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Urban Leopards of National Capital: Estimating Density and Occupancy of Leopard (*Panthera pardus*) in Asola Bhatti Wildlife Sanctuary, New Delhi, India

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ABSTRACT

Studies, in recent past have revealed that obligate carnivores are adapting to human dominated landscapes. Leopards, amongst other large carnivores are highly adaptable and can survive in a range of environments. Although any sporadic sightings of leopards have occurred in New Delhi. However, any reliable population and occupancy estimation was lacking from the region, whereas understanding of population density estimation is important in providing local and regional level conservation and management of the species. Our study is conducted to better understand leopard status and population density estimation in Asola Bhatti Wildlife Sanctuary of New Delhi. During 588 camera trap nights, we detected 8 individual leopards. Based on spatial capture-recapture framework the leopard density inside the sanctuary was estimated at 4.5 ± 0.019 leopards/100km² despite very high anthropogenic pressure. Occupancy modelling based on Inverse Distance Weighted Interpolation showed species distribution across the sanctuary which was highest in the areas adjoining densely populated region of the city from where it was observed that large number of vehicle and people cross the sanctuary daily to for their work. The moderate leopard density in this small protected area with high human population pressure can be due to the absence of any other large carnivore, less competition with co-predators because of their low numbers (i.e., hyenas), high availability of prey base and inclusive protected area management. We encourage further research to explore the landscape connectivity between the neighboring suitable leopard habitats like Sariska Tiger Reserve in Rajasthan, via Aravalli hill range of South Haryana till Asola Bhatti Wildlife Sanctuary of New Delhi for understanding wildlife corridor connectivity in the Northern Aravalli Range at landscape level.

Key words: *Leopard, Co-existence, SECR, Density, Occupancy, New Delhi*

Introduction

Large predators are expanding their geographic range and recolonizing places in which they were formerly extinct in various parts of the world (Chapron *et al*., 2014; Cater and Linnell, 2016). To continue to exist, large carnivores were thought to require their natural habitat freed from human be-

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ings (Woodroffe, 2000; Cater and Linnell, 2016). However, their presence in human dominated areas can be supported with abundant prey base that is constituted by domestic and wild dogs (Gehrt *et al*., 2010; Yirga *et al*., 2013). Being highly adaptable leopard is frequently seen near the human habitations and the edges of many metropolitan cities like Mumbai (Surve *et al*., 2022), Guwahati (Bharali *et al*., 2021) Jaipur (Kumbhojkar *et al*., 2020) and Bangalore (Athreya *et al*., 2015) etc.

Although, there are many reported instances of leopard occurrence in urban regions nonetheless, currently very little is known about the elements contributing to co-adaptability of leopards and human beings in shared spaces (Gehrt *et al*., 2010; Cater and Linnell, 2016). Over the time, behavioral change is observed in the wildlife present near the urban spaces for example they're found to have more generalist type of feeders (Gehrt *et al*., 2010; Moss *et al*., 2016), some carnivores determined to be feeding on natural waste (Lewis *et al*., 2015) or prey on animals that in turn feed on scrap which include Cats, feral dogs and pigs etc. (Athreya *et al*., 2016, Yirgea *et al*., 2016).

A recent study in India found that leopards have experienced catastrophic population decline of about 75 – 90% in the last ~120-200 years, mainly due to anthropogenic issues (Bhatt *et al.,* 2020). In Indian subcontinent poaching, habitat loss, depletion of natural prey and conflict are major identified threats to leopard populations (Athreya *et al.,* 2010). All these have resulted in changing the species status from "Near threatened" to "Vulnerable" by IUCN (Stein *et al.,* 2016). Many sporadic sightings or unconfirmed glimpse of leopards were reported from the New Delhi (Pillai, 2021; Dhankhar, 2022; Bajwa, 2023) in last couple of years. However, any confirm sighting which establish its long-term presence was lacking, which leads towards a proper population estimation of the big cat from the capital city. Therefore, the present study was undertaken to estimate the density and occupancy of the common leopard (*Panthera pardus fusca*) using spatially explicit capture recapture (SECR) methodology which is widely accepted population density estimation tool to monitor population of the large carnivores as it incorporates animal movement in the statistical estimation process (Sharma *et al.* 2014; Sollmann *et al.* 2013).

