VARIATION IN LEOPARD DENSITY AND ABUNDANCE: MULTI-YEAR STUDY IN CAUVERY WILDLIFE SANCTUARY

SEPTEMBER 2021

Nature Conservation Foundation
Holématthi Nature Foundation
#135, 14th Main, 30th Cross,
Banashankari Stage II,
Bengaluru 560070,
Karnataka, India.
Telefax- +91-80-2671 6897
https://www.ncf-india.org/western-ghats/the-secret-lives-of-leopards

Office Location:

Nature Conservation Foundation and
Holématthi Nature Foundation
135, 14th Main, 30th Cross,
Banashankari 2nd Stage,
Bengaluru – 560 070
Karnataka, India
TeleFax: +91-80-2671 6897
Email: amrita@ncf-india.org
Website: www.ncf-india.org

Citation

Gubbi, S., Menon, A.M., Suthar, S, & Poornesha, H.C. (2021) Variation in leopard density and abundance: Multi-year study in Cauvery Wildlife Sanctuary, Nature Conservation Foundation, Mysore and Holématthi Nature Foundation, Bengaluru, India.

Contents

Introduction	1
Study Area	1
Methodology	5
Results	8
Discussion	12
References	17
Appendices	22

Acknowledgements
We sincerely thank the Karnataka Forest Department for permissions to carry out the study in Cauvery Wildlife Sanctuary and all the support provided by them. We are grateful to Shri. Vasantha Reddy K.V., Dr.Ramesh Kumar and Dr. S. Ramesh, the former Deputy Conservator of Forests and Shri. H.C. Girish, the present Deputy Conservator of Forests for all the cooperation during our work.

We would like to acknowledge the support provided by all the Assistant Conservator of Forests and Range Forest Officers. All the Deputy Range Forest Officers, Forest Guards and Watchers have proved to be the greatest source of assistance and we are thankful to them.

Introduction

The leopard (*Panthera pardus*) is a geographically widespread member of the *Felidae* family, and occupies a broad ecological niche from rainforests in the tropics to open grasslands to deserts to islands (Stein *et al.* 2020). Due to their high tolerance for human pressure and catholic diet, they have adapted to human-dominated landscapes and around large metropolitan cities (Hayward *et al.* 2006; Athreya *et al.* 2013; Odden *et al*. 2014; Bhatia *et al.* 2013). This also makes them a highly conflict-prone species.

Out of the nine discrete populations or subspecies recognised by phylogenetic analysis of mitochondrial DNA sequences and polymorphic microsatellite loci, the one present in India is *Panthera pardus fusca* (Uphyrkina *et al.* 2001). Globally, the leopard falls under the 'Vulnerable' category as classified by the IUCN Red List of Threatened Species (Stein *et al.* 2020). At a national level, they are listed as a Schedule 1 species under the Wildlife Protection Act 1972 in India, which provides the highest level of protection.

In order to observe temporal changes in population sizes, along with baseline population estimates, systematic monitoring of the population during regular intervals needs to be carried out. Systematic long-term monitoring studies help identify spatial and temporal trends in population data (Yoccoz *et al.* 2001). Variables that contribute to the increasing or decreasing trend can be identified which will either help evaluate the impact of existing management practices or implement new and more effective management practices (Clutton-Brock & Sheldon 2010; Campbell *et al.* 2011; Caro 2011; Henschel & Ray 2015; Ramesh *et al.* 2017). Additionally, more detailed insight into population dynamics can be achieved through long-term monitoring of wildlife (Pelton & van Manen 1996). Even though there are a few population studies providing baseline information for leopards from within PAs, other forested and human dominated habitats (Harihar *et al.* 2009; Athreya *et al*. 2013; Borah *et al.* 2014; Gubbi *et al.* 2017a, 2019b, 2019c, 2020d, 2021a), there is little to no data on long-term monitoring of leopard populations over temporal scales.

Such long-term monitoring can also help in conservation management of leopards that are exposed to various threats that include habitat loss and fragmentation, retaliatory killing, vehicular collisions, poaching, depletion of prey and other unconventional threats (Gubbi *et al.* 2014a; Jacobson *et al*. 2016; Gubbi *et al.* 2017a, 2019a, 2021c).

This report provides the results of a long-term population monitoring study carried in Cauvery Wildlife Sanctuary (CWS) in southern Karnataka 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

Cauvery Wildlife Sanctuary (CWS), located at the confluence of the Eastern and Western Ghats, was declared a wildlife sanctuary in 1987 covering an area of 527 km^2, then expanded to 1027.5 km^2 in 2011 and furthermore to 1080.9 km^2 in 2019. It lies within three districts of Karnataka, namely, Ramanagara, Chamrajanagara and Mandya districts in Kanakapura,

Kollegala and Malavalli Taluk respectively. There are seven administrative ranges, which includes Halguru, Sangama, Mugguru, Kothanur, Hanur, Cowdalli and Gopinatham.

CWS, named after the river Cauvery flowing for 105 km from west to east through the protected area, is an integral part of the contiguous landscape which forms the confluence between the Eastern and Western Ghats. Apart from the river Cauvery, Arkavathy and Shimsha are important tributaries of Cauvery which are permanent water sources that flow through CWS. The northern boundary of CWS is connected with Bannerghatta National Park (BNP, 260.5 km^2) and in the south it connects to Malai Mahadeshwara Wildlife Sanctuary (MM Hills, 906.1 km^2), which further joins with Biligiri Rangaswamy Temple Tiger Reserve (574.8 km^2) and Sathyamangalam Tiger Reserve (BRT TR, 1411.6 km^2), forming a contiguous forest area of 4234 km^2 (Map 1). CWS is further connected by Reserved Forests in Tamil Nadu to North Cauvery Wildlife Sanctuary (523.1 km^2) also forming a part of this contiguous landscape.

It is typically characterised by woodland savanna, dry deciduous and riparian vegetation but also has thorny scrub, moist deciduous, bamboo forest and semi-evergreen vegetation (Reddy 2015; Gubbi *et al.* 2017b). Map 2 depicts the vegetation structure and other physical features of CWS. The altitude of the CWS ranges between 254 and 1514 m above mean sea level. Annually, the average rainfall of CWS varies between 750-800 mm. The temperature ranges between 15 to 42°C (Reddy 2015).

There are 35 village enclosures within the sanctuary and 72 villages within a two km radius around the sanctuary (Reddy 2015; MoEFCC 2017). The human density within the park is about 18.3 individuals per km^2. The people living in the region mostly belong to the Gounder, Lambani, and Soliga communities (Reddy 2015). They are largely involved in rainfed agriculture and animal husbandry; and they are dependent on the forest for fuel wood, fodder and other non-timber forest products.

Location coordinates
Latitude: 11°56'55.45"N to 12°24'36.70"N
Longitude: 77° 9'35.13"E to 77°46'40.60"E

Figure 1. Cauvery Wildlife Sanctuary is characterised by dry deciduous and riparian vegetation but also have thorny scrub, moist deciduous, bamboo forest and evergreen shola vegetation

