

**ECOLOGY OF LEOPARD (*Panthera pardus*) IN SANJAY
GANDHI NATIONAL PARK, MAHARASHTRA WITH
SPECIAL REFERENCE TO ITS ABUNDANCE, PREY
SELECTION AND FOOD HABITS**

**DISSERTATION SUBMITTED TO
SAURASHTRA UNIVERSITY, RAJKOT,
IN PARTIAL FULFILMENT OF THE MASTER'S DEGREE IN
WILDLIFE SCIENCE**

By

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UNDER THE SUPERVISION OF

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CERTIFICATE

This is to certify that Mr. Nikit Surve, student of Wildlife Institute of India has carried out an original piece of research work entitled “Ecology of leopard (*Panthera pardus*) in Sanjay Gandhi National Park, Maharashtra with special reference to its abundance, prey selection and food habits.” for the partial fulfilment of the M.Sc. Degree in Wildlife Science from the Saurashtra University, Rajkot, India. These investigations were carried out under our supervision from December 2014 to June 2015. We also certify that this research has not been submitted for any other degree to any University.

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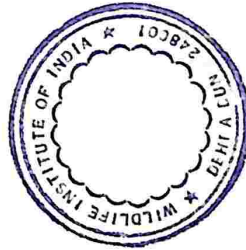
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Executive Summary

Though information is available on the leopard's ecology from natural habitats, very less information is available on the ecology of leopards from human-dominated habitats in India. Hence the study was conducted at Sanjay Gandhi National Park (SGNP), Mumbai where leopard was found to be the apex predator. The total area of SGNP is 104 sq.km. It is covered by human habitations on all the sides leaving just a narrow tip on the northern side. Camera traps were deployed in a systematic manner covering the entire study area to get leopard images. Leopard density of 21.55 ± 4.6 (SE) at 95% confidence interval was calculated in the study area using Spatially Explicit Capture Recapture models. The wild prey densities were estimated inside SGNP using Distance sampling with the help of line transects. The maximum density amongst ungulates was shown by chital (14.49 ± 5.2 [SE]) followed by sambar (7.52 ± 1.7 [SE]). Among primates, maximum density was shown by common langur (48.04 ± 8 [SE]) followed by bonnet macaque (30.78 ± 12 [SE]). Density for other prey species encountered on line transects like wild pig and barking deer were not estimated as they were sighted only twice on the line transects. Dog density on the periphery of SGNP was calculated to be 17.26 ± 0.69 (SE) using mark-recapture technique. Food habits of leopards were studied by conducting dietary analysis using leopard scat. The high density of dogs in the periphery of the National Park also reflected in the leopard's diet. Dogs alone contributed 24.46 % of the total biomass consumed in leopard's diet. Domestic prey contributed to 43% whereas wild prey contributed to 57 % of leopard's diet in terms of relative biomass consumed. The study suggests that the leopards are dependent on both wild as well as domestic prey in the study area. Leopards can coexist with humans even amidst urban environs as long as prey population (both domestic and wild) remain sufficient and their habitat is protected.

1. Introduction

The Leopard (*Panthera pardus fusca*, Meyer, 1794) is the most widely distributed of all wild cats (Bailey 1993; Nowell and Jackson 1996). It is known to occur from across Africa to South Asia northwards to Central Asia and east to Amur valley in Russia (Bailey 1993). In India leopards are found throughout the country with the exception of desert areas and Sunderbans mangrove areas (Khan & Beg 1986; Johnsingh *et. al.*, 1991). Leopard is a solitary animal and being highly adaptable is known to occupy a broad variety of habitats (Bailey 1993; Daniel 2009).

The Leopard in India, is listed in Schedule I of the Indian Wildlife (Protection) Act. (Anon 1972) under the highest level of protection. Leopard falls under the near threatened category of IUCN (IUCN 2014). The leopard remains in the Appendix 1 of CITES.

1.1 Literature Review

Majority of the long term studies conducted on leopards are from protected areas outside India. A few studies on leopard's ecology, population and home range using radio tracking come from Africa (Hamilton 1976; Bertram 1982; Bailey 1993). Studies from Asia include Eisenberg and Lockhart (1972); Seidensticker (1976) and Rabinowitz, (1989). Long term studies on leopards have been conducted in various Protected Areas (PAs) in India such as Bandipur Tiger Reserve (Johnsingh 1983; Andheria *et. al.*, 2007), Nagarhole National Park (Karanth & Sunquist 1995), Rajaji National Park (Mondal 2006; Harihar *et. al.*, 2009), Sariska Tiger Reserve (Mondal *et. al.*, 2011) and Pench Tiger Reserve (Majumder *et. al.*, 2013). Major findings from these studies show that leopards occur at low densities where tigers are present in high abundance and their densities may rise to a certain levels where tigers are absent as it happened in the case of Rajaji National Park (Harihar *et. al.*, 2009) and Sariska Tiger Reserve (Mondal *et. al.*, 2011). A few studies on ecology of leopards in human-dominated landscapes are available from Maharashtra (Edgaonkar and Chellam 1998; Athreya *et. al.*, 2007) and Uttarakhand (Chauhan 2007). These studies show the dependency of leopards on domestic prey. Studies from Mumbai include Edgaonkar and Chellam (1998) who conducted a preliminary study on leopard ecology in Sanjay Gandhi National Park. Bhale *et. al.*, (2005) conducted a short study and gave a concise report on the Sanjay Gandhi National Park. Tiwari and Apte (2006, 2008) from the Bombay Natural History Society (BNHS) also conducted surveys on leopard conflict and conducted awareness campaigns in and around the park and produced city forest reports in 2006 and 2008 and this also includes a preliminary study on diet composition of leopards in Sanjay Gandhi National Park (Tiwari and Prasad 2009). (Mirza *et. al.*, 2013) gave a report on minimum number of leopards based on their opportunistic camera trapping in SGNP.

1.2 Wildlife in urban areas

Large carnivores play an important role in regulating an ecosystem (Terborgh *et. al.*, 1999). They need suitable natural habitats for their survival. However, findings from recent studies show that large carnivores can also persist in human-dominated areas (Yirga *et. al.*, 2012, Athreya *et. al.*, 2013). As species are exposed to anthropogenic stresses that differ from the selective pressures under which they evolved, they may modify their behaviour, or other life-history traits to be successful (Ditchkoff *et. al.*, 2006). The ecology of large felids in the tropics known to us is largely from studies conducted in natural systems where wild



ungulates constitute the majority of the prey base (Karanth and Sunquist 1995; Sankar and Johnsingh 2002). However, human-dominated landscapes with high density of domestic prey can serve as optimal habitats for large carnivores with respect to potential prey (Athreya *et al.*, 2014). Abundant food is available for wildlife in human dominated areas in the form of garbage and other domestic prey (Gehrt *et al.*, 2010). This garbage attracts stray pigs and dogs, which serve as easy food for carnivores.

In Mumbai, the immense amount of garbage available attracts a lot of domestic dogs and feral pigs which in turn attract leopards (Edgaonkar 2002). Even in Los Angeles, USA, it has been reported that the plentiful and readily available household garbage and pet food had made the coyotes to consider private properties and human environment as ideal habitat (Howell 1982). If dietary shifts result in nutritional increases it may substantially lead to increase in population density. Improved nutrition causes increase in reproductive rates, often resulting in greater litter sizes, greater survival of offspring, and ultimately greater densities (Robbins, 1993). However, urban stresses anthropogenic disturbance, heat, noise, pollution, and other stimuli can influence reproductive characteristics (Ditchkoff *et al.*, 2006). Wildlife populations residing in close proximity to high human densities can have substantial negative effects on both wildlife as well as the human population. Due to presence of anthropogenic pressures the carnivores show some behavioural changes (Ditchkoff *et al.*, 2006). Due to low availability of suitable habitat and areas of high-human activity, dispersal distances of juvenile wildlife may be less in urban areas (Etter *et al.*, 2002). Some animals get into negative interactions (conflicts) with humans often causing human injury or death.