Materials and Methods

Study Site

Asola Bhatti Wildlife Sanctuary, ABWLS hereafter (28° 282 3422 N and 77° 132 4822 E) with an area of 32.71 km² is situated at the south-eastern part of South Delhi ridge of Aravalli Hills which stand for one of the oldest mountain systems of the world (Sharma and Chaudhry, 2017). Aravalli ranges starts from Gujarat and ends in Delhi. The northern part of Aravalli hill range is known to be a part of Sariska-

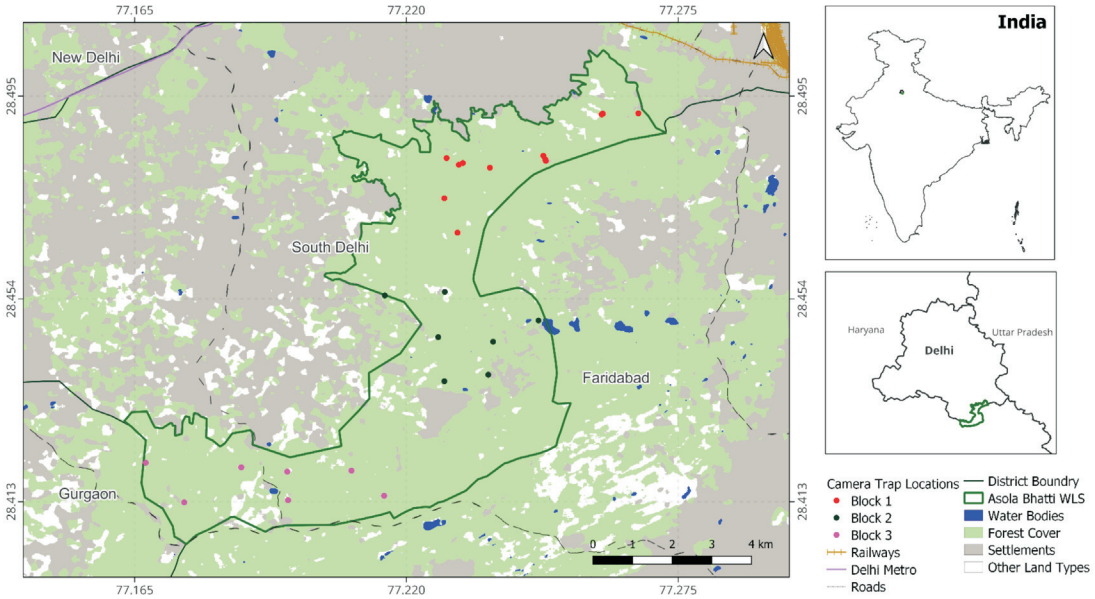

Fig. 1. Map Showing Asola Bhatti Wildlife Sanctuary Location with camera trap sites

Delhi Wildlife Corridor. Biogeographically it is described as Northern tropical thorn forest (Champion and Seth, 1968; http://forest.delhigovt.nic.in/). It was one of the prominent sites for mining and weathering of quartzite yielding high quality silica sand (Bajri/Badarpur) until 1990 when mining was banned. Continuous mining not only left the sanctuary heavily fragmented but also many abandoned pits were created which were later turned into perennial water bodies.

The ABWLS has longitudinal area with 13.5 km length and mere 2.7 km wide leaving greater scope of human influence from sides making it highly porous. The PA is nestled between a unique human dominated landscape, sharing its boundary with a densely populated permanent settlement in southern side known as Sanjay Nagar as well as another highly populated settlement in northern side is Sangam Vihar. In west, the boundary is being shared with sparsely populated Sainik Farms. In south and east, this protected area is connected with a contiguous forest of Faridabad and Gurgaon/Gurugram in Haryana state.