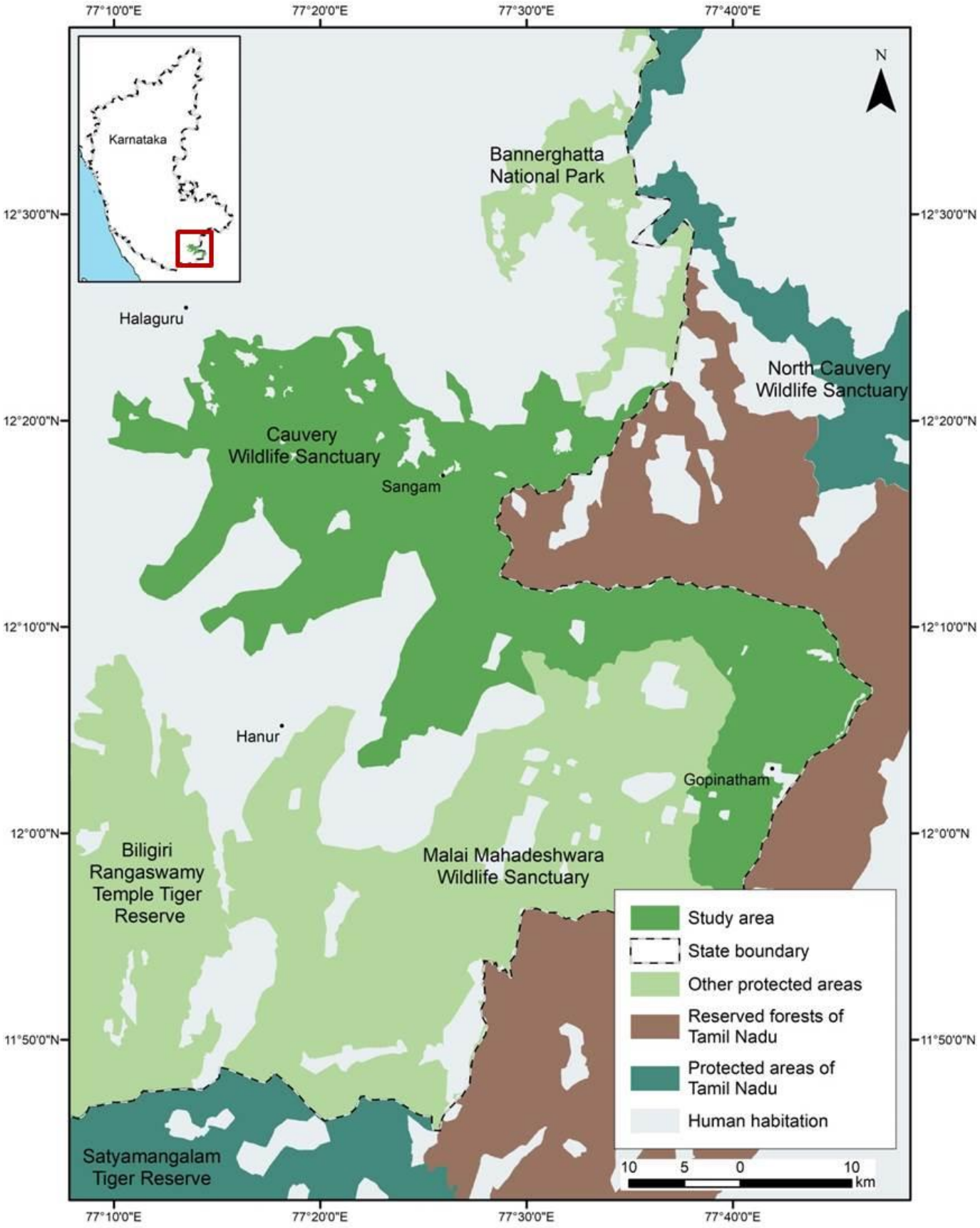
Flora

The various forest and vegetation types in CWS includes southern tropical dry deciduous, woodland savanna, moist deciduous, mixed deciduous evergreen shola and riverine habitat. Some common dry deciduous species such as *Albizzia amara, Acacia leucophloea, Choroxylon swietenia, Azadirachta indica, Tamarindus indica, Emblica officinalis, Anogeissus latifolia, Sapindus emarginatus, Wrightia tinctoria, Terminalia chebula, Zizyphus xylopyrus* are present at lower elevations. *Hardwickia binata* occurs in areas with elevation below 762 m. Moist deciduous forests are usually found above 900 m in areas of Gopinatham range and some common species are *Pterocarpus marsupium*, *Tectona grandis*, *Mangifera indica*. *Dalbergia latifolia, Adina cordifolia, Vitex altissima, Anogeissus latifolia* and *Bridelia retusa*. The bamboo forests present in certain ranges are composed of two main species i.e *Dendrocalamus strictus* and *Bambusa arundinacea.*The riverine vegetation is dominated by *Terminalia arjuna, Tamarindus indica, Pongamia glabra, Vitex altissima, Eugenia jamboolina, Mytragaina spp.* and a few species of Ficus. Sunil *et al.* (2019) suggests that *Terminalia arjuna* is a key stone species of riparian habitats in south India as higher native plant diversity and soil carbon content was observed under its canopy as opposed to areas devoid of *T. arjuna* where the dominance of non-native species was evident. The evergreen shola forests cover only about 3 per cent of the sanctuary. The invasive *Lantana camara* and *Eupatorium* are present in some parts of the sanctuary.

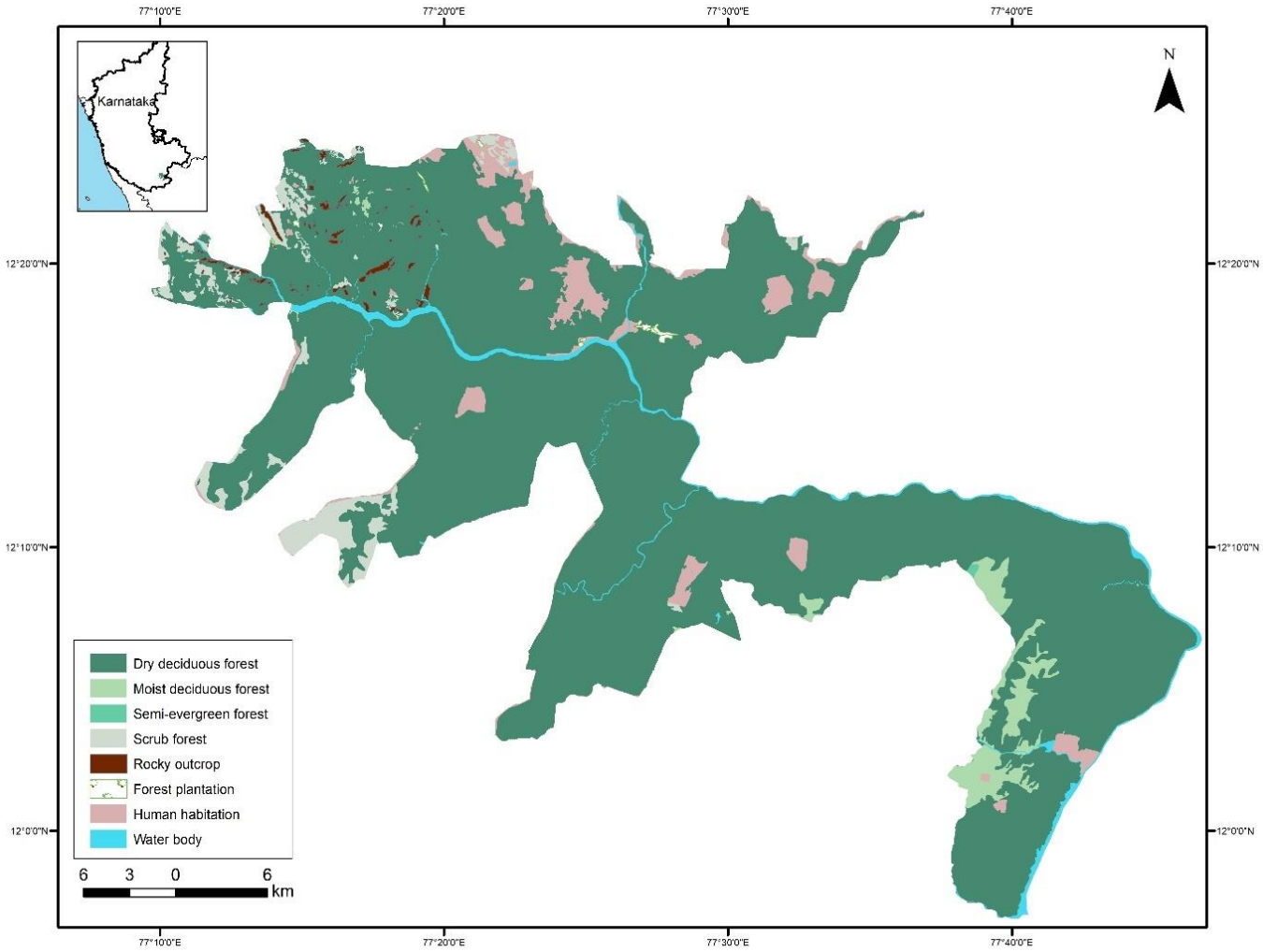
Fauna

CWS harbours large mammals including tiger (*Panthera tigris*), leopard (*Panthera pardus fusca*), dhole (*Cuon alpinus*), jackal (*Canis aureus*), sloth bear (*Melursus ursinus*), elephant (*Elephas maximus*), gaur (*Bos gaurus*), wild pig (*Sus scrofa*), sambar (*Rusa unicolor*), chital (*Axis axis*), barking deer (*Muntiacus muntjak*), 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*), the endangered Indian pangolin (*Manis crassicaudata*) and the endemic Madras tree shrew (*Anathana ellioti*) (Reddy 2015; Gubbi *et al.* 2017a). Jungle cat (*Felis chaus*), rusty spotted cat (*Prionailurus rubiginosus*), small Indian civet (*Viverricula indica*), common palm civet (*Paradoxurus hermaphrodites*), Indian grey mongoose (*Herpestes edwardsii*), ruddy mongoose (*Herpestes smithii*), smooth-coated otter (*Lutrogale perspicillata*) are some of the smaller carnivores found in CWS (Gubbi *et al.* 2017a). The grizzled giant squirrel (*Ratufa macroura*), which is endemic to southern India and Sri Lanka, is found in the riparian forests of CWS and is known to be the northern most population (Nagulu *et al.* 2000; Baskaran *et al.*2011; Arya 2018). The Ratel (*Mellivora capensis*) was captured for the first time in CWS during a camera trap survey in 2014 (Gubbi *et al.* 2014b). Additionally, the Indian grey wolf was photo-captured for the first time in CWS (Gubbi *et al.* 2020b), establishing an extent of its distribution in southern India.

CWS has 58 species of freshwater fishes, of which eight are endemic to the Cauvery river system namely, Arulius barb (*Dawkinsia arulius)*, *Dawkinsia rubrotinctus*, Red Canarese barb *(Hypselobarbus dubius*), Korhi barb (*Hypselobarbus micropogon),* Kantaka barb(*Osteochilichthys brevidorsalis*), Pigmouth carp (*Labeo kontius*), Hump-backed mahseer (*Tor remadevi*) and Nilgiri mystus (*Hemibagrus punctatus*) (Pinder & Raghavan 2013; Sreenivasan *et al.* 2021).



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



Map 2. Major vegetation types and other physical features in Cauvery Wildlife Sanctuary

The marsh crocodile (*Crocodylus palustris*) is found along the river Cauvery (Pinder & Raghavan 2013). Saw-scaled viper (*Echiscarinatus*), Indian cobra (*Naja naja*), Russel's viper (*Daboia russelii*), Indian rock python (*Python molurus*), rat snake (*Ptyas mucosa*) and common sand boa (*Eryx conicus*) are some of the snakes found in CWS (Nagulu *et al.* 2000; Reddy 2015).

CWS supports more than 280 species of birds (Reddy 2015). The White-rumped vulture (*Gyps bengalensis*), Indian vulture (*Gyps indicus*), Red-headed Vulture (*Sarcogyps calvus)* are critically endangered (BirdLife 2021). Some rare birds that occur in CWS include the Nilgiri wood-pigeon (*Columba elphinstonii*), greater spotted eagle (*Clanga clanga*), white-naped tit (*Parus nuchalis*), pied-crested tit (*Parus nuchalis)* and yellow-throated bulbul (*Pycnonotus xantholaemus*) (Sadananda *et al.* 2010; BirdLife 2021). The Cauvery river basin is also important wintering area for the vulnerable Greater Spotted Eagle (*Aquila clanga*) (Shivprakash *et al.* 2006).

Methodology

Camera trapping

The study area was divided into five blocks in the year 2014 and 2016; and into seven blocks for the 2018 and 2020 sessions. The survey area increased from 1027.5 km^2 in 2014 to

1080.9 km^2 in 2016, 2018 and 2020. Even though the PA size was increased only in 2019, the adjoining forested areas were surveyed in 2016 and 2018 as well. In order to ensure high capture probability of leopards, the locations of the camera traps were identified before the initial deployment based on indirect evidences of leopard presence i.e. scat, scrape marks, and pugmarks. Panthera V4 and V6 motion detection cameras were deployed on either side of animal trails or forest roads in order to ensure that both right and left flanks of the animal were photo-captured. The camera trap was secured using python cables to an appropriate support at a height of ~ 40 cm from the ground, which is considered as the optimal height to capture the flanks of a leopard clearly.

