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MONITORING LEOPARD POPULATION IN MALAI MAHADESHWARA WILDLIFE SANCTUARY BETWEEN 2014 AND 2020

SEPTEMBER 2021

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Contents

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Introduction

Leopards (*Panthera pardus*) are the most widely distributed of the big cats and are adapted to a wide variety of habitats such as rainforests, open grasslands, deserts and alpine areas (Nowell & Jackson 1996). They are found in the sub-Saharan Africa while in Asia they are prevalent from the Middle East to the Pacific Ocean (Jacobson *et al.* 2016). Sri Lankan and Javan islands also have endangered population of leopards (Kittle *et al.* 2017; Wibisono *et al.* 2018). They even occur near large metropolitan cities such as Johannesburg, Mumbai and Bengaluru (Bhatia *et al.* 2013; Kuhn 2014; Gubbi *et al.* 2017a). Their adaptability to human dominated landscapes and flexible prey preference makes them a highly conflict-prone species.

Panthera pardus fusca, found in India, is one of the nine recognised subspecies of the leopard by the International Union for Conservation of Nature (IUCN) (Stein *et al.* 2020). Across most of its geographic expanse, leopards are persecuted at a local level due to prevailing conflict with humans even though they are globally and nationally considered as a flagship species and protected. The leopard is listed under the 'Vulnerable' category in the IUCN Red List of Threatened Species (Stein *et al.* 2020). Under the Wildlife Protection Act 1972 in India, they are listed as a Schedule 1 species which provides them with the highest level of protection.

In Asia, 83-87% of the leopards range is estimated to be lost due to various reasons (Jacobson *et al.* 2016). Over the years the conservation status of the leopard has changed from 'Least Concern' to 'Near Threatened' in 2008, then further classified as 'Vulnerable' (Odden *et al.* 2014; Jacobson *et al.* 2016). The status has changed due to the increase in the number of studies showing a potential declining trend in the population and reduction in the distribution range (Jacobson *et al.* 2016). In India, very few studies have established baseline population estimates for leopards in both forested and human-inhabited areas (Harihar *et al.* 2009; Athreya *et al*. 2013; Borah *et al.* 2014; Gubbi *et al.* 2017a, 2019b, 2019c, 2020c, 2021a). However, there is serious lack of population monitoring data to observe the trends in the population sizes over years.

Habitat loss and fragmentation, retaliatory killing, vehicular collisions, poaching, depletion of prey and some unconventional threats such as falling in wells and electrocution are some of the threats that might lead to a declining leopard population (Gubbi *et al.* 2014; Allwin 2015; Jacobson *et al*. 2016; Gubbi *et al.* 2017a, 2019a). In order to implement effective management and conservation strategies or evaluate the impact of existing ones, it is important to establish a baseline population and then study the population trends (Yoccoz *et al.* 2001; Clutton-Brock & Sheldon 2010; Campbell *et al.* 2011; Caro 2011; Henschel & Ray 2015). Spatial and temporal variation can provide additional insights into their population dynamics as well (Yoccoz *et al.* 2001).

This report provides the results of a long-term population monitoring study carried out every alternate year in Malai Mahadeshwara Hills Wildlife Sanctuary (MM Hills) from 2014 to 2020.

The main objectives of the study were

- To estimate baseline population abundance and density of leopards
- To monitor long-term variation in population abundance and density of leopards
- To observe difference in detection rate between male and female leopards
- To establish the Relative Abundance Index (RAI) of prey species

Study Area

Malai Mahadeshwara Wildlife Sanctuary (MM Hills) is located in the intersection of the Western and the Eastern Ghats and falls in the Chamarajanagara district of Karnataka. It was notified as a wildlife sanctuary in 2013 and covers an area of 906.1 km^2. There are six administrative ranges, which includes MM Hills, Paalar, Ramapura, Hoogyam, Hanur and P G Paalya. MM Hills is contiguous with Cauvery Wildlife Sanctuary (CWS, 1080.9 km^2) in the north, Biligiri Rangaswamy Temple Tiger Reserve (BRT TR, 574.8 km^2) in the west and Sathyamangalam Tiger Reserve (1411.6 km^2) in the south (Map 1). The Edayarhalli-Doddasampige wildlife corridor connects MM Hills and BRT Tiger Reserve and is used by large mammals such as leopards, tigers and elephants to move between these large forest patches.

The forest vegetation in MM Hills is dominantly dry deciduous followed by a small percentage of scrub woodland and scattered patches of moist deciduous and riparian forest (Harisha & Padmavathy 2013; Gubbi *et al.* 2017a). Map 2 depicts the vegetation structure and other physical features of MM Hills. The terrain is rugged with varying altitudes from 400m to 1200m above mean sea level. The annual rainfall is less than 900mm and temperature ranges between 18-40°C (Gubbi *et al.*2017a; Aravind & Páll-Gergely 2018). The river Paalar and streams Udthorehalla, Doddahalla are the important water sources within the wildlife sanctuary.

The human density within the wildlife sanctuary is about 47.4 individuals per km^2. The sanctuary has around 16 settlements within the boundary which are occupied mostly by people from the Soliga, Beda gampanna, Uppara, Gounder, Christian and Muslim communities (Harisha & Padmavathy 2013; Soumya *et al.* 2019). They practice agriculture and commonly grow finger millet (*Eleusine coracana*), maize (*Sorghum spp.*) and Hyacinth bean (*Dolichos lablab*). They also depend on the forest for fuel wood and other non-timber forest products (Pradhan *et al.* 2020), which is an added pressure on the natural forests. The wildlife sanctuary was heavily disturbed due to anthropogenic activities such as quarrying, road construction, poaching, etc. (Shaanker *et al.* 2004). The Male Mahadeshwara Temple which is located in the MM Hills range is an important pilgrimage site and hence the footfall generally is higher at all times within the sanctuary (Daniel *et al.* 2012).

Location coordinates

Latitude: 11°45'34.87"N to 12° 9'34.12"N
Longitude: 77°15'9.07"E to 77°40'7.68"E

Flora

The dry deciduous is the dominant forest type within the sanctuary and the common trees species include *Anogeissus latifolia, Boswellia serrata, Hardwikia binata* and *Chloroxylon swietenia* (Harisha & Padmavathy 2013; Pradhan *et al.* 2020). Some parts of the sanctuary have *Dendrocalamus strictus* and *Bambusa arundinace* (Pradhan *et al.* 2020). Common species of the moist deciduous forests include *Pterocarpus marsupium, Tectona grandis* and *Terminalia tomentosa* (Pradhan *et al.* 2020). The evergreen shola type patches are dominated by *Shorea talura* and found in the upper reaches of MM Hills (Karanth 1994). Species such as *Terminalia bellirica, Grewia tiliaefoli, Syzygium cumini, Emblica officinalis, Diospyros melanoxylon, Diospyros montana, Limonia acidissima, Albizia amara, Erythroxylon*