Major part is occupied by invasive species of Vilayati keekar or Mesquite (*Neltuma juliflora,* earlier known as *Prosopis juliflora*) which is widely spread in the sanctuary (Sharma and Chaudhry, 2018; Sinha, 2014). Other prominent tree species are *Acacia nilotica, A. leucophloea, A. catechu* along patches of *Salvadora persica*, *Azadirachta indica*, *Butea monosperma*, *Cassia fistula* and *Anogeissus pendula* etc. Shrub species include *Capparis separia, C. decidua, Tribulus terrestris, Zizyphus aenoplia, Croton sparaijlorus, Tephrocia purpurea* etc. Some common herb species are *Calotropis procera, Withania somnifera, Achyranthes aspera, Aerva scandens, Tridax procumbens, Alycicarpus vaginalis, Euphorbia hierta, Pupalia lappacea* and *Peristrophe bicalyculata* etc. The mammal species includes Nilgai (*Boselaphus tragocamelus*), Cheetal (Axis axis), Hyena (*Hyaena hyaena*) Jungle Cat (*Felis chaus*), Small Indian Civet (*Viverricula indica***)**, Indian grey mongoose (*Urva edwardsii*) Ruddy mongoose (*Urva smithii*), Small Indian mongoose (*Urva auropunctata*; formerly *Herpestes auropunctatus*), Rufous-tailed hare (*Lepus nigricolis*) and Indian Crested Porcupine (*Hystrix indica*) etc. ABWLS is also home to numerous species of reptiles and more than 200 species of avian fauna including both migratory and residents.

Methodology

Camera trap survey based on capture-recapture framework was used (Royle *et al*., 2017) for estimating leopard density during January to July 2022. Camera trap locations were selected so as to maximize the possibility of photographing each individual leopard within the ABWLS for which the study site was divided into 3 blocks of equal areas which were further divided into grids of 1x1 Km^2 each. The area of sanctuary is longer in length and narrower in width hence; even the grids with around 70% of area falling inside sanctuary's boundary were considered. However, due to constraints with the limited number of camera traps, sampling was done block wise in which grids to be sampled were finalized after doing sign surveys based on (Karanth and Nichols, 2002).

Cuddeback Digital model H-1453TM camera traps with 20 MP resolutions were used for data collection. The cameras were set up with date, time and unique ID stamp on the photographs. Each camera trap station was placed with not more than 1-2 km apart from each other and fixed ~2.5 feet above ground ensuring multiple individuals getting captured in multiple locations that is essential in capture-recapture modelling and each station having 2 cameras facing each other to capture both the flanks of individual leopard at almost same time which was used for identification purpose (Karanth and Nichols 1998, 2002). All 3-block having 7 camera trap locations each (Total 21 stations) were active for 28 nights each before shifting therefore a total of 588 nights (21*28 Trap nights) of continuous intensive sampling was done. No bait was used in camera trap surveys.

The difference in rosette patterns was carefully analyzed from limbs, tail, head and forequarter and every leopard thus identified was given a unique identification number (Miththapala *et al*., 1996; Henschel and Ray 2003; Thapa *et al*., 2014; Karanth *et al*., 2017). Two input text files were created for estimating density using Maximum Likelihood Spacially Explicit Capture Recapture (ML-SECR) model with single live detector type; the trap history file (having details of spatial location of each camera trap with specifications of trap deployment schedule), capture history file (having the details of captures such as session, Leopard Id, occasions of capture and Trap Id) and state space mask file (specify-

ing location buffer around outermost trap station). Poisson distribution model was used with a buffer area of 10 km around trapping stations so that no leopard gets captured beyond the buffer zone (Singh *et al.* 2014). Final density was calculated in Programme Density 5.0 (Efford, 2004).