The camera trap exercise was carried out every alternate year from 2014 to 2020. The camera traps were deployed for 55 days in 2014, 80 days in 2016 and 112 days in 2018 and 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.

The camera traps were operational throughout the day and night over 24 hours. They were periodically checked every 2-3 days to download photographs, replace batteries and ensure that they were working properly. An automated classifier built on the Python programming language (version 3.6) was utilised to classify and segregate the downloaded photos into folders based on the species (Rampi *et al.* Unpublished). The classifier was trained to identify species from this region. The folders with images were then validated manually to make sure they were categorised correctly and name of the species was written to the image metadata using the software Digikam (Version 5.8.0; Gilles *et al.* 2018). The unique combination of

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

Year	Survey period	No. of locations	Occasions per block	Camera trapping effort
2014	04-Jan-14 to 04-Mar-14	332	11	3,648
2016	22-Dec-15 to 19-Mar-16	373	16	5,951
2018	12-Aug-18 to 26-Dec-18	472	16	7,490
2020	11-Mar-20 to 26-Jul-20	490	16	7,781

the camera trap location and camera ID provided the date, time and geographical coordinates for each photo-captured species. The leopard images were extracted from the categorised data and individuals were matched based on the rosette patterns on their respective flanks using Wild-ID (Bolger *et al.* 2011). Images that did not show the flanks or part of the flank clearly were not used during this identification process. The flanks, i.e. either right or left, with maximum number of unique individuals were used for analysis.

Density and abundance estimation

SECR package (version 4.2), which is based on Spatially Explicit Capture-Recapture

methodology, was used as the statistical analysis tool to estimate the abundance and density of leopards within the study area (Efford 2018). This was carried out on RStudio (version 1.1.463). The input files used by the SECR analysis include 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 which is represented as 1 and 0 respectively. The mask layer is composed of a shapefile which holds the spatial information about suitable habitat (Efford 2018). A buffer was generated around the camera traps using the 'suggest.buffer' function in the SECR package. The capture history matrix has unique entries of an identified individual, its associated location and sampling occasion. The capture probabilities are then estimated by the SECR package using the spatial information in the input files and models are fitted by maximising the likelihood (Borchers and Efford 2008). The model with the best estimates of density and abundance are selected based on the Akaike's Information Criterion (AIC) for likelihood-based models. 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 total number of male/female detections by the number of male/female individuals identified. The number of years an individual was detected was also recorded (Appendix-4).

Relative Abundance Index calculation

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).

Firstly, different mammal species were segregated into separate folders. An event for a species was extracted by matching photographs from cameras placed on either side of the trail using the timestamp in the image metadata. This process was run using a VBA (Visual Basic for Applications) script in excel. The number of individual events for each species was extracted separately. In the case of livestock, cow, buffalo, donkey and domestic pig were grouped as large livestock while sheep and goat were grouped as small livestock. A threshold time interval (or event duration) was predefined considering 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 2,588 leopard images between 2014-2020 and a total of 191 adult individual leopards were identified. The number of individuals photo-captured in each survey year is tabulated in Table 2. Of the identified individuals, 94 were female and 78 were male. The sex of 19 individuals could not be determined. A total of 12 cubs and 10 subadults were also identified. The low capture probabilities of cubs and the transient nature of subadults make them unsuitable to be used for analysis (Karanth 1995; Grey *et al.* 2013). Accounting for individual heterogeneity, individuals were segregated into two groups with different detection probabilities.

The SECR analysis provided a mean leopard abundance estimates of 59.65 ± 5.51 in 2014, 53.05 ± 1.95 in 2016, 77.22 ± 2.35 in 2018 and 96.94 ± 5 in 2020. Density estimates of leopards per 100 km^2 were 5.29 ± 0.84 in 2014, 4.69 ± 0.67 in 2016, 6.85 ± 0.81 in 2018 and 8.54 ± 0.97 in 2020. The σ values and ranges for all estimated values are given in Table 3. Figure2 and Figure 3 show scatter plots of the population density estimates and abundance in CWS respectively. The pixel densities of leopards for each survey year are depicted in Figure 4.

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

Year	Number of images	Number of individuals	Number of females, males	Number of cubs, subadults
2014	374	43	26, 17	7, 0
2016	461	50	22, 23	0, 0
2018	865	73	38, 32	2, 2
2020	888	87	49, 31	3, 8

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

Year	*N* (SE)	*N* Range	*D* (SE)	*D* Range	σ (SE) in metres	σ Range
2014	59.65 (5.51)	51.88-74.34	5.29 (0.84)	3.88-7.22	1504.93 (325.18)	990.11-2287.43
2016	53.05 (1.95)	50.97-59.6	4.69 (0.67)	3.56-6.2	2313.88 (539.66)	1473.81-3632.79
2018	77.22 (2.35)	74.52-84.72	6.85 (0.81)	5.44-8.62	3234.08 (217.01)	2835.95-3688.12
2020	96.94 (5.00)	90.91-112.23	8.54 (0.97)	6.83-10.66	2242.7 (245.35)	1809.49-2779.68

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)

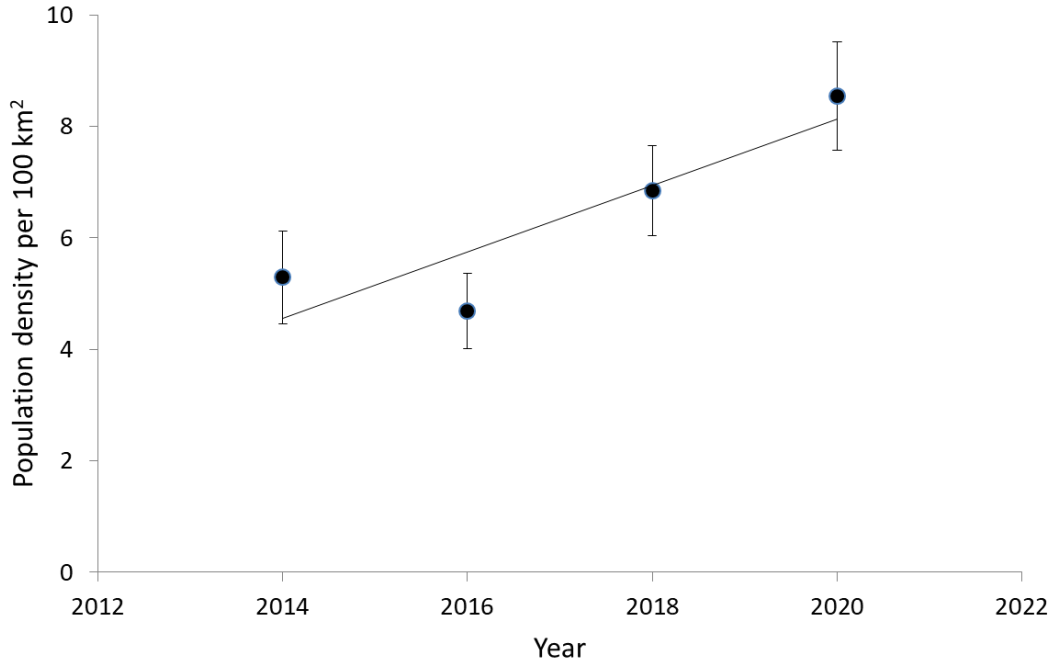


Figure 2. Trend of leopard population density estimate (y-axis) over the survey period (x-axis, in years) with error bars in Cauvery Wildlife Sanctuary

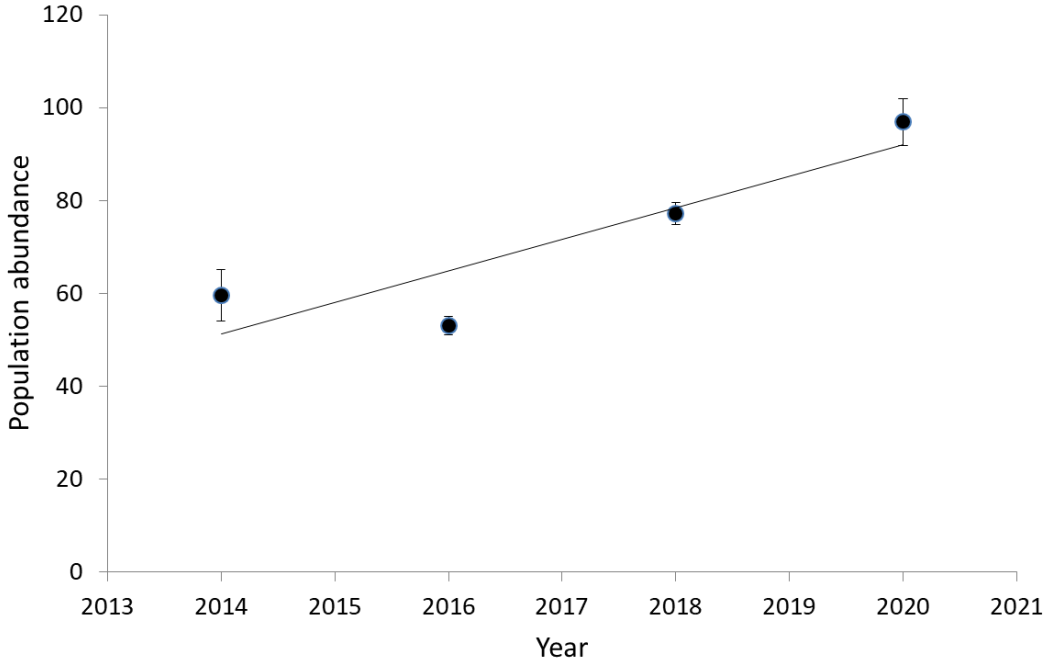


Figure 3. Trend of leopard population abundance estimate (y-axis) over the survey period (x-axis, in years) with error bars in Cauvery Wildlife Sanctuary