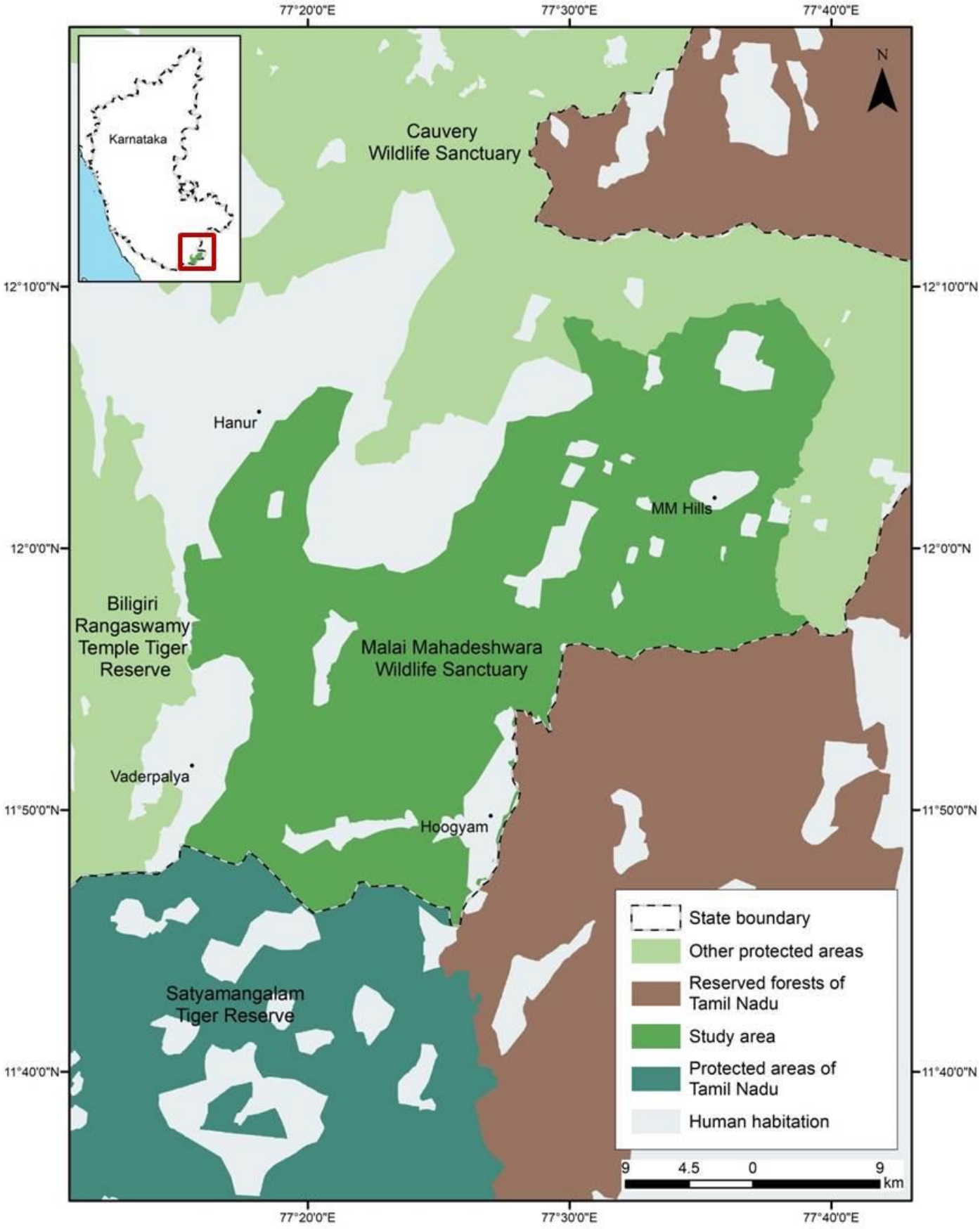
monogynum, Scolopia crenata and *Schleichera oleosa* are few out of 80 wild edible plants identified whose fruits, leaves and stems were used by local communities (Pradhan *et al.* 2020). Some of the other flora found in MM Hills area *Elaeocarpus tuberculatus, Salix tetrasperma, Syzygium malabaricum, Cocculus laurifolius, Viburnum punctatum, Celtis tetrandra, Dalbergia paniculata, Terminalia alata, Terminalia paniculata, Terminilia arjuna, Catunaregam torulosa, Meyna laxiflora, Dimocarpus longan, Elaeocarpus serratus, Litsea floribunda, Mallotus philippensis, Neolitsea zeylanica, Schefflera capitata, Xantolis tomentosa, Grewia tiliaefolia, Stereospermum personatum, Commiphora caudata, Givotia rottleriformis, Gyrocarpus asiaticus, Sterculia urens, Lagerstroemia parviflora, Acacia chundra, Ixora pavetta, Rhus mysorensis,Canthium dicoccum, Ziziphus mauritiana, Pavetta indica and Memecylon umbellatum* (Harisha & Padmavathy 2013).

Invasive plants such as *Lantana camara* and *Chromolaena odoratum* are widespread within the sanctuary and has had a negative impact on the native vegetation. Almost 60% of the natural forest and 58% of fallow land is now covered with *Lantana camara* (Shaankar *et al.* 2004; Aravind *et al.* 2010).

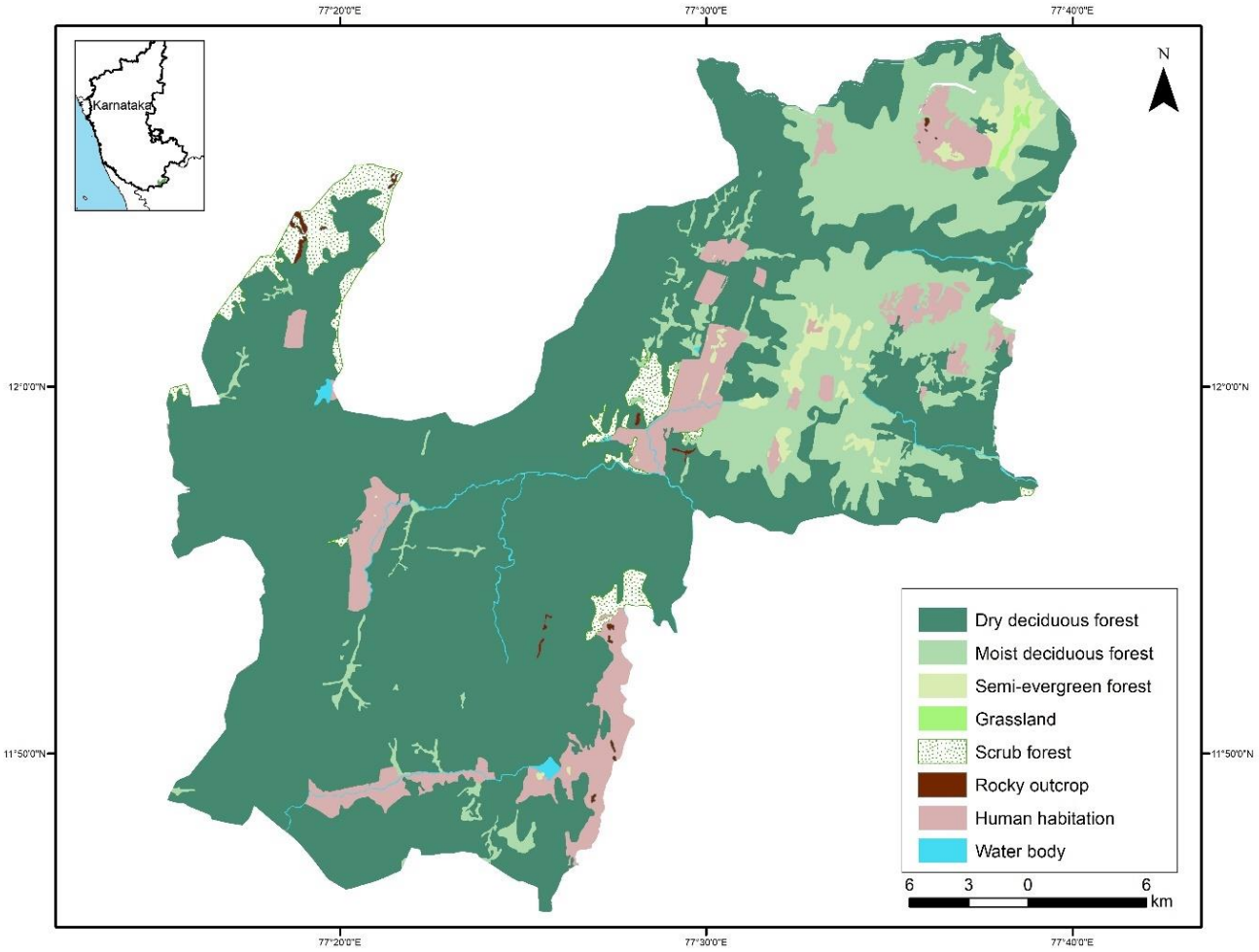
Figure 1. Malai Mahadeshwara Wildlife Sanctuary is characterised by dry deciduous, scrub woodland and scattered patches of moist deciduous and riparian forest

Fauna

MM Hills is inhabited by carnivores such as tiger (*Panthera tigris*), leopard (*Panthera pardus fusca*), dhole (*Cuon alpinus*), jackal (*Canis aureus*), Indian fox (*Vulpes bengalensis*), jungle cat (*Felis chaus*), rusty spotted cat (*Prionailurus rubiginosus*), small Indian civet (*Viverricula indica*), common palm civet (*Paradoxurus hermaphrodites*), Indian grey mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*). Omnivores such as the sloth bear (*Melursus ursinus*) and ratel (*Mellivora capensis*) are found quite frequently as well. MM Hills is an important habitat for elephants (*Elephas maximus*).



