (logL), AICc scores, and Akaike weights (Wt). (D = density, g_0 = detection probability at the activity centre, σ = distance scale parameter, $pmix_{h2}$ = detection-corrected estimate of the proportion of females and males, b = individual behaviour).

Model Criteria	K	logL		AICc		Wt	
		2018	2020	2018	2020	2018	2020
$D \sim 1\ g_0 \sim 1$ $\sigma \sim h_2\ pmix \sim h_2$	5	-383.516	-446.386	778.796	904.772	0.7972	0
$D \sim 1\ g_0 \sim h_2$ $\sigma \sim h_2\ pmix \sim h_2$	6	-383.494	-442.908	781.534	860.713	0.2028	0.4999
$D \sim 1\ g_0 \sim h_2$ $\sigma \sim 1\ pmix \sim h_2$	5	-389.122	-431.793	790.009	875.586	0	0
$D{\sim}1\ g_0 \sim 1$ $\sigma \sim 1\ pmix \sim h_2$	4	-395.069	-446.580	799.28	902.451	0	0
$D \sim 1\ g_0 \sim b$ $\sigma \sim 1\ pmix \sim h_2$	5	-395.069	-446.58	801.902	905.16	0	0

Table 4. Leopard density (individuals/100 km^2) in the Erode Forest Division in 2018 and 2020, derived from spatially explicit capture recapture (SECR) models (M_{t+1} = total number of animals, SE = standard error, CI = confident interval, g_0 = detection probability at the activity centre, σ = distance scale parameter).

Year	Sex	M_{t+1}	Density (SE)	95% CI	g_0 (SE)	95% CI	σ (km)	95% CI
2018	Female	23	5.16 (0.89)	3.68–7.23	0.0039 (0.0007)	0.0027–0.0056	2.44 (0.21)	2.06–2.09
	Male	09			0.0039 (0.0007)	0.0027–0.0056	4.21 (0.43)	3.44–5.14
2020	Female	20	4.00 (0.72)	2.81–5.68	0.0015 (0.0004)	0.0009–0.0025	4.36 (0.53)	3.43–5.53
	Male	12			0.0133 (0.0026)	0.0091–0.0195	2.49 (0.18)	2.15–2.87

the minimum movement area could be estimated, was 6 and 10 individuals in 2018, and 11 and 6 individuals in 2020, respectively; of these, two individuals were common in both sampling years. The average minimum movement area for male leopards (16.8 km^2, range: 0.34–49.95 km^2) was significantly greater than that for female leopards (3.64 km^2, range: 0.37–8.4km^2; *t*-statistic = -3.017; *p*-value = 0.004, Figure 5).