1.3 Rationale

Conserving large mammalian species in a human dominated landscape requires reliable quantitative information regarding their distribution, abundance and habitat requirements (Nowell and Jackson 1996; Karanth and Nichols 2000). Using this information, the effectiveness of management practices can be assessed and goals set for better management in future. Apex predators often are the most vulnerable species in human-dominated forests (Crooks and Soule 1999; Cardillo 2003; Swihart *et al.*, 2003; Borkowski *et al.*, 2011). Humans residing in urban areas are less familiar with wildlife and how to deal with problems posed by wildlife (Ditchkoff *et al.*, 2006). Leopard is an animal which has acquired a bad name in India as far as conflict is concerned (Daniel 1996). Conflict usually involves cattle depredation or human killing. Leopard attacks on human have also been reported from Sanjay Gandhi National Park in Mumbai, Maharashtra (Edgaonkar and Chellam 1998). As urbanization is increasing habitats are shrinking day by day (same is the case with the forests in Mumbai). Every conflict situation is a unique one and needs to be handled and resolved in a specific manner (Madden 2004). As Sanjay Gandhi National Park is one of the few protected areas within the city limits of a metropolis in India, there is a need for a better understanding of the leopard's ecology in this area.

1.4 Objectives

The present study has the following objectives and hypothesis

1. To estimate the abundance of leopard in Sanjay Gandhi NP.

Hypothesis

Leopard densities in Sanjay Gandhi NP would be high due to high abundance of domestic prey in the area.

2. To estimate the abundance of wild and domestic prey in the study area.

Hypothesis

The density of domestic prey would be higher than the density of wild prey.

3. To determine food habits of leopard.

Hypothesis

Feral dogs would form an important component of the leopard's diet than the wild prey species.

2. Study Area

The Sanjay Gandhi National Park (SGNP), also known as the Borivali National Park, extends over an area of 104 km² and spread across some portions of the Mumbai Suburban and Thane districts (19° 8' N, 72° 53' E and 19° 21' N, 72° 58' E) (Figure 1). The Vihar Lake forms the southern boundary of the SGNP. The townships of Bhandup, Mulund, Thane (Plate 3) and Goregao, Malad, Kandivali, Borivali (Plate 2) form the eastern and the western boundary respectively. The northern boundary extends beyond the Bassein creek and includes the Nagla forest block (Plate 1). About 8.5 km² of the total National Park area is covered by lakes. The Tulsi and Vihar lakes have a combined water spread area of about 8.62 km².

For management purposes, the SGNP has been classified into a core zone of 28.1 km², a buffer zone of 66.2 km² and a tourism zone of 8.6 km². The National Park is divided into three ranges i.e. Tulsi, Yeur, and Krishnagiri Upvan. NH-8 the western express highway runs parallel to the park on the western side whereas the Eastern express highway runs on the eastern side connecting Mumbai to Nashik.

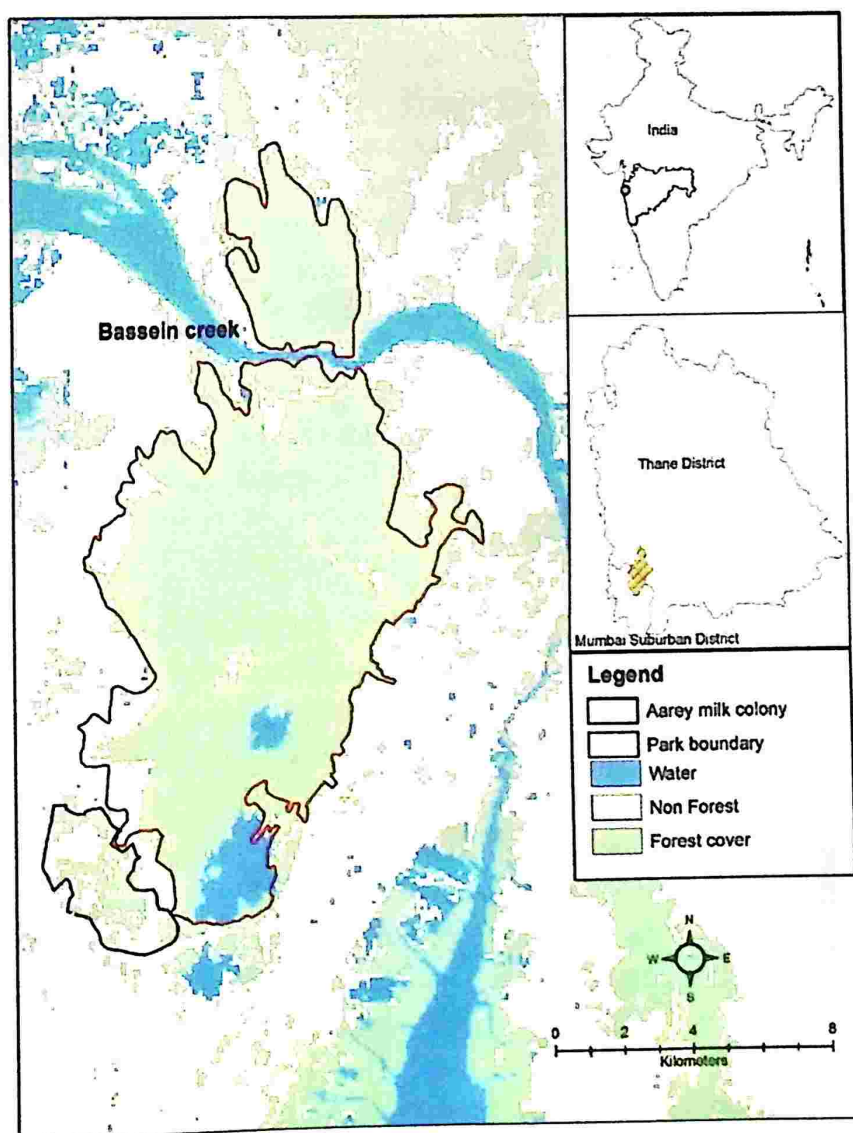


Figure 1. Location of Sanjay Gandhi National Park.

2.1 Geology

The park exhibits a diversity of terrain from 30 to 500 m above sea level. The topography is hilly with only a few plain areas. The hills are steep at certain places, giving way to precipices and rocky outcrops. The park is semi-mountainous; the level ground being between Tulsi and Vihar lakes, the lower westerly reaches of Krishnagiri Upawan and the northern end of Chena forest. These hills are regarded as the outer spurs of the Sahyadris (Western Ghats).

2.2 Climate

The mean annual temperature is 27° C, November to February is generally pleasant with nights tending to be cool, and temperature starts increasing from March and continues to increase till May. These months are quite warm and humid. The proximity of Arabian Sea makes the climate equable. The southwest monsoon gives abundant rainfall to the region. The mean annual rainfall is 2600 mm. The north-east monsoon usually gives a little rainfall of about 50 mm or less in November and December.

2.3 Vegetation

The forest is mainly of the Southern moist deciduous type (Champion and Seth 1968). Due to its proximity to the coast, numerous water courses and hilly terrain, the flora too presents a very diverse picture, ranging from dry and moist deciduous to semi-evergreen, open scrub and halophytes. The major tree species found are: *Tectona grandis* (Teak), *Terminalia tomentosa* (Ain), *Bombax malabaricum* (Red silk cotton tree), *Adina cordifolia* (Kadamba), *Butea monosperma* (Flame of the forest) and *Pterocarpus marsupium* (Bibla). In some densely wooded areas, pockets of semi-evergreen forest are also found. Some Teak plantations are also present as a part of the improvement fellings and silviculture system followed in the past (Rege 1974). Mangrove forests comprising of *Avicennia* sp. are also found along the tidal creeks and estuarine mudflats.

2.4 Fauna

Leopard (*Panthera pardus*) is the top carnivore in the park. Other meso-predators and omnivores found in the study area are jungle cat (*Felis chaus*), rusty spotted cat (*Prionailurus rubiginosus*), Asian palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), Indian Grey mongoose (*Herpestes edwardsii*), and ruddy mongoose (*Herpestes smithii*). The wild prey species found in the study area are spotted deer (*Axis axis*), sambar (*Rusa unicolor*), common langur (*Semnopithecus entellus*), wild pig (*Sus scrofa*), bonnet macaque (*Macaca radiata*), Rhesus macaque (*Macaca mullata*), barking deer (*Muntiacus muntjak*), mouse deer (*Tragulus memmina*) and black naped hare (*Lepus nigricolis nigricolis*) (Edgaonkar and Chellam 1998; Pradhan 2002). Domestic prey species such as cattle, buffaloes, goats, pigs, dogs are also found in the study area and adjoining areas (<http://dairy.maharashtra.gov.in/>).