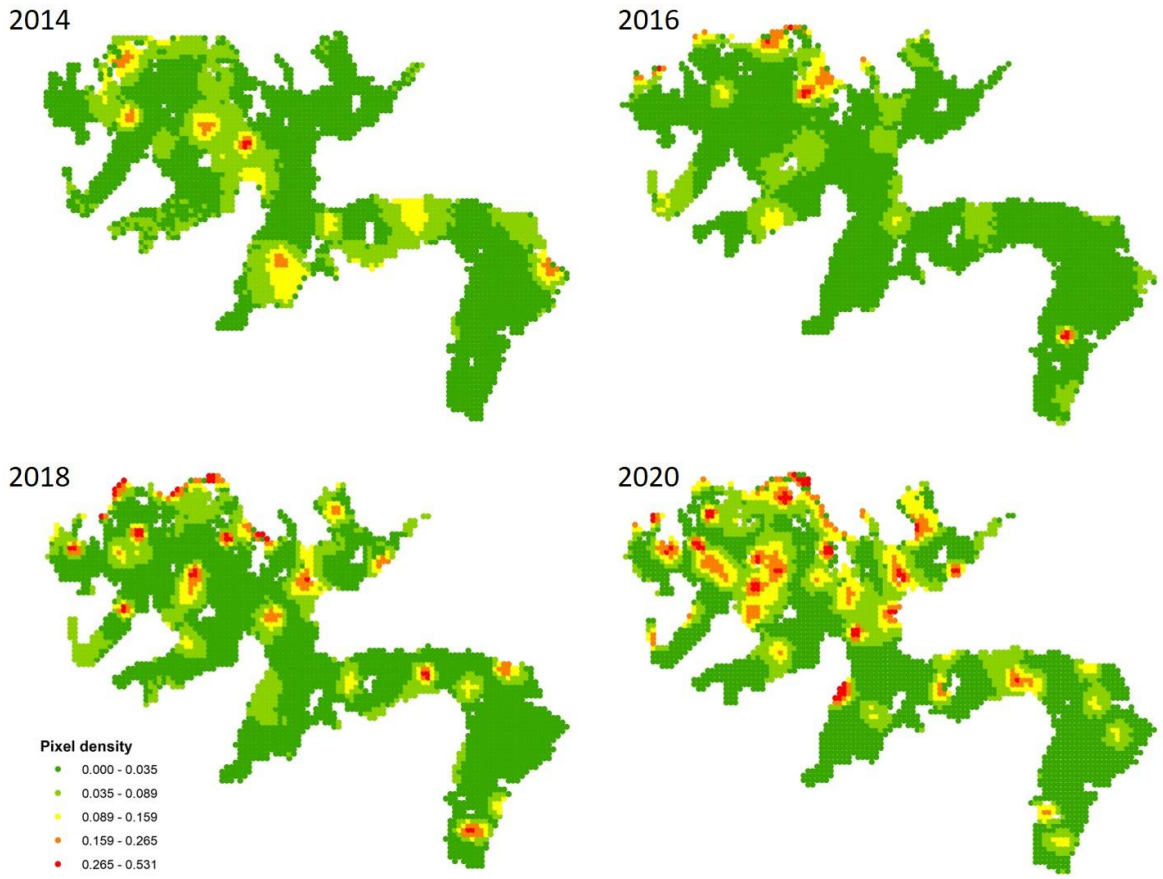


Figure 4. Pixel densities of leopards in Cauvery Wildlife Sanctuary during each of the survey years.

Detection rates

From the total number of individuals identified, the number of females is more than the number of males (Table 2, Figure 5). The number of detections and detection rate for males and females is given in Table 4. The mean of male and female detection rate is 6.68 and 3.24 respectively. The median for male and female detection rate was calculated as 6.94 and 3.19 respectively (Figure 6).

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

Year	Detections[#] (males)	Detection rate* (males)	Detections (females)	Detection rate (females)
2014	79	4.65	75	2.88
2016	151	6.57	66	3
2018	262	8.19	129	3.39
2020	227	7.32	181	3.69

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

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

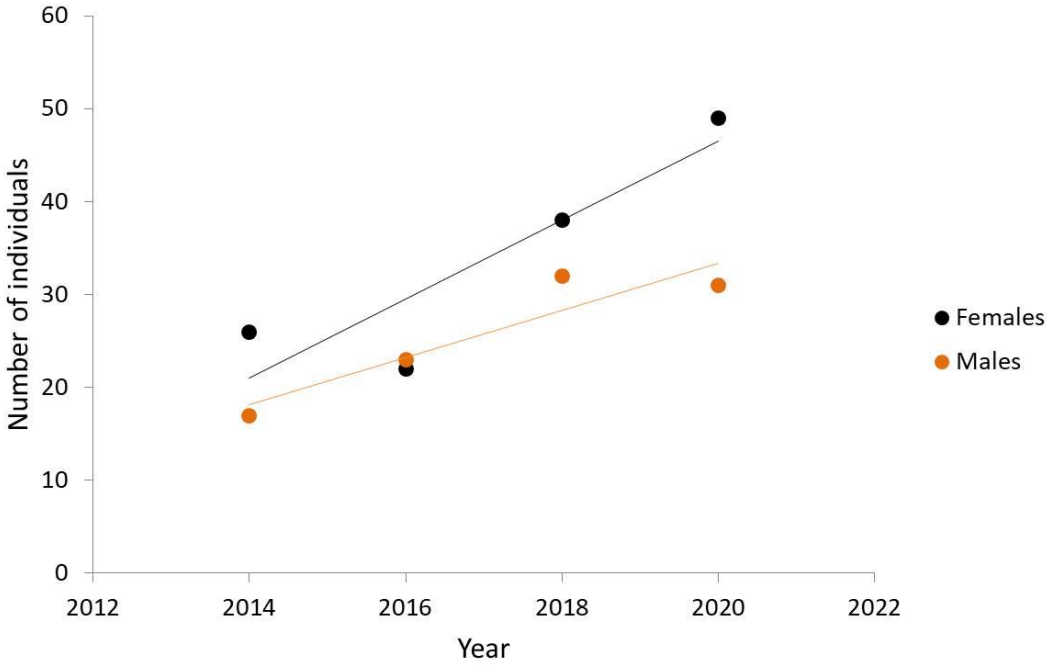


Figure 5. Number of male and female leopards (y-axis) identified in Cauvery Wildlife Sanctuary for each survey year (x-axis).

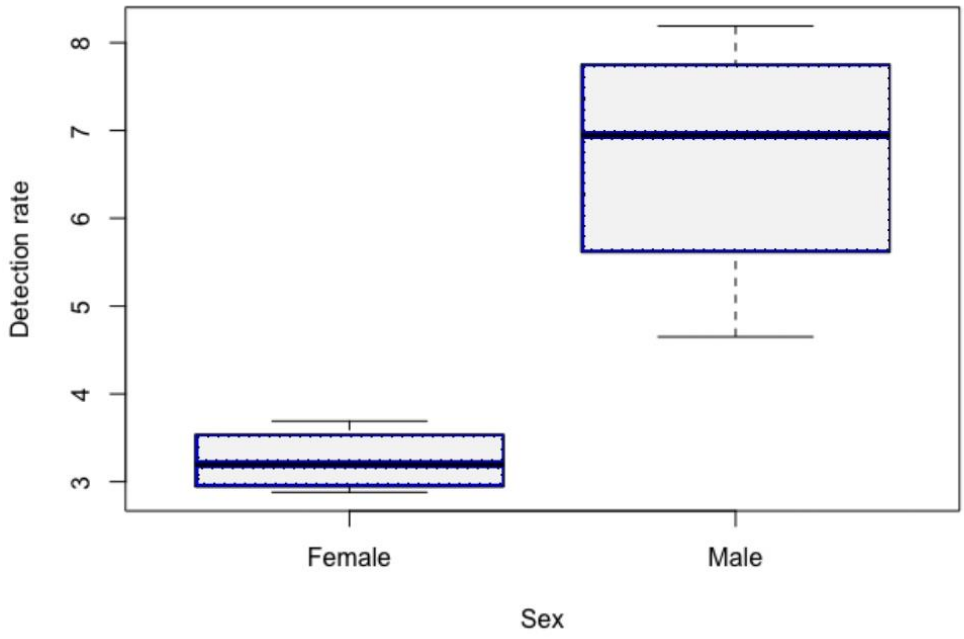


Figure 6. Detection rate of female and male leopards in Cauvery Wildlife Sanctuary

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. Domestic prey species included all livestock and domestic dogs (Table 6). Wild prey species were categorised 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 34 wild mammalian species including the leopard were captured in camera traps at CWS during the study period. All the mammal species apart from prey species and leopards are listed in Table 7Table 7 and photographs are attached as Appendix-1.

Tiger individuals were also identified from the images captured. From 46 images, 6 adults were identified during 2014-2020.

Discussion

Abundance and density variation

The abundance estimates of leopards in CWS is one of the highest reported from PAs in the country. Population estimation in PAs such as Manas National Park (500 km^2) in Assam resulted in an abundance of 47 individuals while in Achanakmar Tiger Reserve (914 km^2) in Chhattisgarh estimated about 30 individuals only (Borah *et al.* 2014; Mandal *et al.* 2017). The density estimates of CWS are similar to adjacent PAs such as MM Hills where the highest density estimates was 7.62 individuals/100km^2 and BNP where the density estimate was 7.96 individuals/100km^2 (Gubbi *et al.* 2019b; 2021b). The densities are also comparable to other leopard habitats in the world like Western shores of iSimangaliso Wetland Park (381 km^2) in the Maputaland Conservation Unit, South Africa which reported a density of 8.4 ± 1.03 leopards/100 km^2 (Ramesh *et al.* 2017) and Huai Kha Khaeng Wildlife Sanctuary (2,800 km^2) in Thailand which had a leopard density of 7.88, 5.21 and 4.86 leopards/100 km^2 over three separate sessions (Simcharoen & Duangchantrasiri 2008).

The abundance estimate shows an overall increasing trend spanning from 2014 to 2020 (Figure 2 and Figure 3). The density estimates show quite an increase from 4.69 to 8.54 leopards per 100 km^2 from 2016 to 2018. This could be attributed to the increase in protection and management. The improvement in forest road infrastructure and staffing has made patrolling easier which might have an overall impact on the protection of habitat and wildlife (Gubbi *et al.* 2017b). The higher abundance and density estimates in 2018 and 2020 could also be due to translocation of individuals from human-leopard conflict areas to CWS. Between 2009 and 2016, 24 leopards were captured and translocated to CWS in response to human-leopard conflict (Gubbi et al. 2020a). Additionally, there might be some temporal variation in detection due to heterogeneity in individuals' behaviour (Harmsen *et al.* 2017) or movement of individuals between the neighbouring PAs such as MM Hills and BNP (Gubbi *et al.* 2019b, 2021b). Figure 4 shows the spatial variation in pixel densities over the four years and this could be due to factors such as prey availability, improvement of habitat quality and decrease in level of disturbance. The distribution of individuals seems to spread throughout CWS in 2020 as opposed to isolated pockets in parts of the wildlife sanctuary.