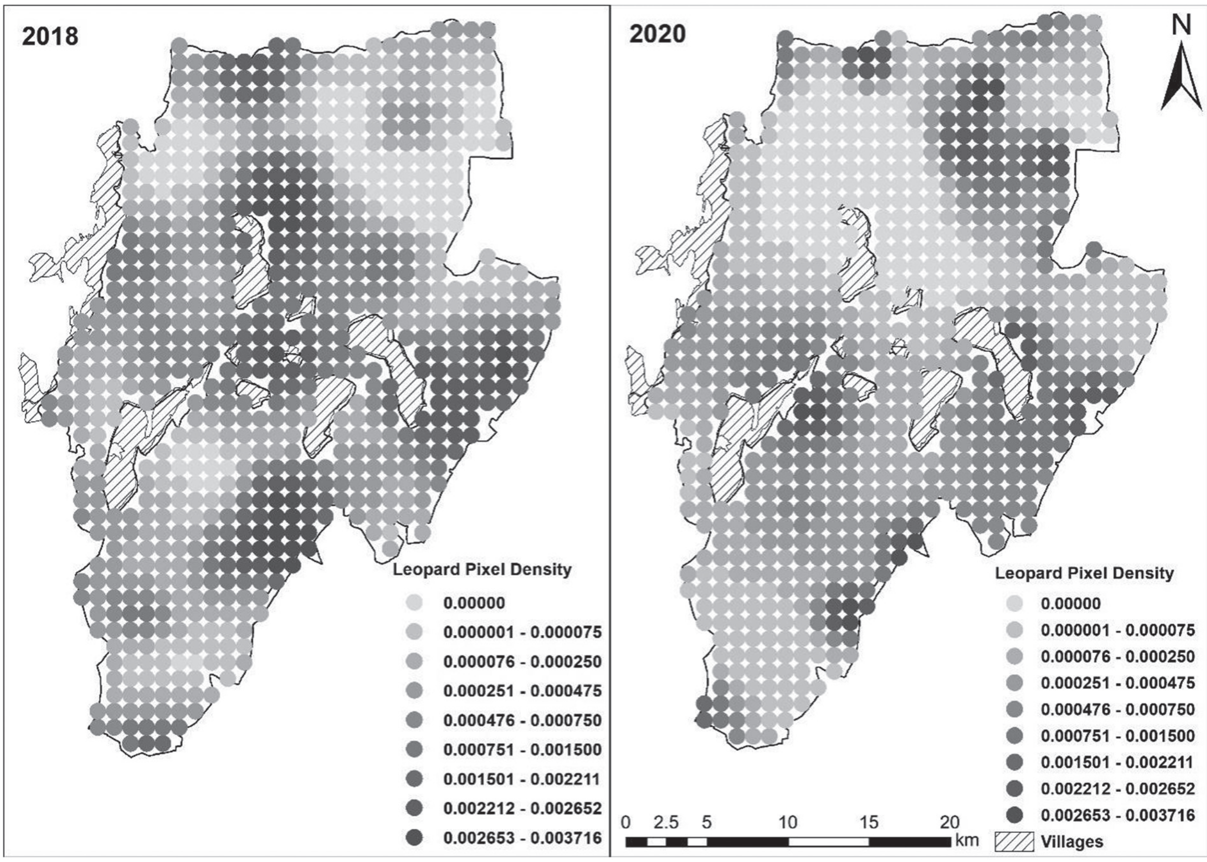

Figure 2. Leopard density in the Erode Forest Division in 2018 and 2020. Density was generated using the model D ~ 1 g_0 ~ h_2 sigma ~ h_2 pmix ~ $h_{2,}$ each pixel represents an area of 580 m^2.

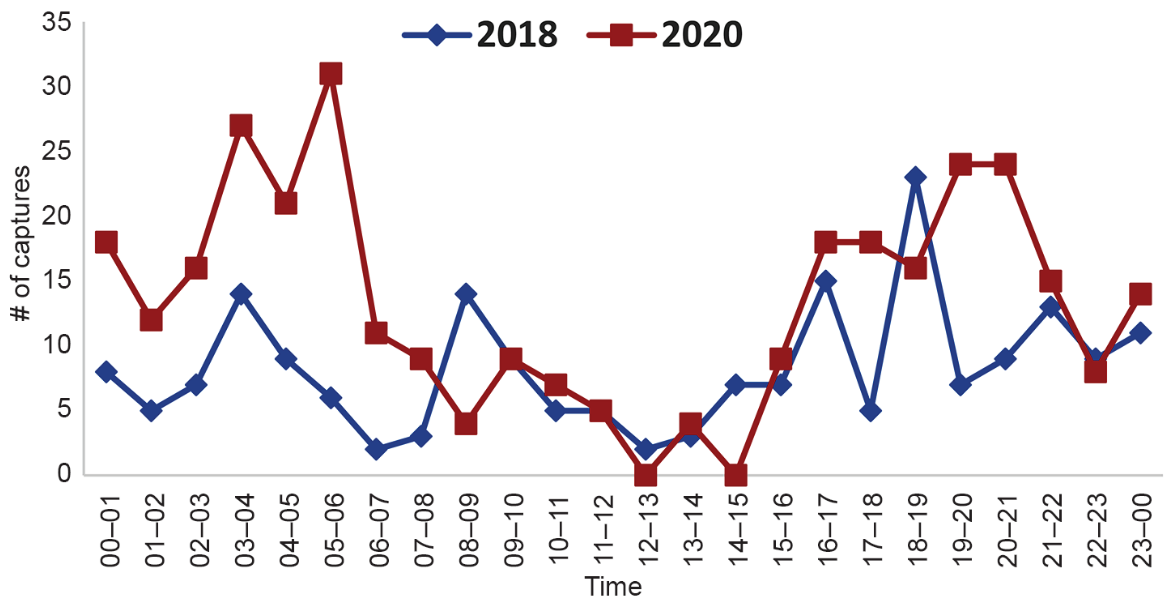

Figure 3. Time activity pattern of leopard photo captures in 2018 and 2020.