Map 1. Malai Mahadeshwara Wildlife Sanctuary, Cauvery Wildlife Sanctuary, Biligiri Rangaswamy Temple Tiger Reserve, Bannerghatta National Park and adjoining forests in Tamil Nadu.



Map 2. Types of vegetation and other physical features in Malai Mahadeshwara Wildlife Sanctuary

Prey species of large carnivores that occur in MM Hills includes gaur (*Bos gaurus*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), chital (*Axis axis*), barking deer (*Muntiacus muntjac*), four-horned antelope (*Tetracerus quadricornis*), mouse deer (*Moschiola indica*), tufted grey langur (*Semnopithecus priam*), bonnet macaque (*Macaca radiata*), black-naped hare (*Lepus nigricollis*), Indian crested porcupine (*Hystrix indica*) and Indian pangolin (*Manis crassicaudata*). The endemic Madras tree shrew (*Anathana ellioti*) is also present in the sanctuary (Gubbi *et al.* 2017a).

The forest harbours about 150 species of birds of which 95 species were recorded by Aravind *et al.* (2010) during a study to understand the effects of *Lantana camara* on bird assemblages. Among the 95 species, 30 were unique to dry deciduous, 13 were unique to moist deciduous and 48 species were common to both.

Methodology

Camera trapping

The study area was divided into five blocks covering an area of 906.1 km^2. The locations to deploy the camera traps were identified before the initial deployment in order to ensure high capture probability. Locations with indirect evidence of presence of leopard including scats, pugmarks, scrape marks were prioritised for placing camera traps. Panthera V4 and V6 motion detection cameras were secured using python cables to a tree bark or stump at a

height of ~ 40 cm from the ground, which is the optimal height to ensure capturing both flanks of a leopard. The camera traps were placed on either side of a trail or forest road to ensure that both flanks of the leopard were captured.

The camera trap exercise was carried out every alternate year starting in 2014 till 2020. The survey period, number of locations and number of unique occasions per block when the camera traps were deployed is given in Table 1. Camera trap effort is calculated by multiplying the number of locations by the number of occasions when camera trap is supposedly functioning. The population of leopards was assumed to be closed (no mortality, natality, immigration and emigration) within the study site due to the short camera-trapping period.

Table 1. Survey period, number of locations, occasions per block and camera trap effort for each survey year in Malai Mahadeshwara Wildlife Sanctuary

Year	Survey period	No. of locations	Occasions per block	Camera trapping effort
2014	10-Nov-14 to 30-Jan-15	477	16	7599
2016	21-Mar-16 to 17-Jun-16	336	16	5366
2018	26-Apr-18 to 04-Aug-18	401	16	6370
2020	30-Nov-19 to 06-Mar-20	420	16	6685

The camera traps were functioning throughout the day and were checked once in 2-3 days to download photographs, replace batteries and ensure that they were working properly. The downloaded images were then categorised using an automated classifier built on the Python platform (version 3.6) which essentially segregated the photos into folders based on species (Rampi *et al.* Unpublished). The categorised images were then validated manually and the name of the identified species was written to the image metadata using the software Digikam (Version 5.8.0; Gilles *et al.* 2018). The camera trap location and camera ID formed a unique combination which enabled extraction of the date, time and location coordinates for each captured image. Finally, images with leopards were extracted from the curated data and individuals were matched based on the rosette patterns on their respective flanks using Wild-ID (Bolger *et al.* 2011). Blurry and unclear images were not used during this process of identifying individuals. The flanks with maximum number of unique individuals were used for analysis.

Density and abundance estimation

The statistical analysis was carried out on Rstudio (version 1.1.463) using SECR package (version 4.2) which is based on Spatially Explicit Capture-Recapture methodology (Efford 2018). The input files used to estimate the abundance and density included the detector layout, capture history matrix and mask layer, which were prepared according to the SECR operational manuals. The detector layout file had information about the functioning and non-functioning camera traps on the different sampling occasions. The habitat mask layer included the suitable forest area encompassed within the boundary of the wildlife sanctuary (Efford 2018). A buffer was generated around the camera traps using the 'suggest.buffer' function in the SECR package. The capture history matrix had one row each for individually identified leopards at a particular location and sampling occasion. The SECR package then utilised this spatial information to estimate capture probabilities and fitted models by maximising the likelihood (Borchers and Efford 2008). In order to select the model with the best estimates of density and abundance, the Akaike's Information Criterion (AIC) for

likelihood-based models was considered. A finite mixture model was selected which used hazard rate as detection function and accounted for the heterogeneity in detection probabilities among individuals. This model considers the difference between frequently captured individuals by the camera trap as opposed to rarely captured individuals.

Detection rates

The number of detections per individual was noted per survey year. A detection was considered if an individual was photo-captured at a location on a discrete occasion i.e. 24 hours apart. The detection rates were calculated separately for males and females per survey year by dividing the sum of male/female detections by the number of male/female individuals identified. Individual captures in each year was tabulated to determine their persistence within the sanctuary.

Relative Abundance Index calculation

In order to observe how different prey species were faring as compared to others, the relative abundance index (RAI) was calculated for all prey species using the photographic capture rate i.e. the number of independent photo captures for a particular species per 100 trap days. The photographic capture rates correlate with density estimates for large terrestrial mammals and thus RAI can be used as a valid index of density for unmarked species (Rovero & Marshall 2009; Palmer *et al.* 2018).

The images of the different mammal species were segregated into separate folders which were then matched using the timestamp in the metadata of the image to extract number of individual events for each species separately. A VBA (Visual Basic for Applications) script in excel was used to run this process. In the case of livestock, cow, buffalo, donkey and domestic pig were categorised as large livestock while sheep and goat were grouped as small livestock. A predefined threshold time interval (or event duration) was considered to categorise photos as an independent event for each species. This was based on the amount of time taken by different species (individually or as a group) to cross the camera trap location (Appendix-2). Photos with multiple individuals of the same species were considered as one event.

After the number of independent events for each species was tabulated, it was divided by the total number of camera trapping days and further multiplied by 100 to give the RAI for each species per 100 trap days.

Results

Abundance and density estimates for leopards

The camera traps captured 2,285 leopard images between 2014 and 2020; and a total of 147 adult individual leopards were identified. The number of individuals photo-captured in each survey year is tabulated in Table 2. Of the identified individuals, 83 were female and 49 were male. The sex of 15 individuals could not be determined. A total of 12 cubs and 17 subadults were also identified but not used for analysis. This was mainly because cubs tend to have low capture probabilities and subadults tend to be transient as they have not established home ranges (Karanth 1995, Grey et al. 2013). Accounting for individual heterogeneity, individuals were segregated into two groups with different detection probabilities.

The SECR analysis provided mean leopard abundance estimates of approximately 48.25 ± 2.34 in 2014, 68.31 ± 3.57 in 2016, 58.72 ± 5.99 in 2018 and 61.8 ± 1.84 in 2020. Density

estimates of leopards per 100 km^2 were 5.39 ± 0.82 in 2014, 7.62 ± 1 in 2016, 6.56 ± 1.08 in 2018 and 6.91 ± 0.9 in 2020. The σ values and ranges for all estimated values are given in Table 3. Figure 2 and Figure 3 show scatter plots of the trend of population abundance and density estimates in MM Hills. The pixel densities of leopards for each survey year are depicted in Figure 4.

Table 2. Results of the camera trapping exercise in Malai Mahadeshwara Wildlife Sanctuary

Year	Number of images	Number of individuals	Number of females, males	Number of cubs, subadults
2014	622	44	29, 15	6, 4
2016	510	60	39, 16	1, 0
2018	440	47	27, 14	2, 4
2020	713	59	38, 20	3, 9

Table 3. SECR analysis results of leopards for all four survey years (2014, 2016, 2018, 2020) in Malai Mahadeshwara Wildlife Sanctuary.

Year	*N* (SE)	*N* Range	D (SE)	D Range	σ (SE) in metres	σ Range
2014	48.25 (2.34)	45.55 – 55.69	5.39 (0.82)	4.01 – 7.26	916.29 (243.85)	548.75 – 1530.03
2016	68.31 (3.57)	63.70 – 78.63	7.62 (1.00)	5.89 – 9.85	1665.72 (280.84)	1199.75 – 2312.66
2018	58.72 (5.99)	51.56 – 77.13	6.56 (1.08)	4.75 – 9.05	3235.48 (439.18)	2482.71 – 4216.49
2020	61.80 (1.84)	59.87 – 68.05	6.91 (0.9)	5.35 – 8.92	2335.01 (242.39)	1906.18 - 2860.29

N - Estimate of total number of individuals in the study area, D – No of leopards/100 km^2, σ – Spatial scale of detection function (in meters)

Detection rates

From the total number of individuals identified, the number of females is significantly more than the number of males (Table 2, Figure 5). The number of detections and detection rates are tabulated in Table 4. The mean of male and female detection rate is 8.07 and 3.31 respectively. The median for male and female detection rate was calculated as 8.26 and 3.39 respectively (Figure 6).