Table 5. Results of the Relative Abundance Index (RAI) and Standard Error (in brackets) calculated for leopards' natural and domestic prey in Cauvery 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	8.69 (0.01)	6.39 (0.002)	6.67 (0.002)	7.07 (0.002)
2	Blackbuck (*Antilope cervicapra*)	I	Least Concern	-	-	0.01 (0.000)	-
3	Chital (*Axis axis*)	III	Least Concern	14.50 (0.007)	8.59 (0.004))	7.40 (0.002)	9.84 (0.002)
4	Barking deer (*Muntiacus vaginalis*)	III	Least Concern	0.88 (0.002)	0.47 (0.0004)	0.57 (0.0004)	0.56 (0.0003)
5	Four-horned antelope (*Tetracerus quadricornis*)	I	Vulnerable	7.65 (0.007)	5.21 (0.002)	3.68 (0.0009)	4.21 (0.0008)
6	Indian Chevrotain (*Moschiola indica*)	I	Least Concern	0.25 (0.001)	0.13 (0.0002)	0.09 (0.0001)	0.12 (0.0001)
7	Wild pig (*Sus scrofa*)	III	Least Concern	8.94 (0.002)	11.07 (0.002)	9.53 (0.001)	14.63 (0.002)
8	Black-naped hare (*Lepus nigricollis*)	IV	Least Concern	59.68 (0.011)	61.86 (0.009)	34.33 (0.004)	32.65 (0.004)
9	Porcupine (*Hystrix indica*)	IV	Least Concern	3.92 (0.002)	10.44 (0.002)	12.55 (0.002)	10.81 (0.002)
10	Indian pangolin (*Manis crassicaudata*)	I	Endangered	-	0.03 (0.0001)	0.01 (0.000)	0.01 (0.000)
11	Bonnet macaque (*Macaca radiata*)	II	Least Concern	14.12 (0.009)	3.56 (0.001)	4.07 (0.001)	4.39 (0.001)
12	Tufted grey langur (*Semnopithecus priam*)	II	Near Threatened	5.51 (0.003)	2.99 (0.001)	3.35 (0.0013)	4.91 (0.001)
	Domestic prey						
1	Large livestock	NA	NA	51.40 (0.035)	57.79 (0.017)	137.85 (0.023)	90.87 (0.014)
2	Small livestock	NA	NA	23.46 (0.02)	30.43 (0.01)	31.26 (0008)	25.47 (0.005)
3	Domestic dog	NA	NA	16.64 (0.008)	13.07 (0.005)	18.88 (0.005)	17.22 (0.005)

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

Year	Domestic prey (SE)	Large wild prey (SE)	Small wild prey (SE)	Wild prey (SE)
2014	90.59 (0.05)	40.65 (0.03)	83.47 (0.02)	124.12 (0.04)
2016	93.51 (0.03)	31.73 (0.006)	79.01 (0.01)	110.74 (0.01)
2018	133.44 (0.03)	21.19 (0.003)	54.41 (0.005)	75.61 (0.006)
2020	191.7 (0.03)	44.72 (0.004)	52.89 (0.005)	97.61 (0.007)

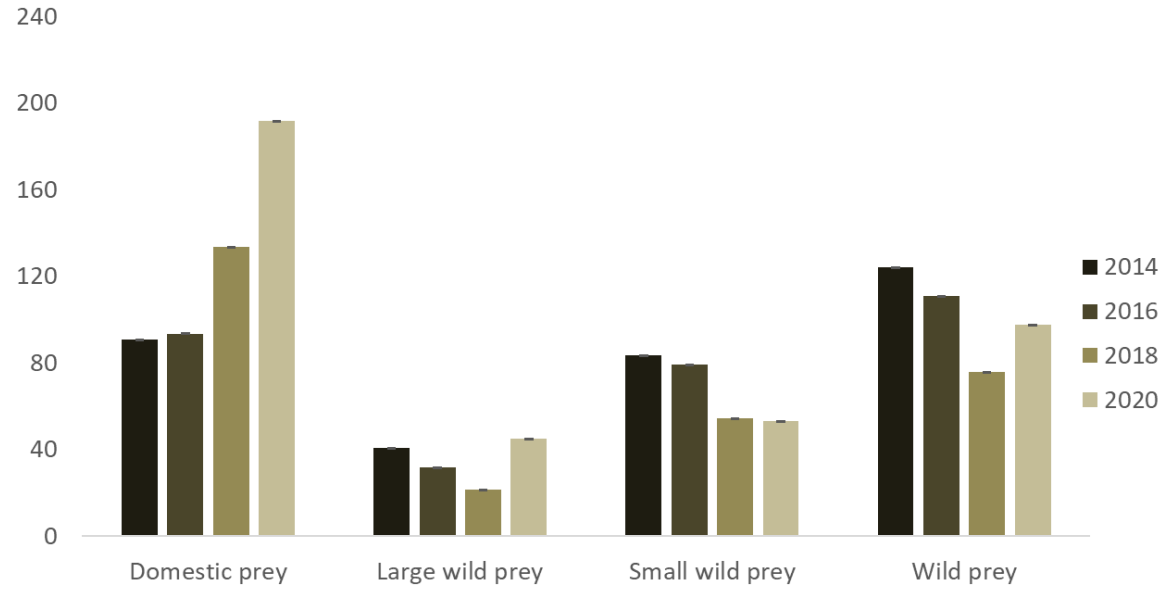


Figure 7. The Relative Abundance Index of domestic prey, large wild prey, small wild prey and total wild prey for each survey year.

Table 7. Other mammal species photo-captured in camera traps in Cauvery 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	Indian grey wolf (*Canis lupus pallipes*)	I	Least Concern
6	Golden jackal (*Canis aureus*)	II	Least Concern
7	Indian fox (*Vulpes bengalensis*)	II	Least Concern
8	Sloth bear (*Melursus ursinus*)	I	Vulnerable
9	Elephant (*Elephas maximus*)	I	Endangered
10	Gaur (*Bos gaurus*)	I	Vulnerable
11	Ratel (*Mellivora capensis*)	I	Least Concern
12	Grizzled giant squirrel (*Ratufa macroura*)	I	Near Threatened
13	Smooth-coated otter (*Lutrogale perspicillata*)	II	Vulnerable
14	Grey mongoose (*Herpestes edwardsii*)	II	Least Concern
15	Ruddy mongoose (*Herpestes smithii*)	II	Least Concern
16	Common palm civet (*Paradoxurus hermaphroditus*)	II	Least Concern
17	Small Indian civet (*Viverricula indica*)	II	Least Concern
18	Madras tree shrew (*Anathana ellioti*)	II	Least Concern
19	Indian gerbil (*Tatera indica*)	IV	Least Concern
20	Fulvous fruit bat (*Rousettus leschenaultii*)	V	Least Concern
21	Rufous horseshoe bat (*Rhinolophus rouxii*)	V	Least Concern

Population turnover

The turnover of new individuals is higher in CWS than the adjoining MM Hills (Gubbi *et al.* 2021b). The baseline population estimation was 46 individuals to which 36 new individual were added in 2016, 61 in 2018 and 48 in 2020. As mentioned before, the new individuals could also be leopards that are translocated from other areas. Within CWS, only three individuals were captured all four years (Figure 8), and 10 were captured during three of the survey years (Appendix-4). Of the 43 captured in two survey years, 29 were common between 2018 and 2020. Since the survey was conducted every alternate year, if individuals were captured two consecutive surveys, we could assume that they could be residents having spent at least three years in the area (Harmsen *et al.* 2017). This information could help establish home ranges for a few resident individuals.

A total of 56 individuals were recorded in at least two survey years and 31of them were identified as females. Even though the number of females were higher than males (Table 2, Figure 5), the detection rates of females were lower compared to males (Table 4, Figure 6). This could be an indication of behavioural differences in female and male movement. Females might be denning or may avoid movement on trails to avoid provoking infanticide of their dependent cubs (Harmsen *et al*. 2017). More female turnover is an indicator of healthy leopard populations as it suggests that habitat quality is good enough to maintain territory and availability of prey (Nowell & Jackson 1996; Kandel *et al.* 2020). The higher number of females corroborates with data in other PAs such as MM Hills and BRT TR (Gubbi *et al.* 2019c, 2021b). The turnover of male individuals has an impact of the reproductive output of the population (Balme *et al.* 2013).

The photo-captures of 12 cubs and 10 subadults suggest the presence of breeding females as well. Breeding females play a crucial role in the population stability of large carnivores (Nowell & Jackson 1996; Balme *et al.* 2013; Kandel *et al.* 2020). Two subadults and one cub were captured in 2018 and 2020 suggesting survival of offspring. More information is required to understand survival of cubs but camera trap surveys might not be ideal due to their low detection probabilities (Karanth 1995; Grey *et al.* 2013; Harmsen *et al*. 2017).

Variables affecting leopard populations

Temporal variation could be attributed to behavioural differences such as females denning or protecting young ones, individuals following prey species or dispersing individuals (Harmsen *et al.* 2017). CWS has 24 common individuals with MM Hills and two individuals which have been recorded in BNP. Movement of individuals within the landscape could contribute to temporal variation in abundance and density in the sanctuary. One of the individuals common to CWS and BNP moved nearly 16 km (shortest distance between the two farthest camera trapped locations) within two months (December 2018 to February 2019) (Gubbi *et al.* 2019b). This highlights the importance of maintaining connectivity within the landscape. The area surrounding the BNP connecting Cauvery Wildlife Sanctuary, which acts as a wildlife corridor, is composed of degraded native forest, agricultural land and plantations (Rashmi & Lele 2010; Adhikari *et al.* 2014).