2.5 Human dimension

Sanjay Gandhi National Park is one of the most highly visited protected areas in the country. Most of them visit the Krishna Upwan sector which comprises the recreation zone comprised of a mini train, nature trails, lion safari, tiger safari, lawns, and paddle boating (on an artificially made lake on Dahisar river). People also visit the Kanheri caves in huge numbers. These caves were built by Buddhist monks over 2000 years ago. This site is managed by the Archaeological survey of India. There exists an Air force communication base inside the NP at the highest point in the park at 500 meters above the sea level. The state electricity board also has a unit within the park boundaries. Bombay Municipal Corporation (BMC) has their water purification plants inside as well as on the periphery of the National Park as the lakes are managed by BMC. There are about six *padas* (Hamlets) inside the National Park boundary (Plate 4). Out of these six *Padas* three have access to electricity. Yeur and Chena are two villages within the National Park boundary. Some of the people living in these *Padas* practice agriculture. But majorly these people work as laborers or go outside the park on a daily basis for jobs. There is no pressure from livestock grazing in this park. People are majorly dependent on the forest for firewood; a lot of firewood collection takes place throughout the park (Plate 5). Collection of non-timber forest products takes place but on a very minor scale mainly of fruits.

2.6 Aarey Milk Colony (AMC)

The Aarey Milk Colony (AMC) located in Goregao East covers an area of 12.8 km² and the Film City are located to the southern border of the Sanjay Gandhi National Park. The vegetation of AMC is heavily human-modified which includes remnant patches of southern moist deciduous forest. Human-modified vegetation includes scrub forest and understory shrubbery composed of jujube (*Zizyphus mauritiana*), Lantana (*Lantana camara*), and plantations of exotic tree species as *Gliricidia* (*Gliricidia sepium*) and forest red gum (*Eucalyptus sp.*) (Punjabi et. al 2012). As these places have much altered forest and scrub patches that are contiguous to SGNP, they will also be included in the study area. The AMC consists of more than 30 cattle production units with a total capacity of over 15,000 head of cattle (Punjabi et. al., 2012). On an average, 16,000 cattle mainly buffaloes are reared on 1,287 hectares of land, and 32 cattle farms (<http://dairy.maharashtra.gov.in/>). The AMC holds domestic prey in the form of feral dogs and pigs, and waste generated from the cattle farms in the form of carcasses.

Plate 1. Bassein creek which lies on the northern side of the park separating Nagla block from the National Park.



Plate 2. Old (non-functional) stone quarry area on the western side of Sanjay Gandhi National Park.

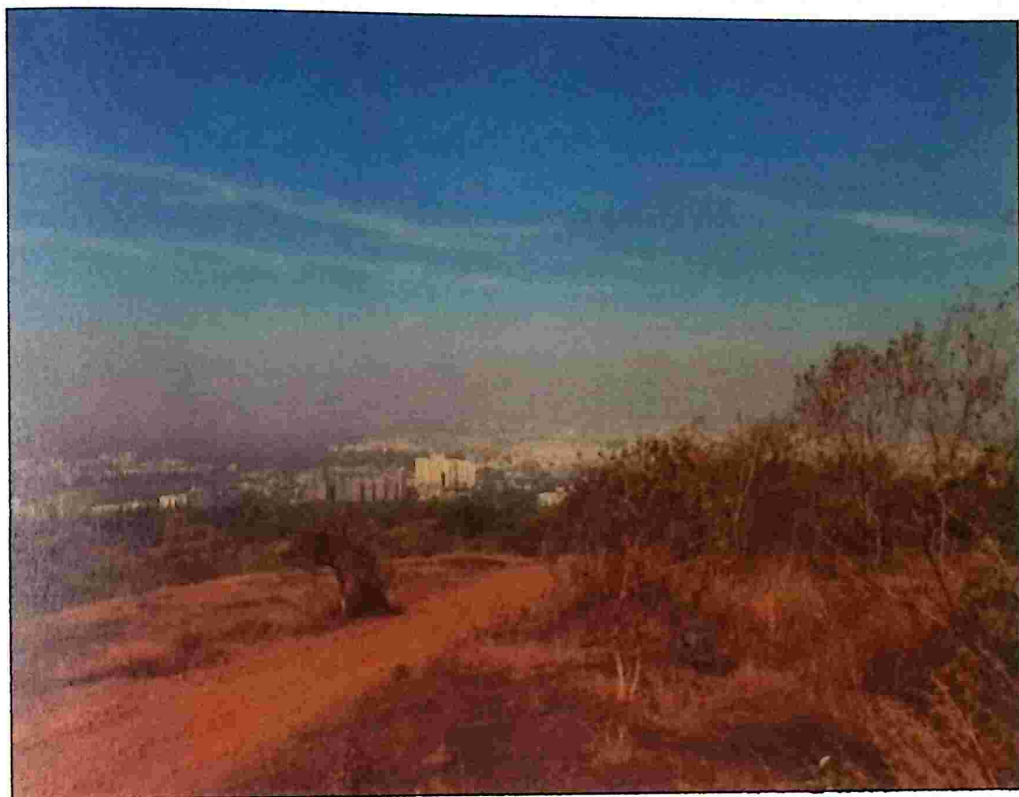


Plate 3. *Mama Bhanja Durgah* on the mountain top and the city on the eastern side of Sanjay Gandhi National Park.

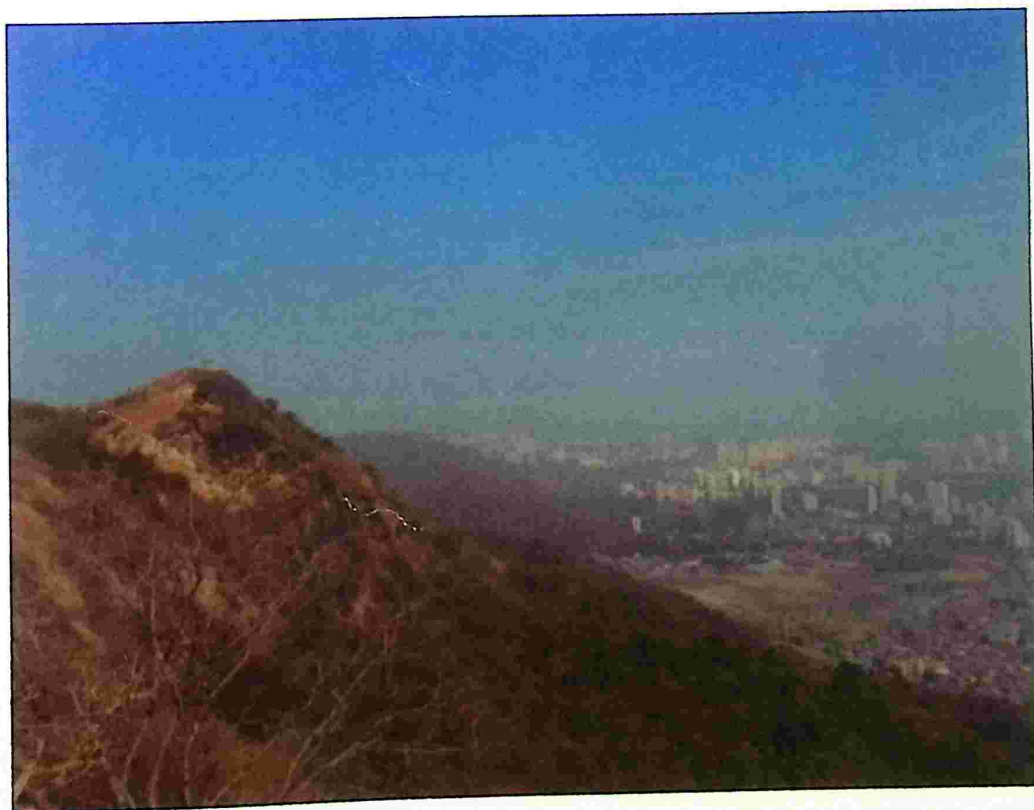


Plate 4. Spotted deer feeding at the Garbage dump near a hamlet inside the National Park.



Plate 5. Firewood collection inside the National Park.



3. Study Period

The study was carried out from December 2014 to 15th April 2015.

The first twenty days of the study period were spent in conducting reconnaissance survey in the study area. The forest beats were walked along with the beat guards covering all the ranges and all possible information on leopard and prey base distribution available was gathered. Using Garmin etrex a Global positioning system (GPS), leopard locations were noted down which would serve useful while doing camera trapping. Available roads and trails inside SGNP were also mapped for further use to conduct field surveys. A motorcycle was used wherever possible.