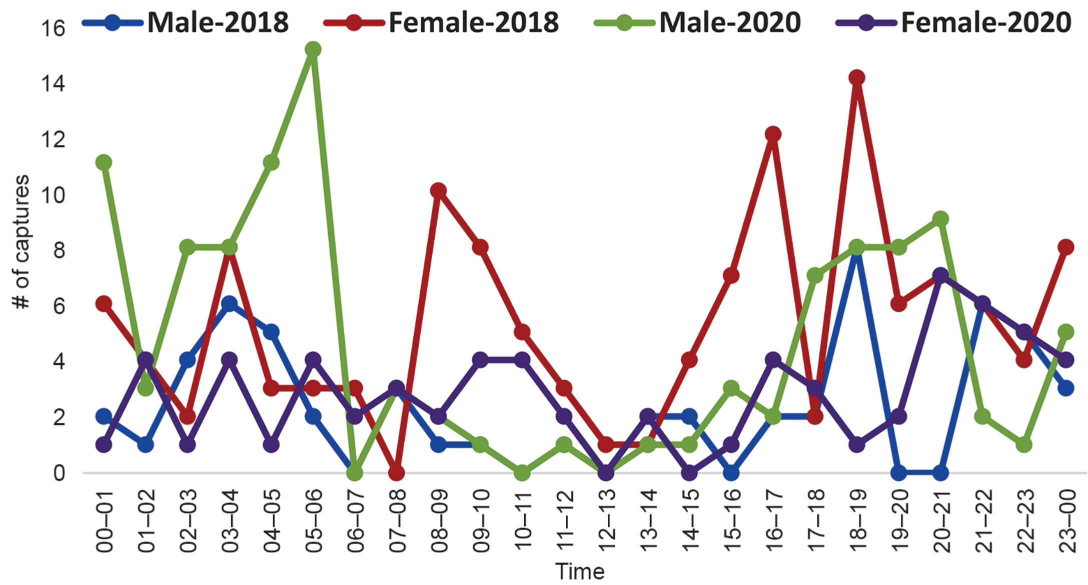

Figure 4. Time activity pattern of male and female leopard photo-captures in 2018 and 2020.