The SECR results are based on three parameters, *i.e.,* Derived Density, g0 - parameter which gives probability of detection at centre of home range and ˜ - Scale of animal movements from home range centre (Efford *et al.* 2009). Final occupancy modelling based distribution map were prepared using spatial interpolation mapping tool Inverse Distance Weighted (IDW) in ESRI ArcGIS 10.1 based on frequency of camera trap photographs of each species. All the statistical analyses were done in R statistical environment (R Core Team, 2021).

Results

Status of Leopard

The camera trap effort yielded more than 14000 photographs of various components of the sanctuary of which majority of photographs belongs to Human beings followed by Cattle. Leopards were captured 111 times with both flanks in 10 of 21 stations. Photographs of left flank only were used for analysis as the rosette patterns on left side were better visible that can be due to placement of camera as well as contrasting background. Blurred photographs were removed from the identification

The presence of leopard was also confirmed by collecting scats and pug marks near the trap stations. A total of 8 leopards of which 4 male, 1 female and 3 sex unidentified were thus identified as unique and probably found home within sanctuary either on a permanent or temporary basis which were assigned UIDs as ABL01, ABL02, ABL03, ABL04, ABL05, ABL06, ABL07 and ABL08 (Fig.2).

Population Size

CAPTURE 2.1 was used for testing whether population was closed during the study period, z value (-3.178) with a probability of smaller value, *i.e.* p = 0.0007. The test result satisfied this assumption of closed population. An encounter history file (.inp) was devised as input using binary number system where 1 denoted presence of individual and 0 indicated absence of particular individual on each sampling occasion. Closed population was estimated using Null estimator E(0) in DENSITY 5.0 software which showed that leopard were captured (NCapture) 38 times and recaptured (NRecapt) 30 times with 8 unique (NAnimal) individual leopards. The capture probability of leopard (P-hat) was 0.0517 whereas population size (N-hat ± SE) at 95% CI was estimated at 8.0 ± 0.3 (8.0 - 8.9). Alternatively, Mh Jackknife estimator gave a population size of 9.0 ± 1.5 with a capture probability (P-hat) of 0.0509.

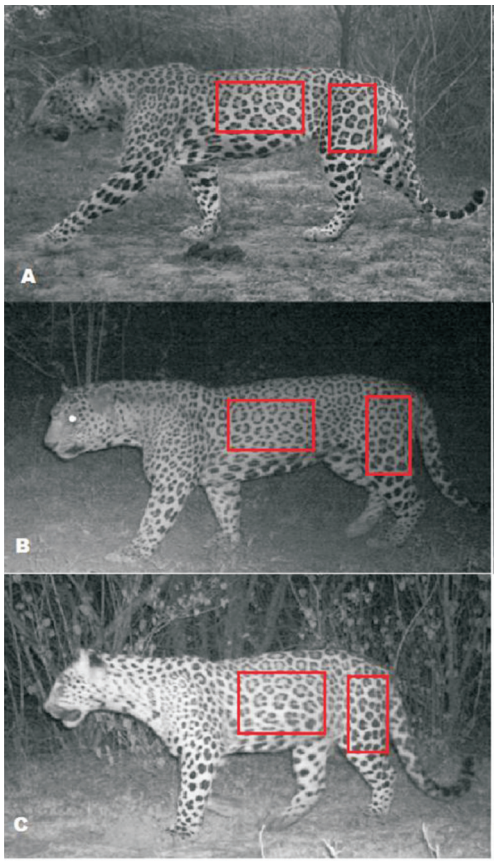

Fig. 2. Photographs showing 2 individual Leopards (A & B) ABL03 and (C) ABL04, with differences in rosette pattern which allow for individual identification

Table 1. Capture frequency of individual leopards

Leopard UIDs	ABL01	ABL02	ABL03	ABL04	ABL05	ABL06	ABL07	ABL08
Capture Frequency	04	11	15	10	03	01	01	05

Density of Leopard

Leopard density was estimated at 4.5 ± 0.019 animals/100km² as per Poisson distribution model in maximum likelihood SECR mode. The detection and distribution model used were half-normal and Poisson model respectively, g(0), *i.e.* detection probability of leopard at the center of home range was estimated at 0.017 (SE = 0.004), *i.e.* scale of individuals movement from home range was found out to be 2.01 km².