4. Methodology

4.1. To estimate the abundance of leopard in Sanjay Gandhi National Park

The entire study area of was divided into grids of 2x2 km. A preliminary survey was carried out throughout the study area to identify probable camera trap sites based on sign surveys for leopard (scats, tracks and others). This being a human dominated area the cameras were not set to function for 24 hours. Cameras were set only from 5pm in the evening to 7am in the morning. This was done to avoid theft of the cameras and loss of data. This involved a lot of effort and the entire study area could not be covered at one go. Hence the entire study area was divided in three blocks and block-wise camera trapping was carried out. Each of these three blocks consisted of 9, 10 and 12 camera trap locations. The cameras in each block were run for fifteen days except for the last block where they were run for fourteen days only. Thereby, the total sampling period amounted for 44 days. Some cameras were not functional on particular days at particular sites. Therefore the total sampling effort after considering all the functional cameras was 422 trap nights. A pair of camera traps was placed at each camera trap location for effective sampling and getting images of both the flanks of individual leopards. The camera traps used (Cuddeback attack and Cuddeback color C1) had built in motion and heat sensors to detect any animal movement. As each leopard individual has a unique rosette pattern (Plate 6) it can be used for individual identification (Henschel & Ray 2003). All Statistical analysis was done in programme R (R development core team 2014).

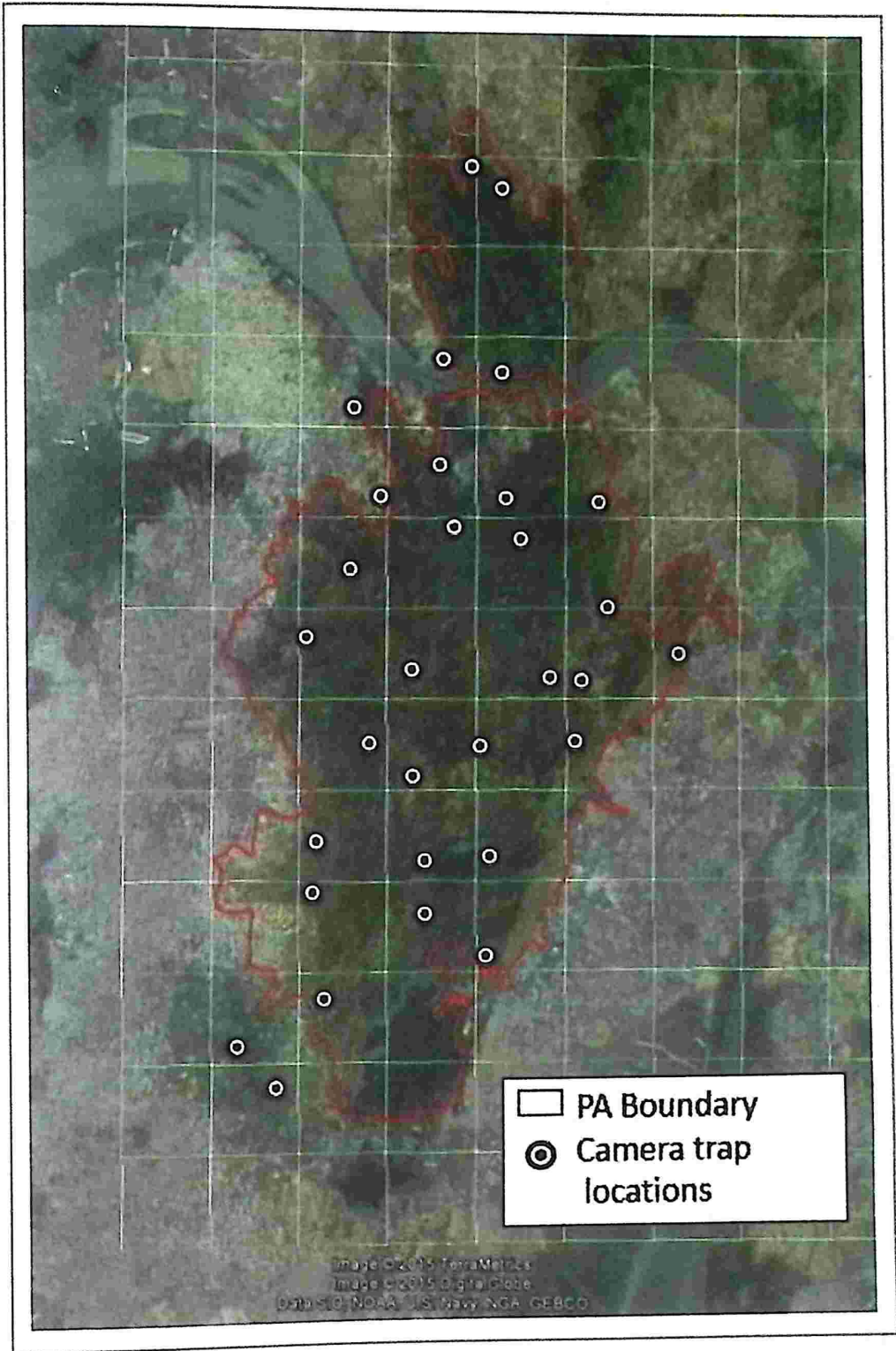
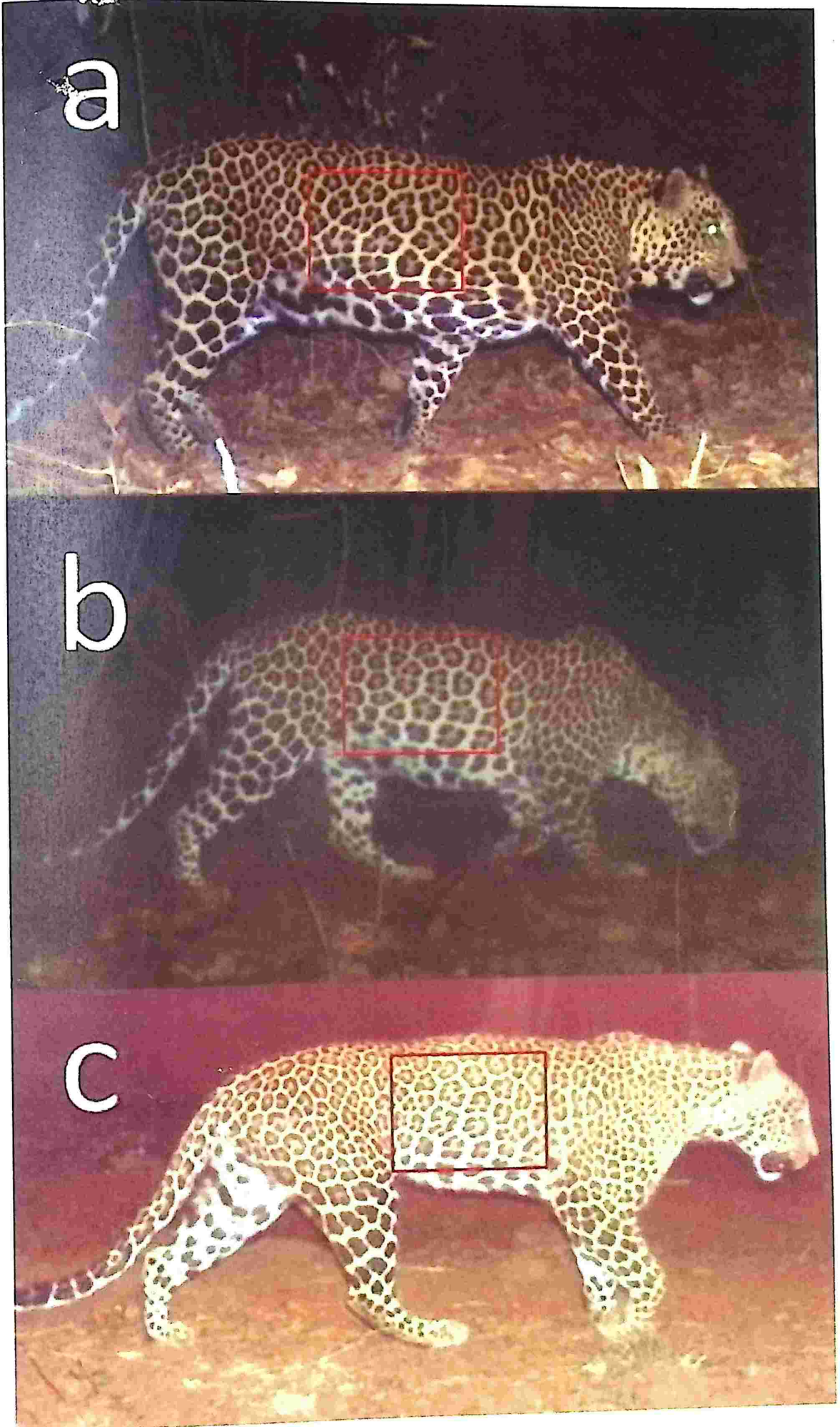


Figure 2. Camera trap locations in Sanjay Gandhi National Park (December 2014-April2015).