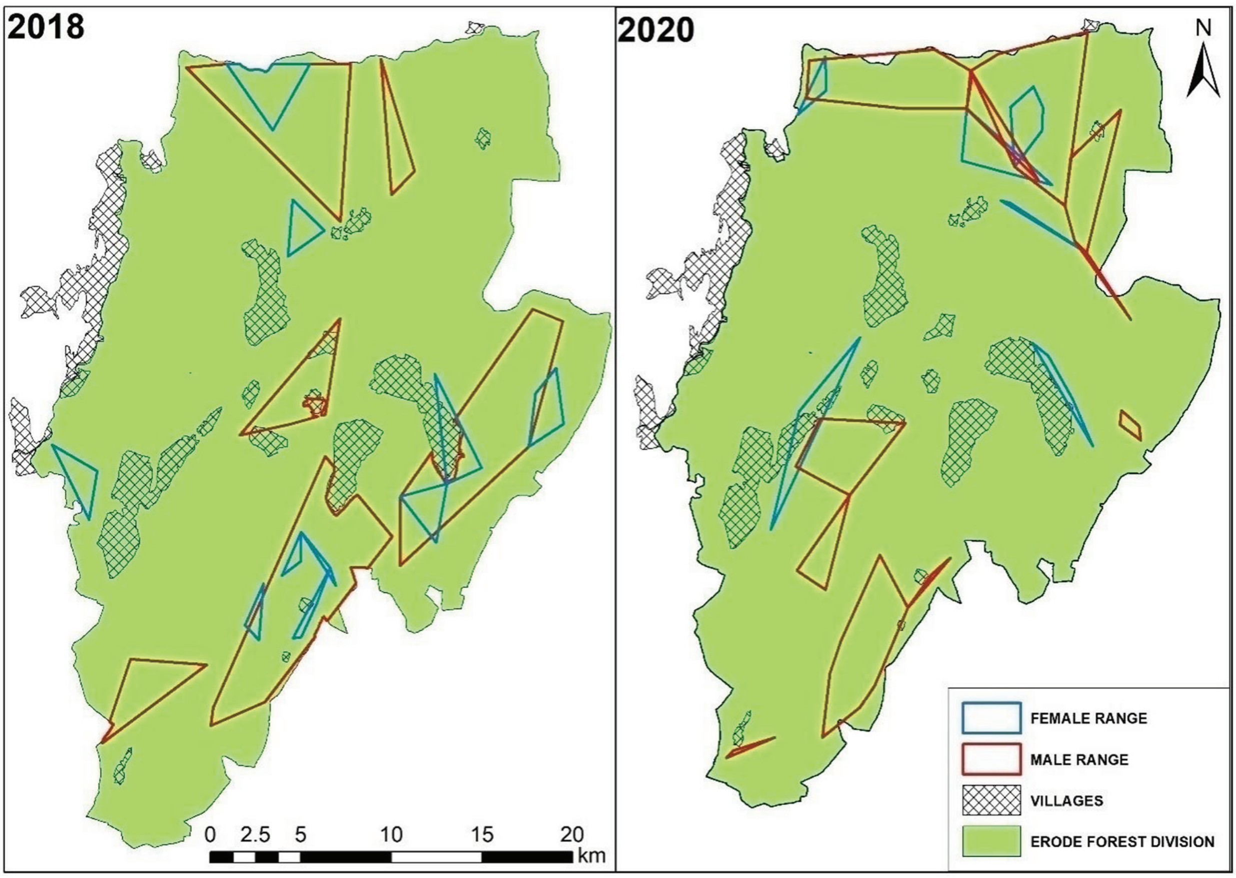

Figure 5. Minimum movement areas of male and female leopards in the Erode Forest Division in 2018 and 2020.

DISCUSSION

This study provides the first estimates of leopard abundance and density in the Erode Forest Division (EFD), which were made using spatially explicit capture-recapture methods with extensive camera-trap sampling of the area in 2018 and 2020. The density of leopards in both years is comparable to estimates from the buffer zone of the Bandhavgarh Tiger Reserve 3.03 ± 0.78 per 100 km^2 (Rather et al. 2021). Leopard density is much lower than in the Mudumalai Tiger Reserve 13.17 ± 3.15 per 100 km^2 (Kalle et al. 2011), however, the Mudumalai

Tiger Reserve is a rich tropical deciduous forest with the highest level of protection, whereas Bandhavgarh is a largely drier mixed deciduous forest and more similar to our study area. The buffer zone of the Tiger Reserve is subject to relatively fewer restrictions, with NTFP collection and other human resource use allowed limitedly. The Erode Forest Division, with minimum protection measures and resources of the Tiger Reserve, still supports as many leopards. In the adjoining forests of the Sathyamangalam Tiger Reserve, leopard density is estimated at 7.05 ± 0.68 per 100 km^2 (Jhala et al. 2021), which is marginally higher than in EFD.

Prey availability is an important determinant of carnivore density (Carbone et al. 2011; Khorozyan et al. 2008). The estimated density of wild prey species (ungulates) in EFD is 17.19 ± 3.04 per km^2 (WWF-India, 2017 unpublished data). Chital (*Axis axis*) density is 14.20 ($\pm$ 6.83) per km^2 and Sambar (*Rusa unicolor*) density is 0.59 ($\pm$ 0.23) per km^2. This is significantly lower than the estimates reported from the adjoining Sathyamangalam Tiger Reserve (STR) with the chital density of 39.66 ($\pm$ 5.39) per km^2 and that of sambar of 8.97 ($\pm$ 1.19) per km^2 (Jhala et al. 2020). Prey density estimates exclusively from the buffer zone of Bandhavargh are not available, but (Rather et al. 2021) used disturbance levels of forest as a proxy for prey abundance and found that leopard density was positively associated with disturbed habitats, i.e., lower prey density. During the sampling period we photo-captured ~25 other species, including the tiger (*Panthera tigris),* elephant *(Elephas maximus indicus*)*,* gaur *(Bos gaurus),* sambar *(Rusa unicolor),* chevrotain *(Moschiola indica),* pangolin *(Manis crassicaudata),* and the rusty-spotted cat (*Prionailurus rubiginosus).* However, there was either an insufficient number of captures to estimate densities or additional methodology was required for analysis, especially, for that of unmarked species such as most herbivores.