Occupancy

The Leopards were spotted in all the three blocks in sanctuary with fair distribution across the PA (Fig 3). The maximum presence was recorded near highly human dominated area of western part of the sanctuary that is surrounded by densely populated area of Fatehpur beri, Asola and Chhatarpur indicating that leopards has been adapted well along with urban habitations. Other prominent sites of occurrence were Neeli Jheel (Lake) and Mangar Bani forest area towards the east of PA.

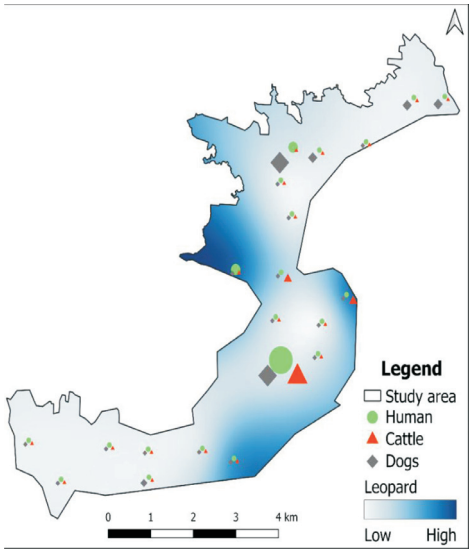

Fig. 3. Human Disturbance Map showing frequency of occurrence of Human, Cattle and Dogs over Leopard occurrence frequency

Discussion

Aravalli hill range is oldest mountain range, which starts from Gujarat and ends in Delhi. Asola Bhatti WL Sanctuary lies into the northern tip of this hill range. Beyond Sariska Tiger Reserve in Rajasthan, Leopard occupies the status of top predator in this fragile rugged mountainous scrub forest ecosystem. Though in the past, Leopard was present in the wilderness of Delhi (Gazetteer of Delhi, 1883, 1976) but over the years of increased anthropogenic pressure in the habitat and lack of major protected area in this tract of Aravalli hill range, their status was not quantified. In last couple of years, many unconfirmed sighting reports were being surfaced about the sighting of this species, a through attempt was envisaged to understand the status. Given the mounting threats faced by leopards in their entire range, our study has provided valuable insights into the status of this elusive species.

In this six-month long study, a total of 8 individual leopards were identified, with 4 males and 1 female frequently being encountered in camera traps. Their frequency of occurrence in a same area, as corroborated with camera trap photos, revealed that most of these leopards are having overlapping home ranges and probably might have become resident population of this urban forest of Delhi. The high occupancy is observed around the periphery of extremely high human dominated area of PA. The activity pattern of leopard here is found to be diur-

Table 2. Capture histories of individual leopards identified using left flank profile in Asola Bhatti Wildlife Sanctuary across 21 samplings undertaken in 3 sampling blocks in phased period during sampling

Leopard ID	Sampling Occasions																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ABL01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
ABL02	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	1	0	0	0
ABL03	0	0	0	0	0	1	1	1	1	0	1	0	0	1	0	0	0	0	0	0	0
ABL04	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0
ABL05	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
ABL06	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABL07	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABL08	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

nal which goes along the earlier findings (Ramesh *et al*. 2012). IDW interpolation showed that highest density was in area of PA adjoining densely populated region of urban hub, near the permanent water source (Neeli Jheel) and Mangar Bani forest area where there is moderate level of parameters of human interventions i.e., presence of human settlements, cattle and dog.