Plate 6. Three unique individuals (a,b,c) identified based on their unique rosette pattern.



4.2. To estimate the abundance of wild and domestic prey in the study area.

The variable distance line transect method was used to estimate prey density in the study area (Burnham *et al.*, 1980; Buckland *et al.*, 1993). Sixteen line transects were initially marked on a SGNP map covering major habitat and terrain types. These were marked taking into consideration the accessibility to the start points. Later the line transects were actually laid and marked on field (Figure 3) using a GPS device to get the exact location, a Sunto compass was used to check the line bearing, and a rope to measure the line length. Transects were cut in an appropriate manner so as to facilitate movement of two people without making much noise. All the line transects were marked and numbered using red paint, the paint was applied at least 6 feet above the ground. Each transect was walked 3 times in the morning and 2 times in the evening making a total of 5 replicates during the study period. Transects were walked with the help of trained forest staff and volunteers. The length of the line transects varied from a minimum of 1km to a maximum of 2 km. A total effort of 120kms was put into walking the line transects. While walking on a transect the bearing at which the animal was sighted and its ocular distance was noted down using a Sunto compass and a Hawk Range finder respectively. This data was noted down in a datasheet which was made in two languages i.e. English and Marathi for convenience of the local staff. The data collected was analysed in the software DISTANCE (Thomas *et al.*, 2010).

Domestic prey

The entire survey to estimate dog populations was conducted at three different locations which were spatially separated from each other (Figure 3). Ensuring geographic closure was the most important criteria while selecting these areas. The three dog survey locations selected i.e. Aarey milk colony, Kashmirira and Yeur village had areas such as 9.31, 1.64 and 1.69 respectively. Initially I surveyed all the three locations on a motorbike to identify certain fixed points where dogs were observed either in groups or singly. GPS locations were taken for all these points. The points selected were usually near garbage dumping sites, water bodies, feeding sites, human settlements and carcass dumping sites, if available. The points were spaced in a manner such that the area covered was large and that the perimeter to area ratio was small, so as to avoid violation of the assumption of geographic closure. In total Aarey milk colony, Kashmirira and Yeur had 50, 10 and 10 points respectively. Majority of the dogs were stray and some were classified as semi-owned but this had no change in the movement of dogs. Dogs were marked using the natural markings on their body even mono-coloured dogs were marked as each and every dog had some marking pattern which was unique to that particular individual. Mark-Recapture method was used to estimate dog numbers in the study area (Totton *et al.*, 2010). Peak activity hours in each of these areas were identified by an initial survey during the first two days. The surveys were carried out during the morning hours from 10 am to 12 am at Aarey milk colony and Kashmirira whereas at Yeur the survey was carried out from 5pm to 7pm. During each survey the observer along with a volunteer would cover all the fixed points at a location in a unidirectional way on a motorbike. At each point five minutes were spent and dogs present in 30-50 meter radius from the point were photographed so as to get good pictures of both the body sides and any distinct patch on their body. This was repeated for three days at Aarey milk colony and four days each at Kashmirira and Yeur. Each day was used as an occasion while analyzing the data in software Mark (White and Burnham 1999).



Figure 3. Line transects in Sanjay Gandhi National Park (December 2014- April 2015).

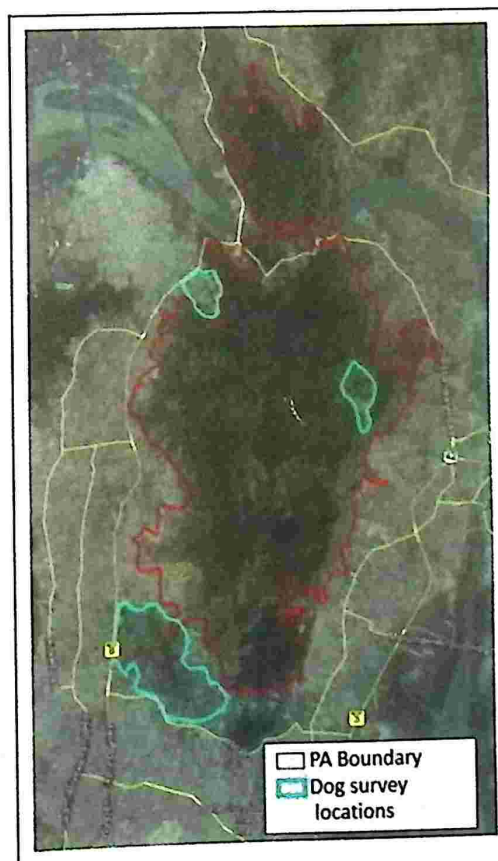


Figure 4. Dog survey locations in Sanjay Gandhi National Park (December 2014- April 2015).

4.3 To determine food habits of leopard.

Diet analysis was conducted using undigested material from leopard scats. Leopard scats were collected systematically along the identified roads and trails (n=25). Trails were walked twice a month. Only confirmed leopard scats were selected for the analysis based on their size, shape and secondary evidences such as scrape marks and pug marks. A total of 103 scats were collected out of which 97 were used for analysis. Scats were collected and stored in zip lock plastic bags with appropriate labels. These scats were sun-dried and then washed in running water. Undigested material like hair, nails and claws were collected from each scat sample. These were again sundried. Individual prey species were identified based on the medullary patterns of the hair and the same was compared with available reference slides (Mukherjee *et. al.*, 1994). The data obtained was analyzed to calculate relative frequencies of occurrence of individual prey in leopard's diet and the prey preference of leopard was assessed using Ivlev's index (Ivlev 1961).

5. Results

5.1 Estimation of population of leopards

Camera trapping resulted in a total of 88 photographs of leopards. Using their unique rosette patterns 31 leopard individuals was identified. A total of 85 captures of 31 individuals were recorded in 44 occasions. Spatially explicit capture-recapture analysis was carried out using secr package 2.9.4 in R programming (Efford and Fewster 2013). Spatially explicit capture-recapture framework was used as it is a more robust method of calculating densities compared to conventional models of MMDM and $\frac{1}{2}$ MMDM. In all I tested for seven models, the models differed by selecting different parameters for the individuals capture probability and movement pattern.

Table 1. Model selection for computing leopard densities based on AIC values.

Model	AIC	AICc	dAICc	AICcwt
g0s0	308.347	310.236	0	0.4039
g0sh2	309.497	310.897	0.661	0.2902
gbs0	311.347	312.885	2.649	0.1074
g0sb	311.347	312.885	2.649	0.1074
gh2s0	311.928	314.328	4.092	0.0522
gbsb	313.347	315.747	5.511	0.0257
gh2sh2	313.573	317.073	6.837	0.0132

AIC- Akaike information criteria

All the models were run successfully to estimate the leopard densities and the best fitted model was selected based on the AIC values. Different models such as the behaviour and heterogeneity models were run but the g0s0 model showed the best fit (Table 1). As the study had poor recaptures the behaviour and heterogeneity models did not fit well. Based on the model fits g0s0 was selected as the best model fit and therefore the leopard densities calculated were $21.55 \pm 4.6(\text{SE})$ at a confidence interval of 95%.

Photo capture rates

To obtain the photo capture rates for all the species captured in the camera traps the photo capture events for each species was divided by the total number of trap nights i.e. 422. This helped me derive a crude index of trapping and visitation rate for other species, for which rigorous capture-recapture sampling analysis was not possible.

Table 2. Photo capture rates for all the species being captured in the camera traps (February 2015 – April 2015 between 17:00 hours and 7:00 hours) at the Sanjay Gandhi National Park.