Table 4. The number of detections and detection rates for males and females in Malai Mahadeshwara Wildlife Sanctuary

Year	Detections[#] (males)	Detection rate* (males)	Detections (females)	Detection rate (females)
2014	128	8.53	107	3.69
2016	108	6.75	108	2.77
2018	112	8	88	3.26
2020	180	9	134	3.53

[#]Number of times an individual was captured in camera traps;

* $\frac{\text{Total number of male/ female detections}}{\text{Number of males / females identified}}$

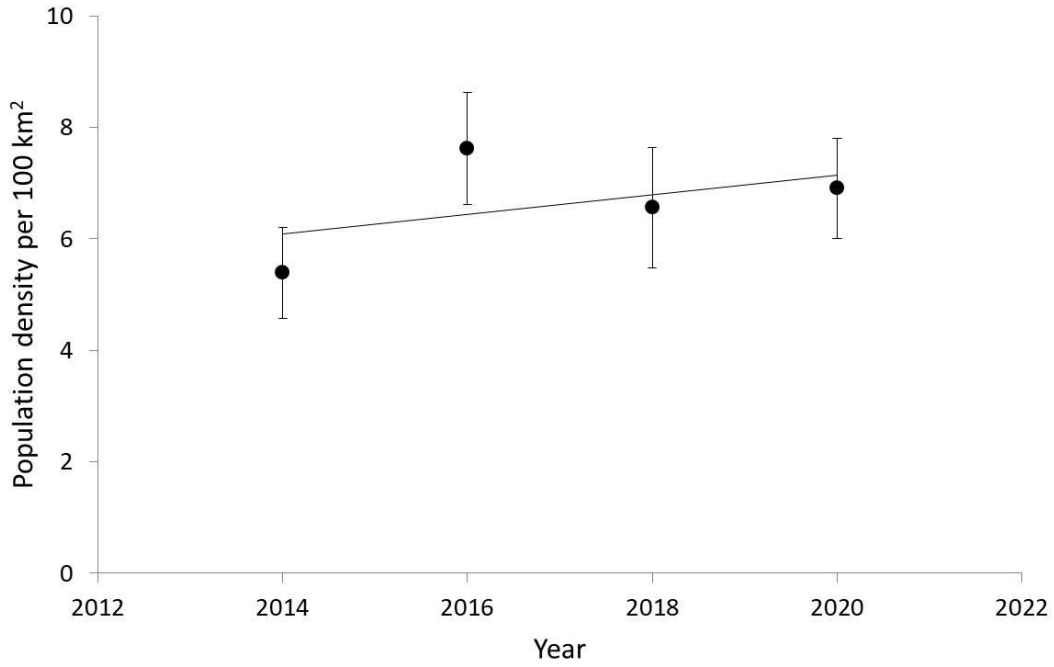


Figure 2. Trend of leopard population density estimate (y-axis) over the survey period (x-axis, in years) with error bars in Malai Mahadeshwara Wildlife Sanctuary

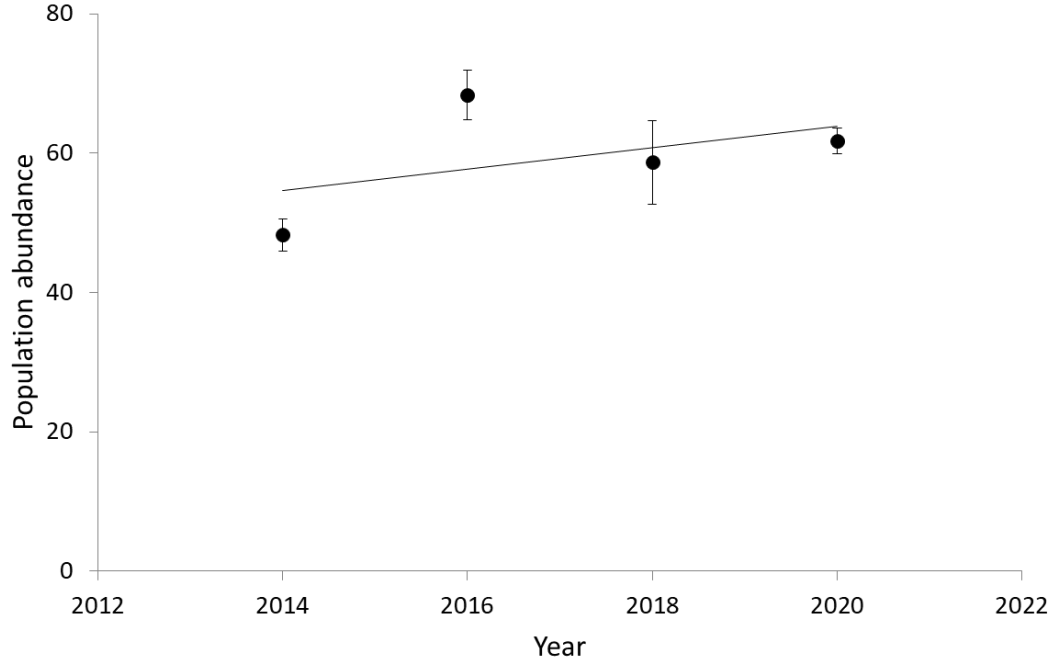


Figure 3. Trend of leopard population abundance estimate (y-axis) over the survey period (x-axis, in years) with error bars in Malai Mahadeshwara Wildlife Sanctuary

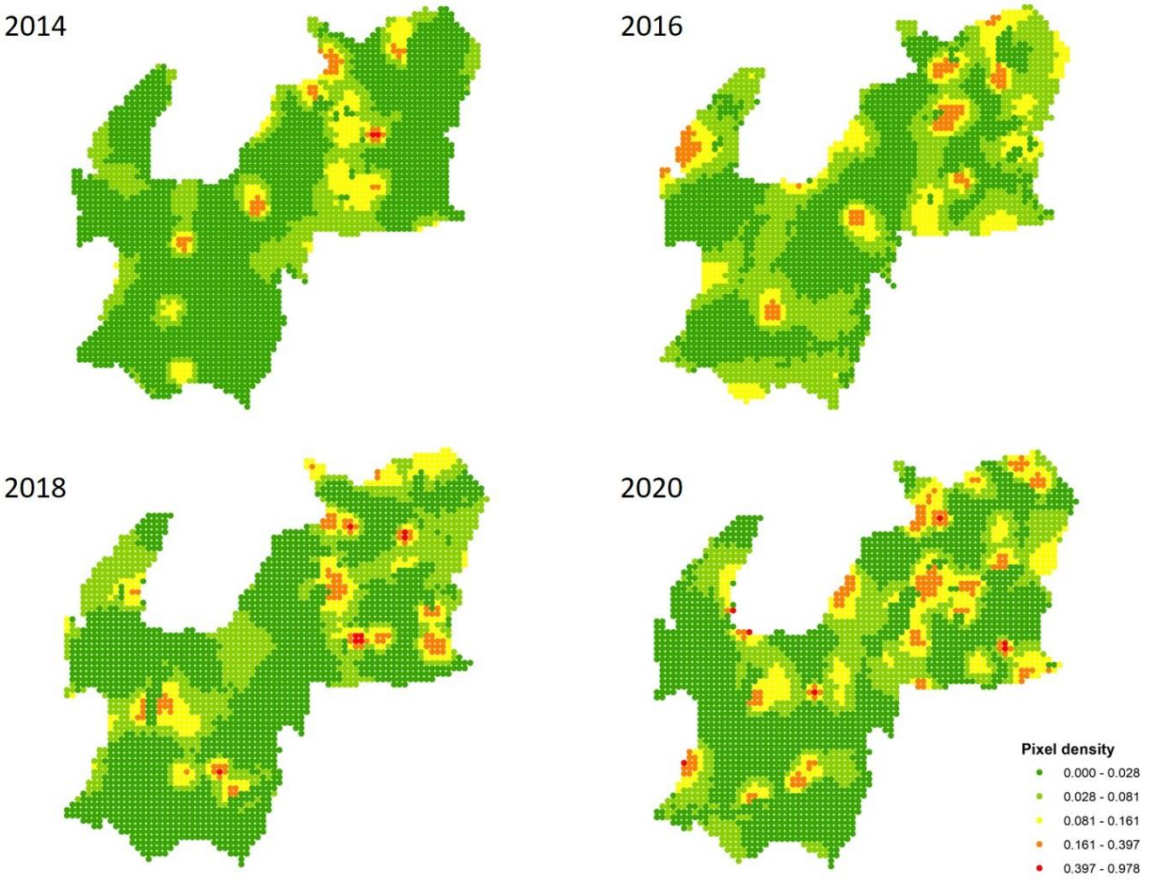


Figure 4. Pixel densities of leopards in Malai Mahadeshwara Wildlife Sanctuary during each of the survey years