Interestingly, the population density is relatively moderate at 4.5 ± 0.019 leopards/100km² which indicated that though leopards in ABWLS occurs at a very modified and fragmented habitat yet prey base remains stable as the prey availability is an important determinant of leopard density and distribution. Kumbhojkar *et al*. (2020) documented home range of leopard at Jhalana forest, on the edge of Jaipur city, which is also an urbanized area showed that home range can extend from mere 9km² to even 451km². Looking at the size of just 32.71 km2 of ABWLS, and limited number of camera trap photos of 3 leopards being noticed as transient ones indicate that their home range extends in the nearby forest patches of bordering districts of Haryana state.

The resident status of few adult leopards, which is being corroborated from the repeated camera trap photos in certain area, indicates towards the health of ecosystem of this unique forest. As leopard were not seen in ABWLS after 1940 (Khanna and Sati, 2003) and recent sighting incidents of leopard in the hills of Southern Haryana (Yadav *et al.,* 2020) indicates that the possible source of movement into the sanctuary can be through Sariska-Delhi wildlife corridor which seems to be still functional. The present study gives strong support and throws light on the importance of identification and acknowledging this linear area as wildlife corridor with leopard as keystone species being the top most predator of this landscape.

To conserve leopard effectively in human dominated landscape, a good understanding of its population estimates is required, which is also important in providing local and regional level conservation and management efforts. The present study is first effort towards the leopard population density estimation in New Delhi's ABWLS which was estimated at 4.5 ± 0.019 animals/100km². It is comparable to the leopard densities from other human dominated landscapes of Ahmednagar district, western Maharashtra which was 6.4 ± 0.78/100 km² (Athreya *et al*. 2013), 6.38 ± 2.4/100 km² in Jawai, Rajasthan (Sharma, 2017) and 3.1 ± 0.4/100 km² in Sariska Tiger Reserve (Mondal *et al*. 2012) and 5.40 ± 2.99 leopards/ 100 km² in Tungareshwar Wildlife Sanctuary, Mumbai (Surve *et al*. 2022). The moderate density of leopards in this small protected area can be due to the lack of any major anthropogenic threats, absence of other large predators, high availability of prey base and intensive integrated wildlife and habitat management by forest department. If habitat is holistically managed and prey base augmentation and attempts to increase the wild harbivores, this sanctuary can sustain a very good leopard population. In India, some of the regions having very high leopard population density are 26.34 ± 4.96 leopards/100 km² in Sanjay Gandhi National Park, Mumbai (Surve *et al*. 2022), 12.04 ± 2.98 leopards/100 km² in Achanakmar Tiger Reserve 14.99 ± 6.9 leopards/100 km² in Rajaji National Park (Harihar *et al*. 2009) etc.

Leopard population density estimation at Sariska before tiger re-introduction was 7.6±0.6 (SE) /100 km2 in 2008 and 6.2±0.8/100 km2 in 2009 whereas, after tiger-reintroduction the density was estimated at 3.1±0.4 /100 km2 in 2010 (Mondal *et al.* 2012). This indicates that leopard and tiger have dietary overlap inside protected areas, where they share the same habitat and for avoiding this, leopard always prefers to live on the periphery of major tiger habitats. The present study opens up many more dimensions to understand the landscape level connectivity between Sariska Tiger Reserve as nearest source population and Asola Bhatti Wildlife sanctuary which is another population pool and final connecting dot of Sariska -Delhi Wildlife Corridor. It is recommended to carry out research for enhanced understanding of the landscape level movement of leopards in Northern Aravalli Range and provide insight into the source populations of the Leopards of New Delhi. If this small population not interconnected with source population, might become vulnerable to demographic stochasticity. Also, future study is recommended to quantify the density gradient and diet of leopards in protected and non-protected areas to understand the anthropogenic impact on leopard populations.

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