Habitat fragmentation caused by changing land-use practices and expansion into forest area can prove detrimental to leopard and their prey populations (Fahrig 2003; Jacobson *et al.* 2016). Movement of individuals between fragmented patches can result in conflict situation

leading to their capture or persecution (Athreya *et al.* 2015; Gubbi *et al.* 2020a). Hence, ensuring that the forest connectivity is maintained is very crucial both for people and wildlife.

Leopards' space use and density depends on the proportion of natural habitats and availability of large wild prey (Dickman & Marker 2005; Khorozyan *et al.* 2008; Ramesh *et al.* 2017; Gubbi *et al.* 2020c). Gubbi *et al.* (2017b) showed a general declining trend in forest cover in this area previously between 2000 and 2014. These areas which have been initially under the pressure of encroachment and extractive activities have been monitored and managed more efficiently after the expansion of the PA in 2011.

Overall wild prey RAI however does not show any drastic increase or decrease (Figure 7). Domestic prey RAI shows a steady increase from 2014 to 2020. The increase in livestock grazing can have a significant impact on the natural vegetation which in turn affects natural wild prey populations (Khan *et al.* 1996; WallisDeVries 1998; Madhusudan 2004). The RAI of large and small wild prey seems to go down in 2018 which could be due to reduced movement during monsoons and post monsoons (August to December), which was the sampling period, due to widespread fodder availability. Prey population dynamics and factors that contribute to their decline should be studied in depth to implement effective strategies to manage dependent predator populations (Hayward *et al.* 2006; Athreya *et al.* 2013). Gubbi *et al.* (2017b) showed the overlap of livestock presence and forest cover decline. Additional to the above mentioned variables, poaching can seriously impact prey species densities (Madhusudan & Karanth 2002). A temporal analysis of forest offence cases of prey poaching could help analyse the trends.

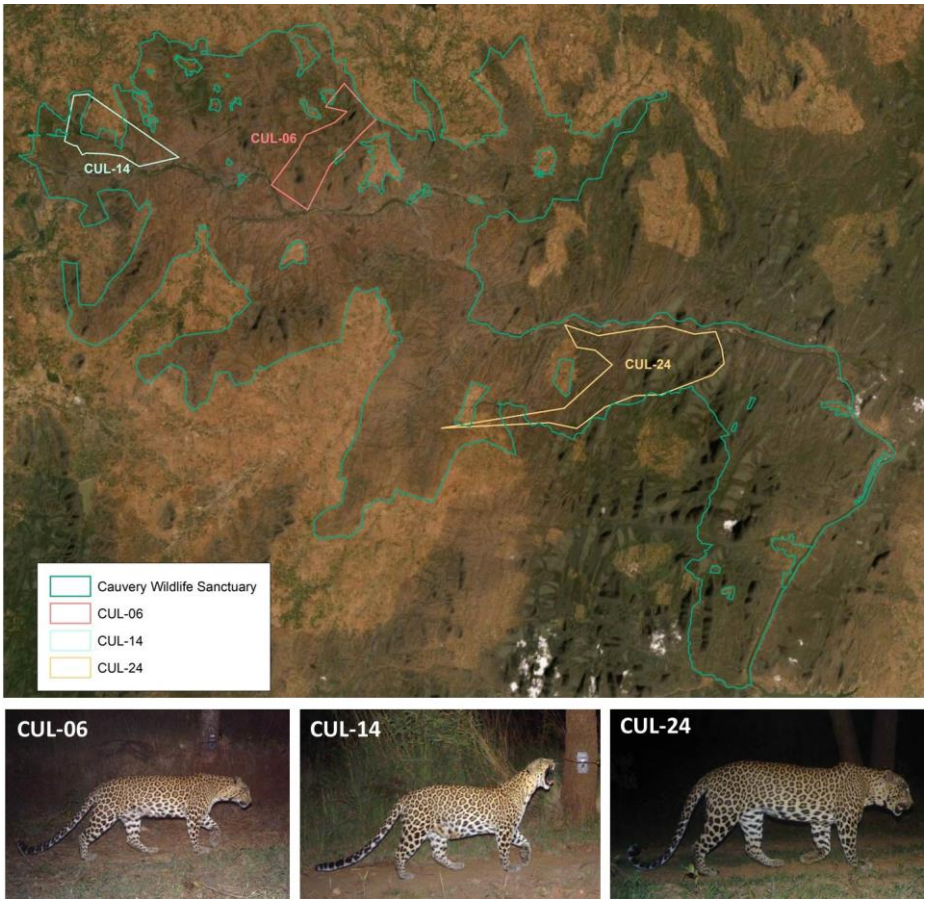


Figure 8. Polygon formed with all capture locations from 2014 to 2020 showing potential home range of CUL-06 (female; gravid), CUL-14 (female) and CUL-24 (male)

Other fauna

Apart from leopards and their prey species, CWS is part of a landscape that is of utmost importance for the conservation of species such as elephants and tigers (Gubbi *et al.* 2017b). Additionally, we have recorded the first photographic evidence of species like ratel and the Indian grey wolf (Gubbi *et al.* 2014b, 2020b), establishing an extent of their distribution in southern India.

Conclusion

Long term monitoring of leopard populations is difficult but extremely important to understand for drawing up suitable management strategies. The status of their population can highlight fundamental issues in the management and protection of their habitats and prey populations. Some habitats such as tropical evergreen forests often get more conservation attention as opposed to other lesser known habitats such as woodland savannah and scrub forests. Leopards are found in a wide variety of habitats and thus Gubbi *et al.* (2020c) argues that leopards can be used as an indicator to prioritise habitats for conservation such as scrub, rocky outcrops and woodland savannah which are usually neglected.

References

Adhikari, S., Southworth, J., & Nagendra, H. (2014). Understanding forest loss and recovery: a spatiotemporal analysis of land change in and around Bannerghatta National Park, India. *Journal of Land Use Science*, *10*(4), 402-424. https://doi.org/10.1080/1747423X.2014.920425

Arya, U. (2018) *Ecology of Grizzled Giant Squirrel R. macroura in Cauvery Wildlife Sanctuary, Karnataka, Southern India* (Master's thesis, India Institute of Science Education and Research, Pune, India). Retrieved from http://dr.iiserpune.ac.in:8080/xmlui/bitstream/handle/123456789/1006/THESIS_upendra_arya.PDF?sequence=1&isAllowed=y

Athreya, V., Odden, M., Linnell, J. D., Krishnaswamy, J., & Karanth, U. (2013). Big cats in our backyards: persistence of large carnivores in a human dominated landscape in India. *PloS one*, *8*(3), e57872. https://doi.org/10.1371/journal.pone.0057872

Athreya, V., Srivathsa, A., Puri, M., Karanth, K. K., Kumar, N. S., & Karanth, K. U. (2015). Spotted in the news: using media reports to examine leopard distribution, depredation, and management practices outside protected areas in Southern India. *PLoS One*, *10*(11), e0142647. https://doi.org/10.1371/journal.pone.0142647

Balme, G. A., Batchelor, A., de Woronin Britz, N., Seymour, G., Grover, M., Hes, L., Macdonald, D.W., & Hunter, L. T. (2013). Reproductive success of female leopards P anthera pardus: the importance of top-down processes. *Mammal Review*, *43*(3), 221-237. doi:10.1111/j.1365-2907.2012.00219.x

Baskaran, N., Senthilkumar, K., & Saravanan, M. (2011). A new site record of the Grizzled Giant Squirrel Ratufa macroura (Pennant, 1769) in the Hosur forest division, Eastern Ghats, India and its conservation significance. *Journal of Threatened Taxa*, 1837-1841.

Bhatia, S., Athreya, V., Grenyer, R., & Macdonald, D. W. (2013). Understanding the role of representations of human–leopard conflict in Mumbai through media-content analysis. *Conservation Biology*, *27*(3), 588-594. doi: 10.1111/cobi.12037

BirdLife International (2021) Important Bird Areas factsheet: Cauvery Wildlife Sanctuary. Downloaded from http://www.birdlife.org on 06 April 2021.

Bolger, D. T., Vance, B., Morrison, T. A., & Farid, H. (2011). Wild-ID user guide: pattern extraction and matching software for computer-assisted photographic mark recapture analysis. Dartmouth College, Hanover, United States of America.

Borah, J., Sharma, T., Das, D., Rabha, N., Kakati, N., Basumatary, A., & Vattakaven, J. (2014). Abundance and density estimates for common leopard *Panthera pardus* and clouded leopard *Neofelis nebulosa* in Manas National Park, Assam, India. *Oryx*, *48*(1), 149-155. doi:10.1017/S0030605312000373

Borchers, D. L., & Efford, M. G. (2008). Spatially explicit maximum likelihood methods for capture–recapture studies. *Biometrics*, *64*(2), 377-385. doi: 10.1111/j.1541-0420.2007.00927.x

Campbell, G., Kuehl, H., Diarrassouba, A., N'Goran, P. K., & Boesch, C. (2011). Long-term research sites as refugia for threatened and over-harvested species. *Biology letters*, *7*(5), 723-726. doi:10.1098/rsbl.2011.0155

Caro, T. (2011). On the merits and feasibility of wildlife monitoring for conservation: a case study from Katavi National Park, Tanzania. *African Journal of Ecology*, *49*(3), 320-331. https://doi.org/10.1111/j.1365-2028.2011.01268.x

Clutton-Brock, T., & Sheldon, B. C. (2010). Individuals and populations: the role of long-term, individual-based studies of animals in ecology and evolutionary biology. *Trends in ecology & evolution*, *25*(10), 562-573. doi:10.1016/j.tree.2010.08.002

Dickman, A. J., & Marker, L. L. (2005). Factors affecting leopard (*Panthera pardus*) spatial ecology, with particular reference to Namibian farmlands. *South African Journal of Wildlife Research*, *35*(2), 105-115.

Efford, M. (2018). Spatially Explicit Capture-Recapture. R package version 3.1.7

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual review of ecology, evolution, and systematics*, *34*(1), 487-515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Gilles, C., Wiesweg, M., Qualmann, M., Hansen, M.G., Rytilahti, T., Welwarsky, M., Narboux, J., Frank, M., Lecureuil, N., Palani, A., Clemens, A., Spendrin, P., Pontabry, J., Baecker, A., Cruz, F.J., Raju, R., Ahrens, J., Albers, T. & Holzer R. (2018). DigiKam: Professional Photo Management with the Power of Open Source [Version 5.8.0], Boston, United States of America.