Additionally, EFD supports sympatric carnivores including tigers and dholes. Coexistence mechanisms such as differential prey selection and interference competition often result in higher densities of the tiger and lower densities of the leopard over time (Harihar et al. 2011). In conditions of competition, leopards tend to move towards habitat edges (Mondal et al. 2012) and resort to domestic prey-based subsistence (Athreya et al. 2014). Currently, EFD exhibits low tiger density (0.66 individuals per 100 km^2, WWF-India, unpublished data). With strong global tiger conservation goals (*The St. Petersburg Declaration on Tiger Conservation* 2010), this could lead to increased protection in the coming years (Harihar et al. 2011). While this may allow for a gradual increase in tiger numbers, it will be pertinent to monitor inter-specific interactions for comprehensive conservation. In habitats with high human presence, it is likely that leopards supplement their diet with domestic prey (Athreya et al. 2014; Kshettry et al. 2018). With villages distributed across EFD and its boundaries, we also found an overlap between leopard home ranges and villages. This could create opportunities for leopards to prey on domestic livestock. Data on livestock depredation would be useful for monitoring this over time. It will be crucial to proactively address the potential conflict through livestock depredation or retaliatory killing that may arise if and when leopards are pushed outwards by rising tiger numbers.

The high number of the new individuals photo-captured in 2020, and the individuals not re-captured from 2018, points to a small resident population of leopards in EFD. All the eight leopards that were recorded in both years were adults, of which two were males and four females. It is possible that other detected adults are part of a transient population. This could be a response to increased disturbance or possibly be indicative of leopard movement between EFD and surrounding forests. Data on disturbance over the years is not available, so it is difficult to establish its effect on the leopard population. However, during our sign surveys, we recorded several cattle pens inside the forest that have been removed by the forest department since then. During the study period, 16 camera traps were lost or stolen, indicating human movement in the forest.

As measured by photo-captures, leopard occurrence at camera trap stations declined from 2018 to 2020 with a 7% decrease in present locations. This is not a statistically significant decline. However, it should be noted that in 2018 the leopard-occupied area was low (18%). Although the number of unique leopard captures does not reflect this, it is possible that the variation in the leopard-occupied and unoccupied sites between 2018 and 2020 is indicative of the underlying pattern of the increasing tiger occurrence in the region. Camera trapping was conducted during the same season in both years. Tiger occurrence in the central region around villages in 2018 was low (Jhala et al. 2020), which shows high leopard occurrence in the same year. However, in 2020, the increased occurrence of the tiger in the central region coincided with the lower occurrence of the leopard (Figure 2), while areas towards the eastern side showed a higher occurrence of the leopard and a lower one of the tiger (WWF-India unpublished data 2020). There are possibly other factors that may influence changes in leopard density and occurrence and further studies could help improve our understanding of these trends.

The activity peaks at dawn and dusk recorded in our study align with the known leopard behaviour in forests with sympatric carnivores (Karanth and Sunquist 2000; Zehra et al. 2019; Odden and Wegge 2005; Odden et al. 2014). Although resource sharing among predators is widely documented, such an activity pattern may be relatively more driven by prey activity patterns than by those of the co-occurring predators (Karanth and Sunquist 2000; Chaudhary et al. 2020).

The measure of the home range, i.e., an area actively used by an individual, tends to vary greatly within species, as a function of varying habitats, seasons, and resource availabilities (Zehra et al. 2019; Odden et al. 2014; Kumbhojkar et al. 2020; Karanth and Sunquist 2000). Although we did not estimate the home range in our study, we found that the minimum movement area of males was significantly larger than that of females and up to two female areas were found within one male's range, conforming to the known patterns in leopards and tigers. Although our data record a wide variation in these values, it should be noted that we present only the minimum area based on the capture history from at least 3 unique camera trap sites. More accurate home range values can be generated through radio-collaring studies.