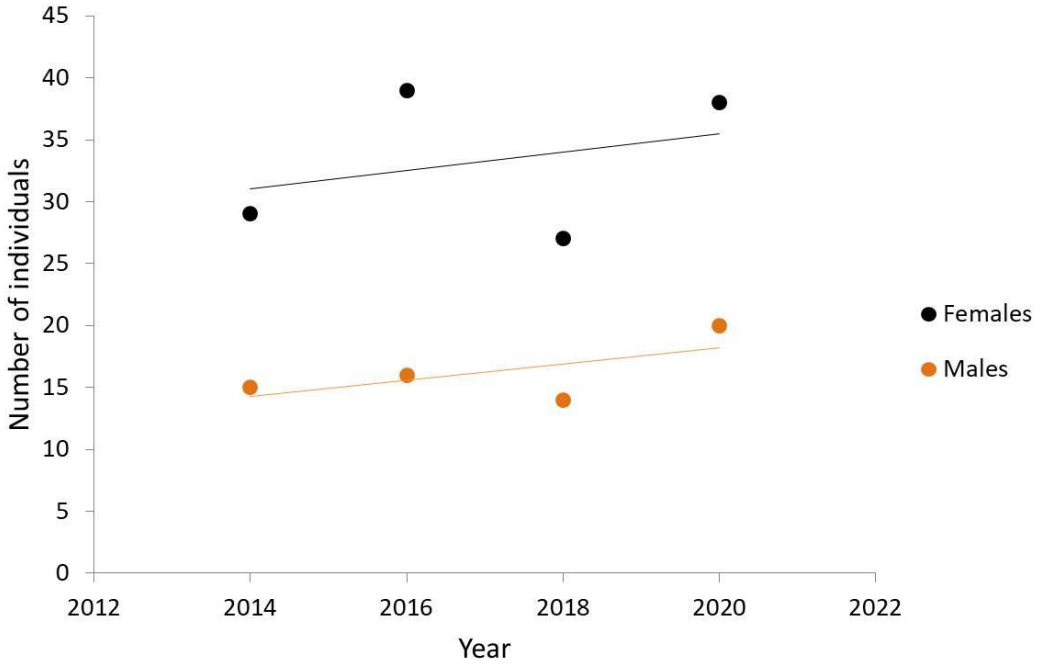


Figure 5. Number of male and female leopards (y-axis) identified in Malai Mahadeshwara Wildlife Sanctuary for each survey year (x-axis).

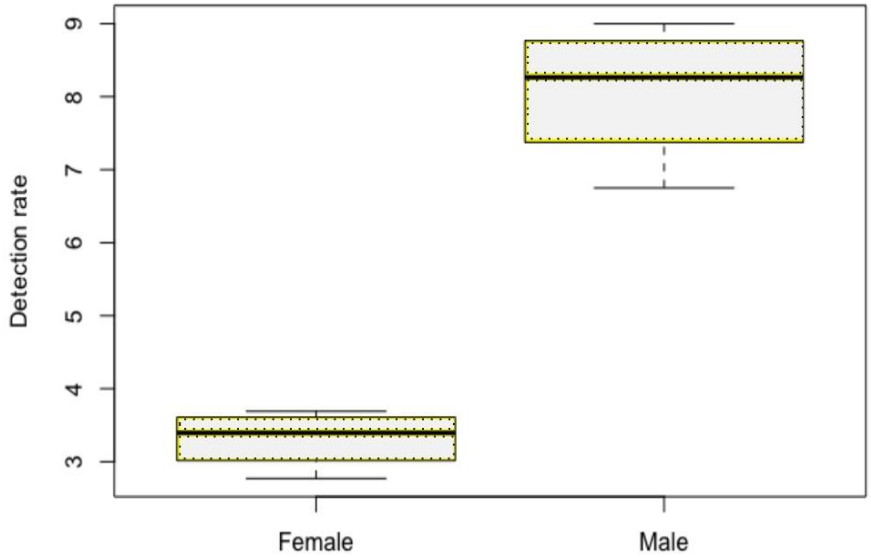


Figure 6. Detection rates of female and male leopards in Malai Mahadeshwara Wildlife Sanctuary

Relative Abundance Index (RAI) of leopard prey

The results of the Relative Abundance Index (RAI) of leopards' natural and domestic prey are given in Table 5.

The Relative Abundance Index (RAI) for domestic and wild prey was calculated separately (Table 6). Domestic prey species included all livestock and domestic dogs. Wild prey species were categorized as large (>20kg) and small (<20kg) depending on their weight. The list of species considered in each category is given in Appendix-3. The variation in RAI for each prey category can be seen in Figure 7.

Other fauna

A total of 32 wild mammalian species including the leopard were captured in camera traps at MM Hills during the study period. All other mammal species other than leopard prey species are listed in Table 7 and photographs are attached as Appendix-1.
Tiger individuals were also identified from the images captured. From 551 images, 21 adults and 4 cubs were identified over the entire study period.

Discussion

Abundance and density variation

The more recent abundance estimates of leopards in MM Hills is high compared to estimates reported from other PAs in India such as Manas National Park (500 km^2) in Assam where the abundance was 47 individuals while Achanakmar Tiger Reserve (914 km^2) in Chhattisgarh had an estimate of only 30 individuals (Borah *et al.* 2014; Mandal *et al.* 2017). The density estimates of MM Hills are similar to adjacent PAs such as CWS where the highest density estimates was 8.54 individuals/100km^2 and BRT TR which was estimated to be 6.97 individuals/100km^2 (Gubbi *et al.* 2019c; 2021b). The densities are also comparable to other leopard habitats in the world such as Zululand Rhino Reserve (234 km^2) in northern KwaZulu-Natal, South Africa which reported a density of 7 leopards/100 km^2 (Chapman &

Table 5. Results of the Relative Abundance Index (RAI) calculated for leopards' natural and domestic prey in Malai Mahadeshwara Wildlife Sanctuary for each survey year.

S/N	Species	Wildlife Protection Act 1972 Status	IUCN Red List Global Status	2014	2016	2018	2020
	Wild prey						
1	Sambar (*Rusa unicolor*)	III	Vulnerable	26.39 (0.008)	14.42 (0.004)	9.44 (0.003)	21.15 (0.004)
2	Chital (*Axis axis*)	III	Least Concern	2.78 (0.0009)	5.85 (0.002)	8.02 (0.002)	5.45 (0.002)
3	Barking deer (*Muntiacus vaginalis*)	III	Least Concern	2.46 (0.0006)	1.53 (0.001)	1.51 (0.001)	1.54 (0.001)
4	Four-horned antelope (*Tetracerus quadricornis*)	I	Vulnerable	1.21 (0.0004)	3.34 (0.001)	2.51 (0.001)	3.25 (0.001)
5	Indian Chevrotain (*Moschiola indica*)	I	Least Concern	1.87 (0.0005)	1.70 (0.001)	-	0.93 (0.000)
6	Wild pig (*Sus scrofa*)	III	Least Concern	9 (0.003)	11.70 (0.003)	7.82 (0.002)	9.71 (0.002)
7	Black-naped hare (*Lepus nigricollis*)	IV	Least Concern	53.02 (0.007)	63.14 (0.016)	37.72 (0.009)	48.9 (0.008)
8	Porcupine (*Hystrix indica*)	IV	Least Concern	9.63 (0.002)	9.84 (0.003)	11.44 (0.002)	18.03 (0.003)
9	Indian pangolin (*Manis crassicaudata*)	I	Endangered	0.13 (0.000)	0.06 (0.000)	0.078 (0.000)	0.16 (0.000)
10	Bonnet macaque (*Macaca radiata*)	II	Least Concern	3.53 (0.001)	2.65 (0.001)	2.82 (0.002)	3.49 (0.003)
11	Tufted grey langur (*Semnopithecus priam*)	II	Near Threatened	0.68 (0.0003)	3.19 (0.004)	1.15 (0.001)	3.64 (0.002)
	Domestic prey						
1	Large livestock	NA	NA	118.2 (0.019)	107.56 (0.037)	93.98 (0.018)	148.53 (0.028)
2	Small livestock	NA	NA	44.64 (0.012)	30.92 (0.013)	31.17 (0.009)	37.10 (0.009)
3	Domestic dog	NA	NA	33.59 (0.009)	24.17 (0.01)	22.15 (0.007)	22.65 (0.007)

Table 6. Results of the Relative Abundance Index (RAI) calculated for domestic and wild prey (small <20kg, large >20kg and combined) in Malai Mahadeshwara Wildlife Sanctuary for each survey year.