Grey, J. N. C., Kent, V. T., & Hill, R. A. (2013). Evidence of a high density population of harvested leopards in a montane environment. *PloS one*, *8*(12), e82832. https://doi.org/10.1371/journal.pone.0082832

Gubbi, S., Poornesha, H. C., Daithota, A., & Nagashettihalli, H. (2014a). Roads emerging as a critical threat to leopards in India. *Cat news*, *60*, 30-31.

Gubbi, S., Reddy, V., Nagashettihalli, H., Bhat, R., & Madhusudan, M. D. (2014b). Photographic records of the Ratel Mellivora capensis from the southern Indian state of Karnataka. *Small Carnivore Conservation*, *50*, 42-44.

Gubbi, S., Nagashettihalli, H., Bhat, R., Poornesha, H.C., Anoop, A., & Madhusudan, M.D. (2017a). Ecology and conservation of leopards in protected and multiple use forests in Karnataka. Nature Conservation Foundation, Mysore, India.

Gubbi, S., Harish, N. S., Kolekar, A., Poornesha, H. C., Reddy, V., Mumtaz, J., & Madhusudan, M. D. (2017b). From intent to action: a case study for the expansion of tiger

conservation from southern India. *Global Ecology and Conservation*, *9*, 11-20. https://doi.org/10.1016/j.gecco.2016.11.001

Gubbi, S., Kolekar, A., Chakraborty, P., & Kumara. V (2019a). Big cat in well: an unconventional threat to leopards in southern India. Oryx. doi:10.1017/S0030605319000280

Gubbi, S., Nagashettihalli, H., Suthar, S. & Menon, A.M. (2019b). Leopards of Bannerghatta National Park: A camera-trapping exercise to estimate abundance and densities of leopards, Nature Conservation Foundation, Mysore, India.

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

Gubbi, S., Kolekar, A., & Kumara, V. (2020a). Policy to on-ground action: Evaluating a conflict policy guideline for leopards in India. *Journal of International Wildlife Law & Policy*, *23*(2), 127-140. https://doi.org/10.1080/13880292.2020.1818428

Gubbi, S., Ramesh, S., Menon, A.M., Girish, M.N., Poornesha, H.C. (2020b). The lone wolf: new distribution update of the Indian grey wolf (Canis lupus pallipes) in southern India. Canid Biology & Conservation 22(6):21-24. URL: http://www.canids.org/CBC/22/Indian_grey_wolf_distribution.pdf.

Gubbi, S., Sharma, K., & Kumara, V. (2020c). Every hill has its leopard: patterns of space use by leopards (Panthera pardus) in a mixed use landscape in India. *PeerJ*, *8*, e10072. doi:10.7717/peerj.10072

Gubbi, S., Suthar, S., Girish, M. N. & Menon, A.M. (2020d). Rosettes in Chikkaballapura: Estimating leopard densities and abundance through camera trapping, Nature Conservation Foundation, Mysore, India.

Gubbi, S., Menon, A.M., Prabhu, K., & Suthar, S. (2021a) The leopards of Marikanive: Population estimation of leopards in the Marikanive State Forest, Chitradurga , Nature Conservation Foundation, Mysore, India.

Gubbi, S., Menon, A.M., Suthar, S. & Poornesha, H.C. (2021b) Monitoring leopard population in Malai Mahadeshwara Wildlife Sanctuary between 2014 and 2020. Nature Conservation Foundation, Mysore, India.

Gubbi, S., Kolekar, A., & Kumara, V. (2021c). Quantifying Wire Snares as a Threat to Leopards in Karnataka, India. *Tropical Conservation Science*, *14*: 1-8 https://doi.org/10.1177/19400829211023264

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*(1), 68-71. doi:10.1515/MAMM.2009.007

Harmsen, B. J., Foster, R. J., Sanchez, E., Gutierrez-González, C. E., Silver, S. C., Ostro, L. E. T., Kelly, M. J. , Kay, E., & Quigley, H. (2017). Long term monitoring of jaguars in the Cockscomb Basin Wildlife Sanctuary, Belize; Implications for camera trap studies of carnivores. *PloS one*, *12*(6), e0179505. https://doi.org/10.1371/journal.pone.0179505

Hayward, M. W., Henschel, P., O'brien, J., Hofmeyr, M., Balme, G., & Kerley, G. I. H. (2006). Prey preferences of the leopard (Panthera pardus). *Journal of Zoology*, *270*(2), 298-313. doi:10.1111/j.1469-7998.2006.00139.x

Henschel, P., & Ray, J. (2015). Leopards in African Rainforests-Survey and Monitoring Techniques. Wildlife Conservation Society, Bronx, United States of America

Jacobson, A. P., Gerngross, P., Lemeris Jr, J. R., Schoonover, R. F., Anco, C., Breitenmoser-Würsten, C., Durant, S. M., Farhadinia, M. S., Henschel, P., Kamler, J. F., Laguardia, A., Rostro-Garcia, S., Stein, A. B., & Dollar, L. (2016). Leopard (*Panthera pardus*) status, distribution, and the research efforts across its range. *PeerJ*, *4*, e1974. https://doi.org/10.7717/peerj.1974

Kandel, S. R., Lamichhane, B. R., & Subedi, N. (2020). Leopard (*Panthera pardus*) density and diet in a forest corridor of Terai: implications for conservation and conflict management. *Wildlife Research*, *47*(6), 460-467. https://doi.org/10.1071/WR19126

Karanth, K. U. (1995). Estimating tiger Panthera tigris populations from camera-trap data using capture—recapture models. *Biological conservation*, *71*(3), 333-338. https://doi.org/10.1016/0006-3207(94)00057-W

Khan, J. A., Chellam, R., Rodgers, W. A., & Johnsingh, A. J. T. (1996). Ungulate densities and biomass in the tropical dry deciduous forests of Gir, Gujarat, India. *Journal of Tropical Ecology*, 149-162. https://doi.org/10.1017/S0266467400009366

Khorozyan, I. G., Malkhasyan, A. G., & Abramov, A. V. (2008). Presence–absence surveys of prey and their use in predicting leopard (*Panthera pardus*) densities: a case study from Armenia. *Integrative Zoology*, *3*(4), 322-332. doi: 10.1111/j.1749-4877.2008.00111.x

Madhusudan, M. D., & Karanth, K. U. (2002). Local hunting and the conservation of large mammals in India. *Ambio*, 49-54.

Madhusudan, M. D. (2004). Recovery of wild large herbivores following livestock decline in a tropical Indian wildlife reserve. *Journal of Applied Ecology*, *41*(5), 858-869.

Mandal, D., Basak, K., Mishra, R. P., Kaul, R., & Mondal, K. (2017). Status of leopard Panthera pardus and striped hyena Hyaena hyaena and their prey in Achanakmar Tiger Reserve, Central India. *Journal of Zoology Studies*, *4*(4), 34-41.

Ministry of Environment, Forest and Climate Change (2017) The Gazette of India: Extraordinary, 46(152), Controller of Publication, Delhi, India.

Nagulu, V., Rao, V. V., & Srinivasulu, C. (2000). Wildlife Heritage of the Deccan. *Deccan Heritage*, 34-38.

Nowell, K., & Jackson, P. (1996). 'Wild Cats: Status Survey and Conservation Action Plan (Vol. 382)'. IUCN, Gland, Switzerland.

Odden, M., Athreya, V., Rattan, S., & Linnell, J. D. (2014). Adaptable neighbours: movement patterns of GPS-collared leopards in human dominated landscapes in India. *PLoS One*, *9*(11), e112044. https://doi.org/10.1371/journal.pone.0112044

Palmer, M. S., Swanson, A., Kosmala, M., Arnold, T., & Packer, C. (2018). Evaluating relative abundance indices for terrestrial herbivores from large-scale camera trap surveys. *African journal of ecology*, *56*(4), 791-803. https://doi.org/10.1111/aje.12566

Pelton, M. R., & van Manen, F. T. (1996). Benefits and pitfalls of long-term research: a case study of black bears in Great Smoky Mountains National Park. *Wildlife Society Bulletin*, 443-450.

Pinder, A. C., & Raghavan, R. (2013). Conserving the endangered mahseers (Tor spp.) of India: the positive role of recreational fisheries. *Current Science*, *104*(11), 1472-1475.

Ramesh, T., Kalle, R., Rosenlund, H., & Downs, C. T. (2017). Low leopard populations in protected areas of Maputaland: a consequence of poaching, habitat condition, abundance of prey, and a top predator. *Ecology and evolution*, *7*(6), 1964-1973. doi: 10.1002/ece3.2771

Rashmi, M. K., & Lele, N. (2010). Spatial modeling and validation of forest cover change in Kanakapura region using GEOMOD. *Journal of the Indian Society of Remote Sensing*, *38*(1), 45-54.

Reddy, V. K. V. (2015) Management Plan of Cauvery Wildlife Sanctuary, 2015-16 to 2024-25. Government of Karnataka, Bangalore, India.

Rovero, F., & Marshall, A. R. (2009). Camera trapping photographic rate as an index of density in forest ungulates. *Journal of Applied Ecology*, *46*(5), 1011-1017. doi: 10.1111/j.1365-2664.2009.01705.x

Sadananda, K. B., Tanuja, D. H., Sahana, M., Girija, T., Sharath, A., Vishwanath, M. K., & Shivaprakash, A. (2010). Observations on the White-naped Tit Parus nuchalis in Cauvery Wildlife Sanctuary, Karnataka. *Indian Birds*, *6*(1), 12-14.

Shivprakash, A., Das, K. K., Shivanand, T., Girija, T., & Sharath, A. (2006). Notes on the breeding of the Indian Spotted Eagle Aquila hastata. *Indian Birds*, *2*(1), 2-4.

Simcharoen, S., & Duangchantrasiri, S. (2008). Monitoring of the leopard population at Khao Nang Rum in Huai Kha Khaeng Wildlife Sanctuary. Thai J For 27: 68-80.