Sr. No	Species	Photo capture events	No. of captures /100 trap nights
1	Human being	123	29.15
2	Leopard	92	21.80
3	Wild pig	43	10.19
4	Sambar	41	9.72
5	Dog	29	6.87
6	Chital	15	3.55
7	House cat	10	2.37
8	Small indian civet	9	2.13
9	Cattle	9	2.13
10	Black naped hare	8	1.90
11	Palm civet	6	1.42
12	Bonnet macaque	5	1.18
13	Barking deer	4	0.95
14	Jungle cat	3	0.71
15	Mouse deer	1	0.24
16	Rusty spotted cat	1	0.24

5.2 Wild and domestic prey densities inside Sanjay Gandhi National Park

The density of all prey species was calculated using the program DISTANCE (Thomas *et al.* 2005). The analysis involved fitting of different detection functions to the observed data for estimation of densities. The best model was selected on the basis of the lowest Akaike Information Criteria (AIC) values (Burnham *et al.*, 1980; Buckland *et al.*, 1993). In total 8 potential leopard prey species were encountered on line transects viz., chital, sambar, barking deer, wild pig, common langur, bonnet macaque, grey jungle fowl and red spur fowl. Densities were calculated only for chital, sambar, common langur and bonnet macaque as rest of the species did not have enough number of sightings to be analysed in the program DISTANCE. Half normal cosine was found to be the best fitted model for chital and sambar and half normal hermite was the best fitted model for bonnet macaque and common langur (Table 3). All density estimations were made after truncation of the farthest sightings data from the line transect (Figure 5,6,7,8).

Table 3 Individual and group densities of major wild prey species of leopards estimated in Sanjay Gandhi National Park, Mumbai, Maharashtra.

Species	No. of groups (n)	Model	Min AIC	D	SE	DS	SE	ESW	SE	MCS	SE	N/I	SE
Chital	38	Half Normal Cosine	111.15	14.49	5.2	4.83	1.67	2.8	4.46	3.15	0.75	0.31	0.10
Sambar	40	Half Normal Cosine	56.07	7.52	1.7	4.28	0.86	39	4.25	2.07	0.29	0.33	0.06
Bonnet macaque	26	Half Normal Hermite	74.71	30.78	12	3.68	1.23	9.4	4.72	8.35	1.44	0.21	0.06
Common langur	92	Half Normal Hermite	130.15	48.04	8	13.07	1.86	29	2.45	3.66	0.29	0.76	0.09

- n : Number of groups
 Min AIC : Minimum Akaike Information Criteria value
 D : Individual density
 DS : Group density
 ESW : Effective strip width
 SE : Standard error
 MCS : Mean cluster size
 n/I : Number of animals encountered per kilometer of transect walk.

The highest density found was of common langur followed by bonnet macaque, chital and sambar (Table 3). Mouse deer was captured on one occasion in one of the camera traps on the north eastern side of the park. Rhesus macaque and mouse deer were not encountered on the line transects although they occur in the study area.

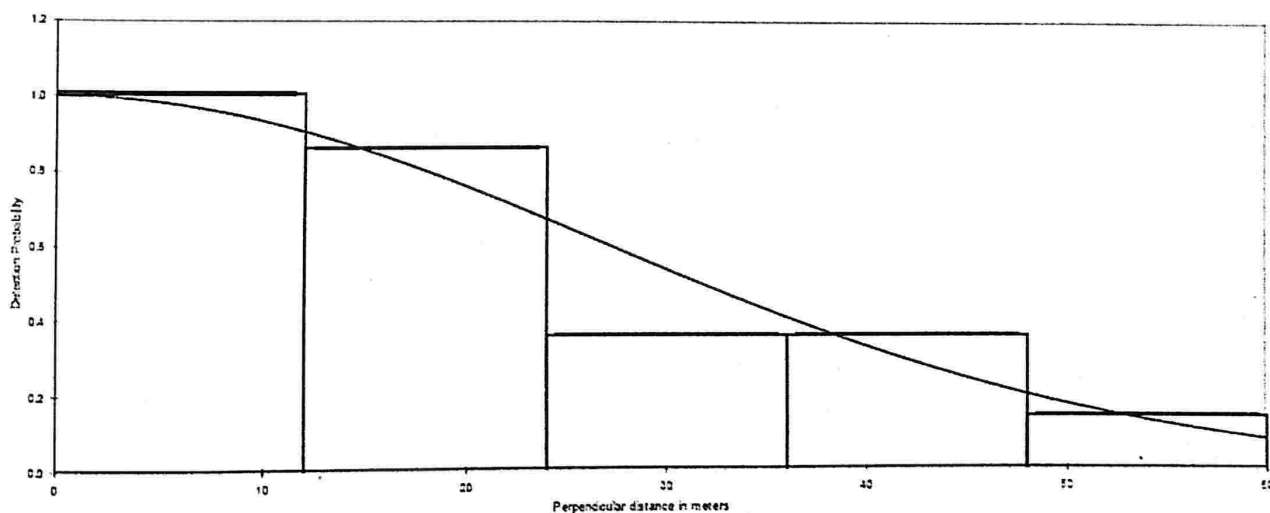


Figure 5. Detection probability of chital.

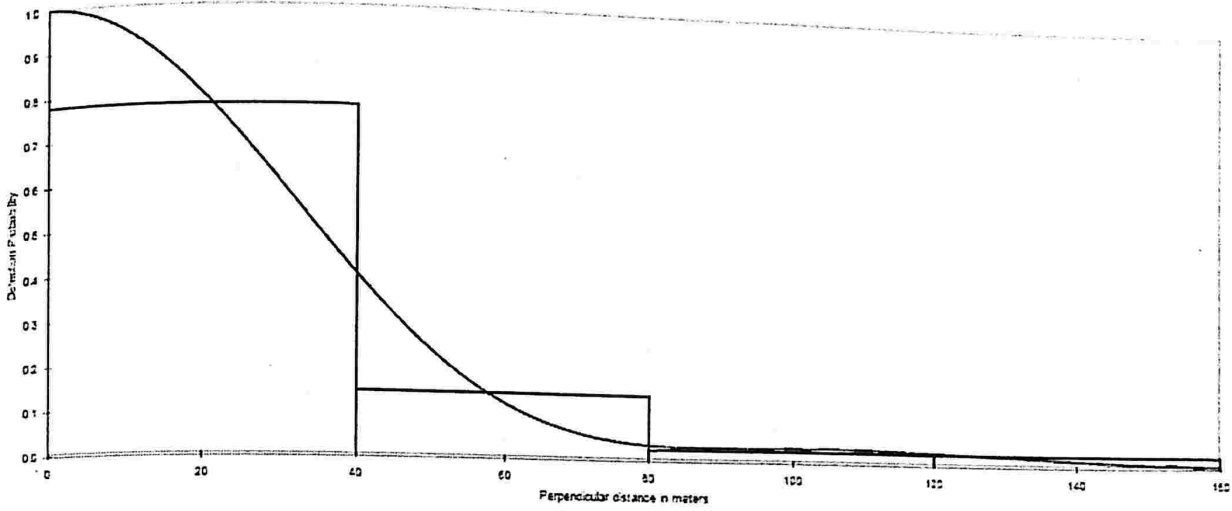


Figure 6. Detection probability of sambar.

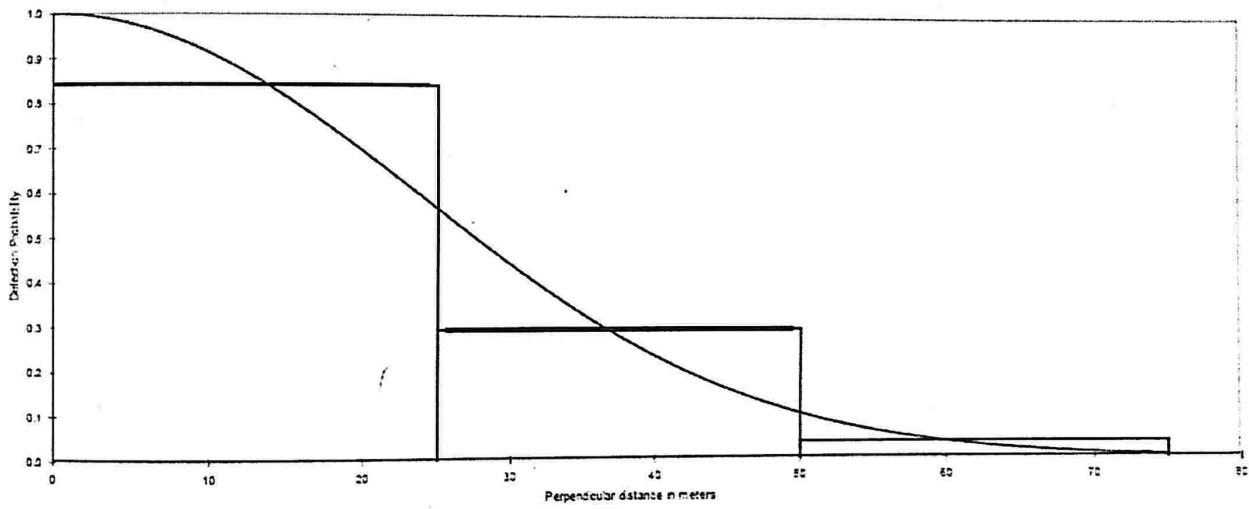


Figure 7. Detection probability of common langur.