Year	Domestic prey (SE)	Large wild prey (SE)	Small wild prey (SE)	Wild prey (SE)
2014	170.54 (0.03)	41.85 (0.01)	68.86 (0.007)	110.71 (0.01)
2016	150.32 (0.05)	36.82 (0.01)	80.56 (0.02)	117.39 (0.02)
2018	176.97 (0.03)	29.29 (0.004)	54.18 (0.009)	83.47 (0.01)
2020	128.47 (0.02)	44.67 (0.005)	74.97 (0.008)	119.64 (0.01)

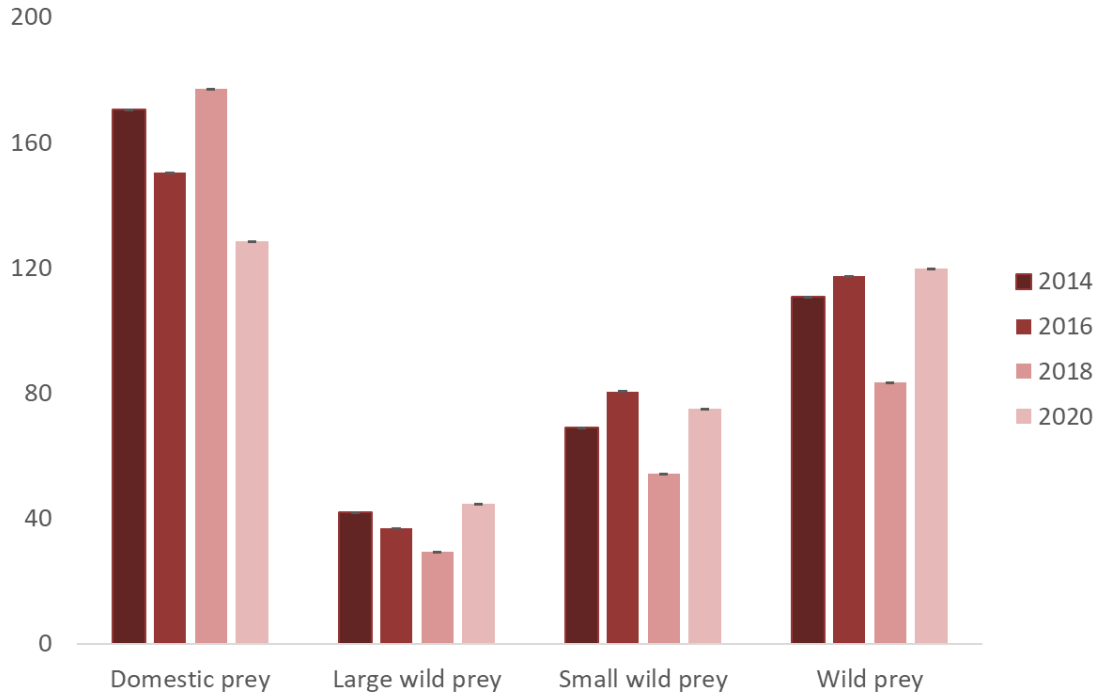


Figure 7. The Relative Abundance Index of leopards' domestic prey, large wild prey, small wild prey and total wild prey for each of the survey years.

Table 7. Other mammal species photo-captured in camera traps in Malai Mahadeshwara Wildlife Sanctuary

S/N	Species	Wildlife Protection Act 1972 Status	IUCN Red List Global Status
1	Tiger (*Panthera tigris*)	I	Endangered
2	Jungle cat (*Felis chaus*)	II	Least Concern
3	Rusty spotted cat (*Prionailurus rubiginosus*)	I	Near Threatened
4	Dhole (*Cuon alpinus*)	II	Endangered
5	Golden jackal (*Canis aureus*)	II	Least Concern
6	Indian fox (*Vulpes bengalensis*)	II	Least Concern
7	Sloth bear (*Melursus ursinus*)	I	Vulnerable
8	Elephant (*Elephas maximus*)	I	Endangered
9	Gaur (*Bos gaurus*)	I	Vulnerable
10	Ratel (*Mellivora capensis*)	I	Least Concern
11	Smooth-coated otter (*Lutrogale perspicillata*)	II	Vulnerable
12	Grey mongoose (*Herpestes edwardsii*)	II	Least Concern
13	Ruddy mongoose (*Herpestes smithii*)	II	Least Concern
14	Stripe-necked mongoose (*Herpestes vitticollis*)	II	Least Concern
15	Common palm civet (*Paradoxurus hermaphroditus*)	II	Least Concern
16	Small Indian civet (*Viverricula indica*)	II	Least Concern
17	Madras tree shrew (*Anathana ellioti*)	II	Least Concern
18	Indian gerbil (*Tatera indica*)	IV	Least Concern
19	Lesser woolly horseshoe bat (*Rhinolophus beddomei*)	V	Least Concern
20	Greater false vampire bat (*Megaderma lyra*)	V	Least Concern

Balme 2010) and Huai Kha Khaeng Wildlife Sanctuary (2800 km^2) in Thailand where leopard density estimates were 7.88, 5.21 and 4.86 leopards/100 km^2 over three separate sessions (Simcharoen & Duangchantrasiri 2008).

The density and abundance estimate shows an overall increasing trend spanning from 2014 to 2020 (Figure 2 and Figure 3). The spike in 2016 where 68.31 ± 3.57 leopards was estimated is an anomaly and could be due to temporal variation or heterogeneity in behaviour of individuals. It could be due to increased movement of individuals looking for prey species or dispersing individuals and in case of females, there might be increased movement looking for mates (Harmsen *et al.* 2017). The density estimates seem to stabilise between the survey done in 2018 and 2020 (Table 3, Figure 2). MM Hills has a slightly higher baseline abundance estimate since it was established in 2013 and the whole area was instantly under strict management as compared to CWS which underwent expansion in different stages (Gubbi *et al.*2017b, 2021b). The general increasing trend of population can be attributed to the structural changes brought during the expansion of these PAs. The reserved forests under Kollegala division were combined to form MM Hills and the sizes of the forest range were reduced so that they could be better managed (Gubbi *et al.* 2017b). This coupled with increased staff and anti-poaching camps might have had a large scale impact on the wildlife. The movement of individuals between the nearby PAs which include CWS and BRT TR, and other forests of Tamil Nadu flanking the southern boundary might also contribute to the temporal variation (Gubbi *et al.* 2019c; 2021b). The spatial variation in pixel densities shows the increase in distribution throughout MM Hills from 2014 to 2020 (Figure 4).

Population turnover

In 2014, a total of 50 adult leopards were identified and the number of new individuals was 35 in 2016, 24 in 2018 and 38 in 2020. The turnover of new individuals is lesser than adjacent CWS. This could be because MM Hills had a healthy population to begin with which then remained stable through the survey years. Over the long term monitoring period, eight individuals were captured during all four years, 10 over three years and 27 over two years. Since the surveys span over seven years, the individuals that have been recorded at least during two survey periods could be considered as residents as they have spent at least three years within MM Hills (Harmsen *et al.* 2017). This could establish potential home ranges for a few individuals.

Out of the 45 individuals which were captured at least for two years, 34 individuals were identified as females suggesting that the habitat quality might be good enough to maintain their territory and breed (Nowell & Jackson 1996; Kandel *et al.* 2020). Even though females were more in number in all the survey years, the detection rate of males was much higher than females. This would mean that females move around lesser while denning or are more cautious to use trails when they have dependent cubs (Harmsen *et al.* 2017).