Our study provides the first leopard density estimates for the Erode Forest Division and tracks density and occurrence over two years. These findings are significant because they show the population status of the species of recent conservation concern. Although its adaptability to human-use areas is unique, it poses a challenge alongside the increasing negative human-wildlife interactions. Increased protection and focussed conservation measures such as habitat restoration and removal of invasive plants such as *Lantana camara* is likely to provide more natural forage for ungulates and boost prey density. Management plans and conservation strategies must move towards inclusive approaches to safeguard human rights and dignity while remaining adaptive and flexible to changing resources and consequently, wildlife patterns and populations.

ACKNOWLEDGEMENT

We wholeheartedly thank the Tamil Nadu Forest Department especially the Erode Forest Division for granting permission and providing logistic support during our field data collection. Our sincere thanks go to WWF-India for giving the permission to use the data for writing this manuscript and field assistants for data collection. We also express our sincere gratitude to Ms. Saloni Salariafor help with data analysis. We thank the Principal, Head of the Departments of Zoology and Wildlife Biology, Government Arts College, the Nilgiris, Tamil Nadu, India for rendering continuous support and encouragement.

REFERENCES

Athreya, V., Odden, M., Linnell, J.D.C., Krishnaswamy, J., & Karanth, K.U. 2014. A cat among the dogs: Leopard *Panthera pardus* diet in a human-dominated landscape in western Maharashtra, India. *Oryx* 50, 156–162.

Burton, A.C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J.T., Bayne, E., & Boutin, S. 2015. Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology* 52, 675–685.

Carbone, C., Pettorelli, N., & Stephens, P.A. 2011. The bigger they come, the harder they fall: body size and prey abundance influence predator-prey ratios. *Biology Letters* 7, 312–315.

Champion, H.G., & Seth, S.K. 1968. *A revised survey of the forest types of India*. New Delhi.

Chaudhary, R., Zehra, N., Musavi, A., & Khan, J.A. 2020. Spatio-temporal partitioning and coexistence between Leopard (*Panthera pardus fusca*) and Asiatic lion (*Panthera leo persica*) in Gir protected area, Gujarat, India. *PLoS One* 15, 1–14.

Efford, M.G., & Fewster, R.M. 2013. Estimating population size by spatially explicit capture-recapture. *Oikos* 122 (6), 918–928.

Gubbi, S., Nagashettihalli, H., Suthar, S., & Menon, A. 2019. *Report on monitoring of leopards at Biligiri Rangaswamy Temple Tiger Reserve in Karnataka*. India: Nature Conservation Foundation, Mysore.

Gubbi, S., Menon, A., Suthar, S., & Poornesha, H. 2021. *Monitoring Leopard Population in Malai Mahadeshwara Wildlife Sanctuary Between 2014 and 2020*. Bengaluru, India: Nature Conservation Foundation, Mysore, India and Holématthi Nature Foundation.

Harihar, A., Pandav, B., & Goyal, S.P. 2009. Density of Leopards (*Panthera pardus*) in the Chilla Range of Rajaji National Park, Uttarakhand, India. *Mammalia* 73, 68–71.

Harihar, A., Pandav, B., & Goyal, S.P. 2011. Responses of Leopard *Panthera pardus* to the recovery of a Tiger *Panthera tigris* population. *Journal of Applied Ecology* 48, 806–814.

Jacobson, A.P., Gerngross, P., Lemeris, J.R., Schoonover, R.F., Anco, C., Breitenmoser-Würsten, C., Durant, S.M., Farhadinia, M.S., Henschel, P., Kamler, J.F., Laguardia, A., Rostro-García, S., Stein, A.B., & Dollar, L. 2016. Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. *Peer Journal.* 1–28.