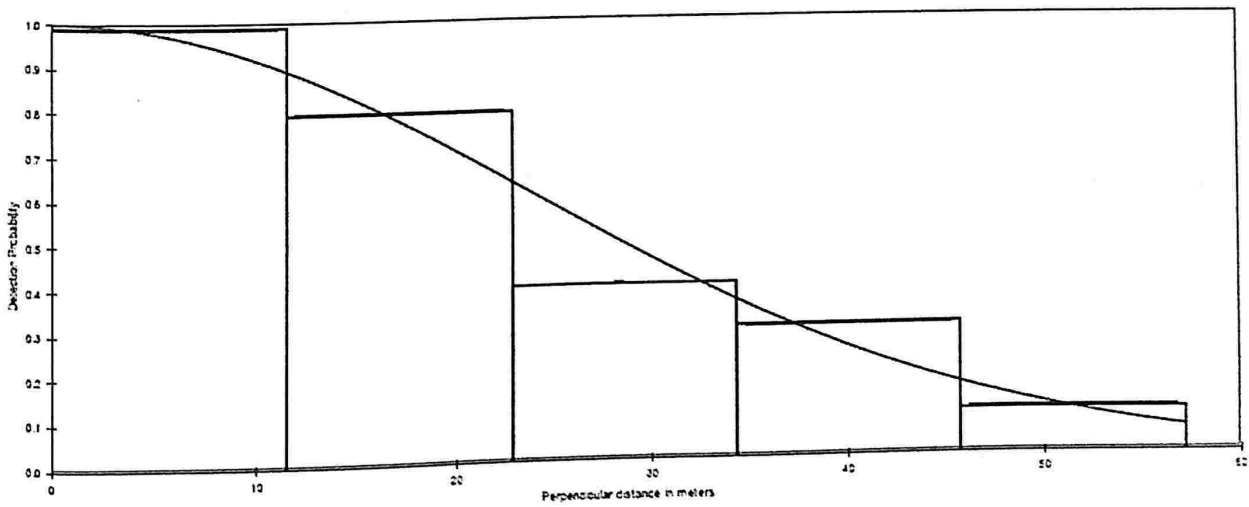


Figure 8. Detection probability of bonnet macaque.

Density of Dogs

Dogs were identified based on the natural markings present on their body. The number of dogs identified in each of the three locations is provided in table 4.

Table 4. Summary of captures of dogs in three dog locations.

Location	No. of dogs identified	Area (sq.km)	Occasions
Aarey Milk colony	274	9.31	3
Kashimira	61	1.64	4
Yeur	53	1.69	4

I used a total of four models viz. null model (Mo), behaviour model (Mb), heterogeneity model (Mh), and a combination of heterogeneity and behaviour model (Mbh) to analyse the dog data and derive their abundance. The Huggins closed captures model was used to estimate dog abundance using the Program MARK (White and Burnham 1999). Based on the Akaike's information criteria values which is corrected for small sample size (AICc values), the best model fit was chosen. The best fit model was found different for different sites.

Table 5. Model selection based on AICc values for different locations.

Area	model	npar	AICc	Delta AICc
Aarey milk colony	Mo	1	949.056	0
	Mb	2	950.572	1.516084
	Mh	3	953.0804	4.024462
	Mbh	5	955.9991	6.943171
Kashimira	Mb	2	321.4439	0
	Mo	1	322.6804	1.236506
	Mh	3	326.7639	5.319977
	Mbh	5	327.6462	6.202308
Yeur	Mo	1	288.8661	0
	Mb	2	289.8841	1.017959
	Mh	3	292.9625	4.096337
	Mbh	5	296.1179	7.251805

npar- no. of parameters.

AICc- Akaike information criteria corrected values for smaller sample size

Based on the AICc values for all the models which were run, Mb showed the best model fit for Kashimira and Mo showed the best fit for Aarey milk colony and Yeur (Table 5). Hence it was selected to derive reliable estimates of dog abundance from those particular areas. Aarey milk colony showed the highest abundance of dogs i.e. 280.66 ± 2.89 (SE) followed by Kashimira and Yeur (Table 6).

Table 6. Abundance of dogs at three different locations.

Area	Abundance	se	lcl	ucl
Aarey milk colony	280.66	2.89	276.96	289.02
Kashimira	61.49	0.79	61.05	65.51
Yeur	56.04	2.06	53.91	63.16

To estimate densities of the dogs in three different survey locations I calculated effective trapping area by putting a buffer around the trapping area. The buffer widths were taken from mean home range radius calculated from the trapping area. The buffer widths were taken from study of Vanak *et. al.*, (2010). This helped me derive densities for dogs from three locations namely Aarey milk colony, Kashmirira, Yeur. Maximum density of dogs was found at Aarey milk colony i.e. 20.22 ± 5.28 (SE) per km. sq. followed by Kashmirira ie. 16.1 ± 8 (SE) per km. sq. and Yeur 14.4 ± 7.1 per km. sq. (SE) respectively. A weighted mean of the densities from three areas was calculated for further analysis. The mean dog density calculated was 17.26 ± 0.69 (SE) per km. sq.

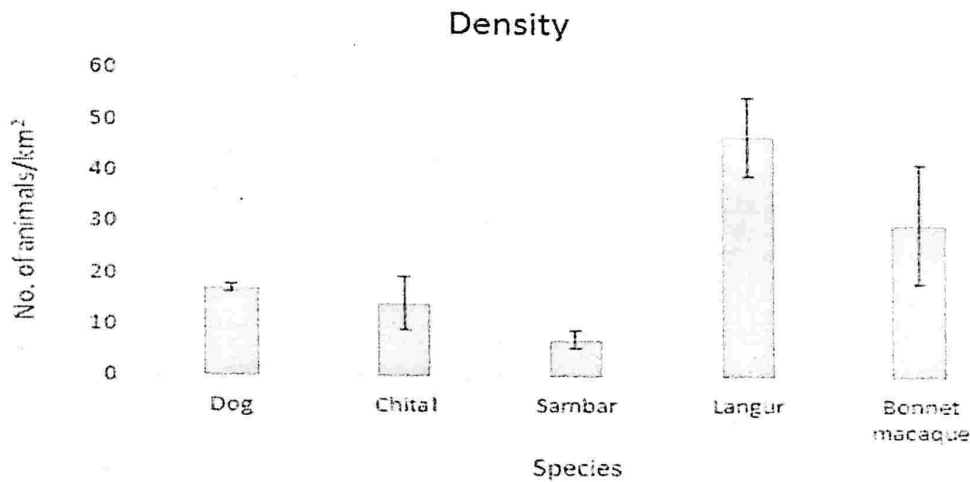


Figure 9. Densities of domestic and wild prey for leopards in and around Sanjay Gandhi National Park.

5.3 Leopard's diet composition

Altogether 133 remains from 13 prey species were found in 97 leopard scats. Sixty-six percent of leopard scats contained single prey species and 34 percent contained two prey species. Domestic prey contributed to 43% of leopard's diet whereas wild prey contributed to 57 % of it in terms of relative biomass consumed calculated using Ackerman's equation (Ackerman *et. al.*, 1984). To check the adequacy of sample size an observation-area curve was calculated (Odum and Keunzler 1955). A curve for the per cent frequency of occurrence of major species represented in the diet was calculated at an interval of every five scats, after randomising the order of the results obtained (Figure 9).

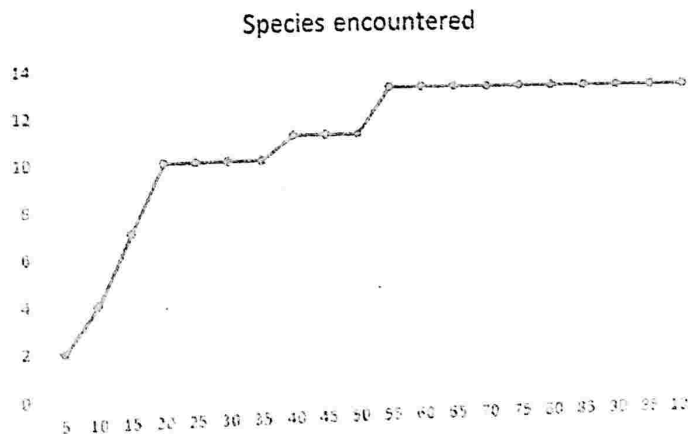


Figure 10. Observation-area curve for determining adequacy of sample size to determine leopard food habits based on scat analysis.