Males and females have been captured together at several occasions. In 2016, one such instance also suggested polyandry in a short time frame, when a male was captured with two females and a female was captured with two males just five days apart. The photo-captures of cubs and subadults show the presence of breeding females. Breeding females have been considered to play a crucial role in the population stability of large carnivores (Nowell & Jackson 1996; Balme *et al.* 2013; Kandel *et al.* 2020). Further, three of the individuals who were recorded during at least three consecutive surveys were initially photo captured as cubs.

The polygon formed by their capture locations of two such individuals is mapped in Figure 8 The female seems to have a much smaller polygon than the male.

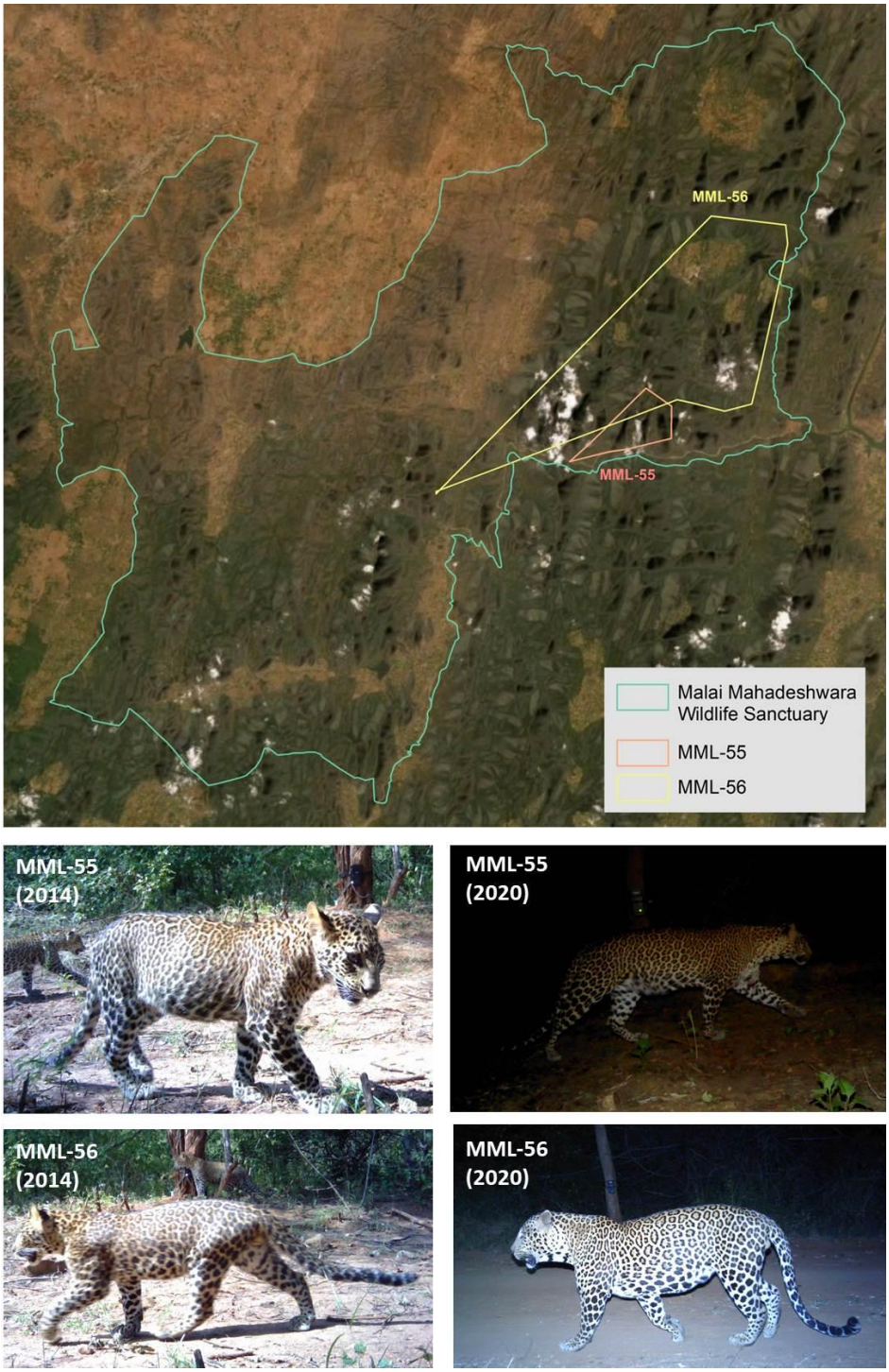


Figure 8. Polygon formed with all capture locations from 2014 to 2020 showing potential home range of MML-5 (female) and MML-56 (male)

Variables affecting leopard population

Habitat fragmentation is a major factor that affects leopards and its' natural prey population (Fahrig 2003). MM Hills and CWS share 24 leopard individuals who move between the PAs as they are contiguous. The encroachment of enclosures within these PAs as well as settlements on the boundary can pose a threat in the future (Jacobson *et al.* 2016). The

conversion of natural forests into agricultural land can lead to fragmentation of the habitat and lead to more human-wildlife conflict issues (Athreya *et al.* 2015; Gubbi *et al.* 2020a). One common individual between BRT TR and MM Hills possibly used the Doddasampige-Edyaralli forest corridor which shows the functionality of wildlife corridors in connecting forested areas and facilitating dispersal of animals.

The proportion of natural habitats and availability of large wild prey plays a very important role in maintaining a healthy leopard population (Dickman & Marker 2005; Khorozyan *et al.* 2008; Gubbi *et al.* 2020b). The forest cover in parts of the sanctuary was shown to be declining, and the livestock distribution suggests an increased pressure of grazing on the natural habitat (Gubbi *et al.*2017a, 2017b). In addition to over grazing, the high RAI of domestic prey might also affect the wild prey population directly (Madhusudan 2004). Even though leopards have been found to depend on domestic prey in human dominated landscapes (Athreya *et al.* 2013), natural prey populations are important for the long term stability of leopard populations (Ramesh *et al.* 2017; Gubbi et al. 2020b). There is no clear trend in the RAI of domestic and wild prey over the four survey periods. In 2018, there seems to be a dip in the wild prey population which could be attributed to seasonal variations in prey populations. Understanding prey population dynamics is important to the implement effective management practices within PAs.

The local communities are dependent on the forests for firewood and other non-forest timber products (Pradhan *et al.* 2020). This dependence along with encroachment and livestock grazing can prove detrimental for the conservation of this landscape. Besides the above mentioned threats, poaching is an issue that still poses a threat to the large mammals in South India (Madhusudan & Karanth 2002).

Other fauna

Apart from leopards, MM Hills is a very important habitat for maintaining tiger population. The neighbouring BRT TR and Sathyamangalam Tiger Reserve act as source for tiger populations which disperse into MM Hills. Recently MM Hills has been proposed to be declared as a Tiger Reserve as it serves as an important element to conserve tiger populations. There are four individuals which were photo-captured in CWS, seven individuals in BRT TR, and one in Sathyamangalam Tiger Reserve, which were common to MM Hills (Gubbi *et al.* 2019c, 2021b). One of the tiger individuals was found to move between CWS and MM Hills and also use the Doddasampige-Edyaralli forest corridor connecting BRT TR with MM Hills. This evidence of corridor utilisation emphasises the importance of maintaining connectivity between these PAs. Besides tigers, MM Hills is extremely important to maintain connectivity for elephants between BRT TR and CWS.

Conclusion

Understanding the status of leopard populations through long term monitoring is extremely important to deduce factors that might be threatening its' persistence in a landscape. Tropical evergreen and rainforest habitats often get more conservation attention as opposed to other lesser known habitats such as woodland savannah and scrub forests.

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Appendices

Appendix – 1

Photographs of mammal species captured in Malai Mahadeshwara Wildlife Sanctuary during camera trapping session in 20104, 2016, 2018 and 2020.