Jhala, Y.V., Qureshi, Q., & Nayak, A.K. 2020. *Status of tiger, copredators and prey in India, 2018.* National Tiger Conservation Authority, Goverment of India, New Delhi, and Wildlife Institute of India, Dehradun. ISBN No. 81-85496-50-1

Jhala, Y.V., Qureshi Q., & Yadav, S.P. 2021. *Status of leopard, co-predators, and mega herbivores in India. 2018*. National Tiger Conservation Authority, Goverment of India, New Delhi, and Wildlife Institute of India, Dehradun. ISBN No. 81-85456-0

Kalle, R., Ramesh, T., Qureshi, Q., & Sankar, K. 2011. Density of tiger and leopard in a tropical deciduous forest of

Mudumalai Tiger Reserve, Southern India, as estimated using photographic capture-recapture sampling. *Acta Theriologica (Warsz)* 56, 335–342.

Karanth, K.U., & Sunquist, M.E. 2000. Behavioural correlates of predation by tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) in Nagarahole, India. *Journal of Zoology* 250, 255–265.

Khorozyan, G.I., Malkhasyan, A.G., & Abramov, A.V. 2008. Presence-absence surveys of prey and their use in Leopard (*Panthera pardus*) densities: a case study from Armenia. *Integrative Zoology* 3(4), 322–332.

Kshettry, A., Vaidyanathan, S., & Athreya, V. 2018. Diet Selection of Leopards (*Panthera pardus*) in a Human-Use Landscape in North-Eastern India. *Tropical Conservation Science* 11, 1–9.

Kumbhojkar, S., Yosef, R., Mehta, A., & Rakholia, S. 2020. A camera-trap home-range analysis of the Indian Leopard (*Panthera pardus fusca*) in Jaipur, India. *Animals* 10, 1–22.

Mondal, K., Gupta, S., Bhattacharjee, S., Qureshi, Q., & Sankar, K. 2012. Response of leopards to re-introduced tigers in Sariska Tiger Reserve, Western India. *International Journal of Biodiversity Conservation* 4, 228–236.

Odden, M., & Wegge, P. 2005. Spacing and activity patterns of Leopards *Panthera pardus* in the Royal Bardia National Park, Nepal. *Wildlife Biology* 11(2), 145–152.

Odden, M., Athreya, V., Rattan, S., & Linnell, J.D.C. 2014. Adaptable neighbours: Movement patterns of GPS-collared leopards in human dominated landscapes in India. *PLoS One* 9(11), e 112044. https://doi.org/10.1371/journal.pone.0112044

Pawar, D., Nelson, H.P., Pawar, D.R.L., & Khanwilkar, S. 2019. Estimating Leopard *Panthera pardus fusca* (Mammalia: Carnivora: Felidae) abundance in Kuno Wildlife Sanctuary, Madhya Pradesh, India. *Journal of Threatened Taxa* 11(5), 13531–13544.

Punjabi, G.A., & Rao, M.K. 2017. Large herbivore populations outside protected areas in the human-dominated Western Ghats, India. *Mammalian Biology* 87, 27–35.

Rather, T.A., Kumar, S., & Khan, J.A. 2021. Density estimation of tiger and leopard using spatially explicit capture-recapture framework. *Peer Journal* 9, 1–16.

Stein, A.B., Athreya, V., Gerngross, P., Balme, G., Henschel, P., Karanth, U., Miquelle, D., Rostro-García, S., Kamler, J.F., Laguardia, A., Khorozyan, I., & Ghoddousi, A. 2020. *Panthera pardus* (amended version of 2019 assessment). *IUCN Red List of Threatened Species* 2020.

Thapa, K., Shrestha, R., Karki, J., Thapa, G.J., Subedi, N., Pradhan, N.M.B., Dhakal, M., Khanal, P., & Kelly, M.J. 2014. Leopard *Panthera pardus fusca* density in the seasonally dry, Subtropical Forest in the Bhabhar of Terai Arc, Nepal. *Advances in Ecology* 1–12.

The St. Petersburg Declaration on Tiger Conservation. 2010 (accessed on 30th March 2022)

Zehra, N., Chaudhary, R., & Khan, J.A. 2019. Ecology of Leopard (*Panthera pardus fusca* Meyer) in dry tropical forests of Gir National Park and Sanctuary, Gujarat, India. *International Journal of Ecology and Environmental Sciences* 45(3), 241–255.