Sreenivasan, N., Mahesh, N., & Raghavan, R. (2021). Freshwater fishes of Cauvery Wildlife Sanctuary, Western Ghats of Karnataka, India. *Journal of Threatened Taxa*, *13*(1), 17470-17476. https://doi.org/10.11609/jott.6778.13.1.17470-17476

Stein, A.B., Athreya, V., Gerngross, P., Balme, G., Henschel, P., Karanth, U., Miquelle, D., Rostro-Garcia, S., Kamler, J.F., Laguardia, A., Khorozyan, I. & Ghoddousi, A. (2020). *Panthera pardus* (amended version of 2019 assessment). *The IUCN Red List of Threatened Species* 2020: e.T15954A163991139. https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T15954A163991139.en. Downloaded on 01 March 2021.

Sunil, C., Somashekar, R. K., & Nagaraja, B. C. (2019). Influence of Terminalia arjuna on the riparian landscapes of the River Cauvery of South India. *Landscape Research*. https://doi.org/10.1080/01426397.2018.1560400

Uphyrkina, O., Johnson, W. E., Quigley, H., Miquelle, D., Marker, L., Bush, M., & O'Brien, S. J. (2001). Phylogenetics, genome diversity and origin of modern leopard, Panthera pardus. *Molecular ecology*, *10*(11), 2617-2633. https://doi.org/10.1046/j.0962-1083.2001.01350.x

WallisDeVries, M. F. (1998). Habitat quality and the performance of large herbivores. In *Grazing and conservation management* (pp. 275-320). Springer, Dordrecht.

Yoccoz, N. G., Nichols, J. D., & Boulinier, T. (2001). Monitoring of biological diversity in space and time. *Trends in ecology & evolution*, *16*(8), 446-453. https://doi.org/10.1016/S0169-5347(01)02205-4

Appendices

Appendix – 1

Photographs of mammal species captured in Cauvery Wildlife Sanctuary during camera trapping session in 2014, 2016, 2018 and 2020.

Leopard
(*Panthera pardus fusca*)

Tiger
(*Panthera tigris*)

Jungle cat
(*Felis chaus*)

Rusty spotted cat
(*Prionailurus rubiginosus*)

Dhole
(*Cuon alpinus*)

Indian grey wolf
(*Canis lupus pallipes*)

Golden jackal
(*Canis aureus*)

Indian fox
(*Vulpes bengalensis*)

Sloth bear
(*Melursus ursinus*)

Elephant
(*Elephas maximus*)

Gaur
(*Bos gaurus*)

Grizzled giant squirrel
(*Ratufa macroura*)

Smooth-coated otter
(*Lutrogale perspicillata*)

Ratel
(*Mellivora capensis*)

Sambar
(*Rusa unicolor*)

Chital
(*Axis axis*)

Blackbuck
(*Antilope cervicapra*)

Barking deer
(*Muntiacus vaginalis*)

Four-horned antelope
(*Tetracerus quadricornis*)

Indian chevrotain
(*Moschiola indica*)

Wild pig
(*Sus scrofa*)

Black-naped hare
(*Lepus nigricollis*)

Indian pangolin
(*Manis crassicaudata*)

Porcupine
(*Hystrix indica*)

Bonnet macaque
(*Macaca radiata*)

Tufted grey langur
(*Semnopithecus priam*)

Grey mongoose
(*Herpestes edwardsii*)

Ruddy mongoose
(*Herpestes smithii*)

Common palm civet
(*Paradoxurus hermaphroditus*)

Small Indian civet
(*Viverricula indica*)

Madras tree shrew
(*Anathana ellioti*)

Indian gerbil
(*Tatera indica*)

Fulvous fruit bat
(*Rousettus leschenaultii*)

Rufous horseshoe bat
(*Rhinolophus rouxii*)

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
Blackbuck (*Antilope cervicapra*)	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*
Blackbuck	*Antilope cervicapra*
Chital	*Axis axis*
Four-horned antelope	*Tetracerus quadricornis*
Sambar	*Rusa unicolor*
Wild pig	*Sus scrofa*
Domestic prey	
Buffalo	*Bubalus bubalis*
Cow	*Bos taurus*
Donkey	*Equus africanus asinus*
Goat	*Capra aegagrus hircus*
Sheep	*Ovis aries*
Domestic pig	*Sus scrofa domesticus*
Domestic dog	*Canis lupus familiaris*

Appendix-4

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

Individual	Sex	2014	2016	2018	2020	Number of years captured
CUL-06	Female	■	■	■	■	4
CUL-14	Female	■	■	■	■	4
CUL-24	Male	■	■	■	■	4
CUL-17	Male	■	■	■		3
CUL-18	Female	■	■		■	3
CUL-27	Female	■	■		■	3
CUL-40	Female	■	■	■		3
CUL-51	Female	■	■	■		3
CUL-65	Female		■	■	■	3
CUL-71	Female		■	■	■	3
CUL-83	Female		■	■	■	3
CUL-87	Female		■	■	■	3
CUL-89	Male		■	■	■	3
CUL-01	Male	■	■			2
CUL-03	Female	■	■			2
CUL-05	Male	■	■			2
CUL-13	Male	■	■			2
CUL-28	Female	■	■			2
CUL-31	Female	■	■			2
CUL-33	Female	■	■			2
CUL-39	Female	■	■			2
CUL-44	Female	■	■			2
CUL-61	Male		■	■		2
CUL-63	Male		■	■		2
CUL-70	Male		■	■		2
CUL-73	Female		■	■		2
CUL-82	Male		■	■		2
CUL-90	Female			■	■	2
CUL-93	Male			■	■	2
CUL-94	Female			■	■	2
CUL-95	Female			■	■	2
CUL-97	Female			■	■	2
CUL-99	Male			■	■	2
CUL-105	Female			■	■	2
CUL-109	Male			■	■	2
CUL-110	Female			■	■	2
CUL-111	Male			■	■	2
CUL-113	Female			■	■	2
CUL-114	Female			■	■	2
CUL-115	Male			■	■	2
CUL-116	Male			■	■	2
CUL-119	Male			■	■	2
CUL-120	Female			■	■	2

CUL-125	Male					2
CUL-126	Female					2
CUL-127	Female					2
CUL-128	Male					2
CUL-129	Female					2
CUL-131	Male					2
CUL-135	Male					2
CUL-138	Female					2
CUL-139	Male					2
CUL-146	Female					2
CUL-148	Female					2
CUL-149	Female					2
CUL-151	UID					2
CUL-02	Male					1
CUL-04	Male					1
CUL-07	Female					1
CUL-08	Male					1
CUL-09	Male					1
CUL-10	Female					1
CUL-11	Female					1
CUL-12	Female					1
CUL-15	Male					1
CUL-16	Male					1
CUL-19	Female					1
CUL-20	Female					1
CUL-21	Male					1
CUL-22	Male					1
CUL-23	Male					1
CUL-25	Male					1
CUL-26	Female					1
CUL-29	Female					1
CUL-30	Female					1
CUL-32	Female					1
CUL-34	Female					1
CUL-35	Male					1
CUL-36	Female					1
CUL-37	Female					1
CUL-38	Female					1
CUL-41	Female					1
CUL-42	Female					1
CUL-47	UID					1
CUL-48	UID					1
CUL-50	Male					1
CUL-53	UID					1
CUL-54	Male					1
CUL-57	Male					1
CUL-58	Male					1
CUL-59	Male					1

CUL-60	Male					1
CUL-62	Male					1
CUL-64	Female					1
CUL-66	Male					1
CUL-67	Male					1
CUL-68	Female					1
CUL-69	Male					1
CUL-72	Female					1
CUL-74	UID					1
CUL-75	UID					1
CUL-76	Male					1
CUL-77	UID					1
CUL-78	Male					1
CUL-79	Female					1
CUL-80	Male					1
CUL-81	Male					1
CUL-84	Male					1
CUL-85	Female					1
CUL-86	UID					1
CUL-88	UID					1
CUL-91	Female					1
CUL-92	Female					1
CUL-96	Female					1
CUL-98	Male					1
CUL-100	Female					1
CUL-101	Female					1
CUL-102	Male					1
CUL-103	Female					1
CUL-104	Male					1
CUL-106	Male					1
CUL-107	Female					1
CUL-108	Female					1
CUL-112	Male					1
CUL-117	Female					1
CUL-118	Female					1
CUL-121	Male					1
CUL-122	Female					1
CUL-123	Female					1
CUL-124	Male					1
CUL-130	Male					1
CUL-132	Male					1
CUL-133	Female					1
CUL-134	Male					1
CUL-136	Male					1
CUL-137	Female					1
CUL-140	UID					1
CUL-141	UID					1
CUL-142	Male					1

CUL-143	Male					1
CUL-144	Female					1
CUL-145	UID					1
CUL-147	UID					1
CUL-152	UID					1
CUL-153	Female					1
CUL-154	UID					1
CUL-155	Female					1
CUL-156	Male					1
CUL-157	Male					1
CUL-158	Male					1
CUL-159	Male					1
CUL-160	Female					1
CUL-161	Male					1
CUL-162	Female					1
CUL-163	Female					1
CUL-164	Female					1
CUL-165	Male					1
CUL-166	Female					1
CUL-167	Female					1
CUL-168	Female					1
CUL-169	Female					1
CUL-170	UID					1
CUL-171	Female					1
CUL-172	Female					1
CUL-173	Female					1
CUL-174	Male					1
CUL-175	Male					1
CUL-176	Female					1
CUL-177	Male					1
CUL-178	Female					1
CUL-179	Female					1
CUL-180	Male					1
CUL-181	Female					1
CUL-182	Female					1
CUL-183	Female					1
CUL-184	Male					1
CUL-185	Male					1
CUL-186	Female					1
CUL-187	Male					1
CUL-188	Female					1
CUL-189	Male					1
CUL-190	Female					1
CUL-191	Male					1
CUL-192	Male					1
CUL-193	Male					1
CUL-194	Female					1
CUL-195	Female					1

CUL-196	UID					1
CUL-197	UID					1
CUL-198	Female					1
CUL-199	UID					1

Research team

Dr.Sanjay Gubbi

Harish N.S.

Girish M. N.

Shravan Suthar

Poornesha H.C.

Amrita M. Menon

Sandesh Appu Naik

Gnanendra L.

Ravidas Ganesh Gawda

Ruma K. Kandurkar

Praveen T. V.