Leopard
(*Panthera pardus fusca*)

Tiger
(*Panthera tigris*)

Jungle cat
(*Felis chaus*)

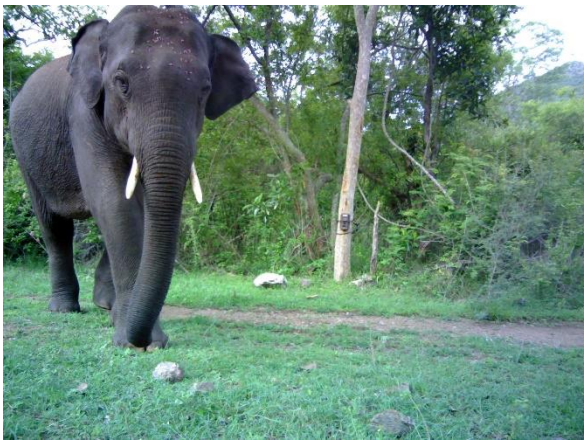
Rusty spotted cat
(*Prionailurus rubiginosus*)

Dhole
(*Cuon alpinus*)

Golden jackal
(*Canis aureus*)

Indian fox
(*Vulpes bengalensis*)

Sloth bear
(*Melursus ursinus*)



Elephant
(*Elephas maximus*)

Gaur
(*Bos gaurus*)

Smooth-coated otter
(*Lutrogale perspicillata*)

Ratel
(*Mellivora capensis*)

Sambar
(*Rusa unicolor*)

Chital
(*Axis axis*)

Barking deer
(*Muntiacus vaginalis*)

Four-horned antelope
(*Tetracerus quadricornis*)

Indian chevrotain
(*Moschiola indica*)

Wild pig
(*Sus scrofa*)

Black-naped hare
(*Lepus nigricollis*)

Porcupine
(*Hystrix indica*)

Bonnet macaque
(*Macaca radiata*)

Tufted grey langur
(*Semnopithecus priam*)

Indian pangolin
(*Manis crassicaudata*)

Grey mongoose
(*Herpestes edwardsii*)

Ruddy mongoose
(*Herpestes smithii*)

Stripe-necked mongoose
(*Herpestes vitticollis*)

Common palm civet
(*Paradoxurus hermaphroditus*)

Small Indian civet
(*Viverricula indica*)

Madras tree shrew
(*Anathana ellioti*)

Indian gerbil
(*Tatera indica*)

Lesser woolly horseshoe bat
(*Rhinolophus beddomei*)

Greater false vampire bat
(*Megaderma lyra*)

Appendix – 2

Event duration used for calculating Relative Abundance Index (RAI) of leopards' natural and domestic prey

Wild prey	**Event duration (seconds)**
Sambar (*Rusa unicolor*)	60
Chital (*Axis axis*)	120
Barking deer (*Muntiacus vaginalis*)	60
Four-horned antelope (*Tetracerus quadricornis*)	60
Indian Chevrotain (*Moschiola indica*)	60
Wild pig (*Sus scrofa*)	60
Black-naped hare (*Lepus nigricollis*)	60
Porcupine (*Hystrix indica*)	60
Indian pangolin (*Manis crassicaudata*)	60
Bonnet macaque (*Macaca radiata*)	360
Tufted grey langur (*Semnopithecus priam*)	180

Domestic prey	**Event duration (seconds)**
Large livestock	300
Small livestock	180
Domestic dog	60

Appendix – 3

Categorisation of prey species into large and small wild prey

Species	Scientific name
Small Wild Prey (SWP) <20 kg	
Black-naped hare	*Lepus nigricollis*
Bonnet macaque	*Macaca radiata*
Tufted grey langur	*Semnopithecus priam*
Mouse deer	*Moschiola indica*
Porcupine	*Hystrix indica*
Indian pangolin	*Manis crassicaudata*
Large Wild Prey (LWP) >20 kg	
Barking deer	*Muntiacus vaginalis*
Chital	*Axis axis*
Four-horned antelope	*Tetracerus quadricornis*
Sambar	*Rusa unicolor*
Wild pig	*Sus scrofa*
Domestic prey	
Buffalo	*Bubalus bubalis*
Cow	*Bos taurus*
Goat	*Capra aegagrus hircus*
Sheep	*Ovis aries*
Domestic pig	*Sus scrofa domesticus*
Domestic dog	*Canis lupus familiaris*

Appendix-4

Leopard individuals captured in Malai Mahadeshwara Wildlife Sanctuary in each survey year are depicted with the darkened cells.

Individual	Sex	2014	2016	2018	2020	Number of years captured
MML-08	Female	■	■	■	■	4
MML-14	Female	■	■	■	■	4
MML-18	Female	■	■	■	■	4
MML-24	Female	■	■	■	■	4
MML-29	Female	■	■	■	■	4
MML-39	Male	■	■	■	■	4
MML-55	Female	■	■	■	■	4
MML-56	Male	■	■	■	■	4
MML-05	Male	■	■	■		3
MML-15	Female	■	■	■		3
MML-28	Male	■	■	■		3
MML-30	Female	■		■	■	3
MML-38	Female	■	■	■		3
MML-59	Male		■	■	■	3
MML-61	Female		■	■	■	3
MML-73	Female		■	■	■	3
MML-76	Female		■	■	■	3
MML-87	Female		■	■	■	3
MML-02	Female	■	■			2
MML-04	Male	■	■			2
MML-06	Female	■	■			2
MML-09	Female	■	■			2
MML-20	Male	■	■			2
MML-23	Female	■	■			2
MML-34	Female	■	■			2
MML-36	Female	■	■			2
MML-37	Female	■	■			2
MML-40	Female	■	■			2
MML-42	Female	■	■			2
MML-44	Female	■	■			2
MML-46	Female	■	■			2
MML-60	Female		■	■		2
MML-67	Female		■	■		2
MML-70	Male		■	■		2
MML-71	Male		■	■		2
MML-72	Female		■		■	2
MML-85	Female		■	■		2
MML-88	Female		■	■		2
MML-99	Female			■	■	2
MML-101	Male			■	■	2
MML-102	Female			■	■	2
MML-106	Female			■	■	2
MML-111	Male			■	■	2
MML-116	Female			■	■	2
MML-123	Female			■	■	2
MML-01	Male	■				1

MML-03	Male					1
MML-07	Female					1
MML-10	Male					1
MML-11	Male					1
MML-12	Female					1
MML-13	Male					1
MML-16	Female					1
MML-17	Male					1
MML-19	Male					1
MML-21	Male					1
MML-22	Female					1
MML-25	Female					1
MML-26	Female					1
MML-27	Male					1
MML-31	Female					1
MML-32	Female					1
MML-33	Female					1
MML-35	Male					1
MML-41	Female					1
MML-43	Female					1
MML-45	Male					1
MML-47	UID					1
MML-57	Female					1
MML-58	Male					1
MML-62	Male					1
MML-63	UID					1
MML-64	UID					1
MML-65	UID					1
MML-66	Female					1
MML-68	Female					1
MML-69	Male					1
MML-74	Female					1
MML-75	Female					1
MML-77	Female					1
MML-78	Male					1
MML-79	Female					1
MML-80	UID					1
MML-81	Female					1
MML-82	Female					1
MML-83	Male					1
MML-84	Female					1
MML-86	Male					1
MML-89	Female					1
MML-91	UID					1
MML-92	Male					1
MML-93	UID					1
MML-95	Male					1
MML-96	Female					1
MML-97	UID					1
MML-98	Male					1
MML-100	Male					1

MML-103	Female					1
MML-104	Male					1
MML-105	Female					1
MML-107	Female					1
MML-108	Female					1
MML-109	Male					1
MML-110	UID					1
MML-112	UID					1
MML-113	Female					1
MML-114	UID					1
MML-115	UID					1
MML-117	UID					1
MML-124	Male					1
MML-125	Female					1
MML-126	Female					1
MML-127	Female					1
MML-128	Male					1
MML-129	Female					1
MML-130	Male					1
MML-131	Male					1
MML-132	Male					1
MML-133	Male					1
MML-134	Female					1
MML-135	Male					1
MML-136	Female					1
MML-137	Female					1
MML-138	Female					1
MML-139	Female					1
MML-140	Male					1
MML-141	Female					1
MML-142	Male					1
MML-143	Male					1
MML-144	Female					1
MML-145	Female					1
MML-146	Female					1
MML-147	Female					1
MML-148	Female					1
MML-149	Female					1
MML-150	Male					1
MML-151	Female					1
MML-152	Male					1
MML-153	Male					1
MML-154	Male					1
MML-155	Female					1
MML-156	Female					1
MML-157	Male					1
MML-158	Female					1
MML-159	Female					1
MML-160	UID					1
MML-161	UID					1

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