After analysing 60 leopard scats the curve flattened out as there was no more increment in the number of prey species encountered. This indicates that a sample size of 60 leopard scats were adequate to represent the diet spectrum of leopards in Sanjay Gandhi National Park.

Table 7. Frequency of occurrence of prey in leopard scats.

Prey species	Prey Species remains (f=113)	Average body weight (X)	Whole collectable scat (W=97)	Frequency of occurrence (F)	Relative frequency of occurrence
Dog	36	18	27	37.11	27.07
Chital	20	30	16	20.62	15.04
Rodent	21	0.5	9	21.65	15.79
Common langur	19	7	16	19.59	14.29
Cat	12	2	9	12.37	9.02
Sambar	5	200	5	5.15	3.76
Cattle	3	175	2	3.09	2.26
Bonnet macaque	3	6	3	3.09	2.26
Wild pig	6	47	5	6.19	4.51
Domestic fowl	4	2	2	4.12	3.01
Goat	2	30	1	2.06	1.50
Black-naped Hare	1	4	1	1.03	0.75
Bird	1	2	1	1.03	0.75

Although the frequency of occurrence of dogs was shown to be highest among all other prey species we cannot conclude about the contribution of dogs in leopard's diet (Table 7). The reason for this being, frequencies of the identifiable prey remains in the scat do not tell us about the actual proportion of prey type eaten. This is more so when the prey items vary in size to a considerable degree. Smaller prey species have more undigested material (hair) due to higher body surface to mass ratio. Hence, intake of smaller body sized prey induces relatively more amount of scat production per unit mass of prey leading to an over estimation of smaller prey species in the diet of carnivores (Floyd et. al., 1978; Ackerman et. al., 1984). The average weight of wild prey species of the leopard required for the biomass estimation was taken from Hayward *et. al.*, (2006) and that of domestic prey species was taken from Athreya *et. al.*, (2014). Using the given information relative prey biomass consumed was calculated (Table 8). Prey selectivity was estimated (Figure 9) using Ivlev's Index (Ivlev 1961) for each prey species by comparing their availability and utilization data.

Table. 8 Total biomass consumed for each prey in Sanjay Gandhi National Park.

Prey species	Biomass consumed/collectable scat ($Y=1.98+0.035X$)	Prey biomass consumed ($B=Y \times W$)	Relative biomass consumed
Dog	2.61		
Chital	3.03	70.47	24.46
Sambar	8.98	48.48	16.83
Langur	2.23	44.9	15.59
Cat	2.05	35.6	12.36
Wild pig	3.63	18.45	6.4
Rodent	2	18.13	6.29
Cattle	8.11	17.98	6.24
Bonnet macaque	2.19	16.21	5.63
Domestic fowl	2.05	6.57	2.28
Goat	3.03	4.1	1.42
Black-naped Hare	2.12	3.03	1.05
Bird	2.05	2.12	0.74
		2.05	0.71

Ivlev's index gives us a fair idea about prey selection by the predator (Figure 11). The index value is in the range of -1 to +1, where negative values indicate that the prey item is less utilized and positive values indicate that it is utilized more. It was found that domestic dogs were the most utilized prey species by leopards. Sambar was less utilized by leopards. Only four prey species were taken for comparison as densities could not be estimated for other prey species and these were the major contributors in the leopard's diet in terms of biomass (Figure 9).

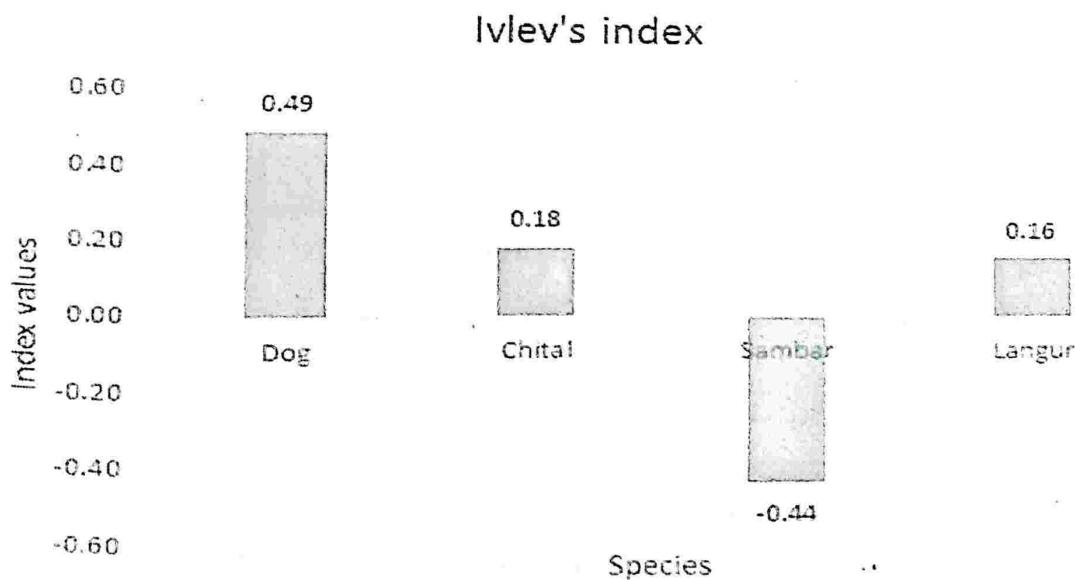


Figure 11. Ivlev's index for major prey species of leopards in Sanjay Gandhi National Park

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6. Discussion

6.1 Leopard population

Sanjay Gandhi National Park located in Mumbai is one of the few Protected Areas in the country which falls within the municipal limits of a metropolis. The National Park has human pressure from all four sides leaving a small window on the northern tip. The minimum human density on the periphery of the park is about 20,000 people per sq.km. The encounter rate as given in table 2. also indicated the high usage of the National Park by humans. Even though the camera traps were set only during the night hours, the photo capture rates shown by humans was higher than any other wild or domestic prey species captured. This situation is perhaps unique in the world where such a high density of a large cat is sharing space with extremely high density of humans. When seen in context of attacks on people it is extremely interesting as there were no attacks on people reported in the study period. Sanjay Gandhi National Park shows a leopard density of 21.55 ± 4.6 (SE)/100 sq.km based on the present study which, has one of the highest density of leopards found anywhere.

This study is the first to obtain density estimates of leopards from Sanjay Gandhi National Park based on a scientific approach. The only existing leopard numbers available from Sanjay Gandhi National Park are those from the total counts done by the Forest Department on a yearly basis. This was based on counting individual leopards at different water holes at the same time which may not give reliable estimation of leopard population due to untested assumptions involved in it. Another study which was conducted in Sanjay Gandhi National Park (Mirza *et. al.*, 2013) also gave a minimum number of 21 leopards present in the park using camera trapping. In this study the cameras were placed opportunistically. Leopard is the apex predator in the study area. Absence of tigers can also help us better understand the high density of leopards in the study area. Two studies available from India have proved that when tigers were introduced in an area where they were absent previously, resulted in drastic decrease in leopard densities (Harihar *et. al.*, 2011; Mondal *et. al.*, 2012). Leopard densities available from India cannot be directly compared to my study, majority of the studies have been conducted in natural systems unlike this. And the density estimates are derived using conventional models such as MMDM and $\frac{1}{2}$ MMDM. The only existing study on leopard densities from a human-dominated landscape in Maharashtra (Athreya *et. al.*, 2013) showed a density as low as $4.8 \pm 1.2/100$ sq.km. The probable reason for such high density of leopard in Sanjay Gandhi National Park could be due to availability of domestic prey. The available prey biomass has been observed to strongly influence tiger (Karanth *et. al.*, 2004) and leopard densities (Carbone and Gittleman 2002; Khorozyan *et. al.*, 2008). The available prey in terms of domestic dogs was high on the periphery of the SGNP (figure 5.2). The leopards are largely dependent on dogs as evident from the present study. Camera trapping also revealed territorial overlap of a few leopards to a certain extent in the present study. On many occasions leopards have been reported and observed in the periphery of the buildings present on the boundary of the National Park. Many apartments on the periphery of the park which have CCTV cameras installed have recorded leopards in their vicinity. Therefore it can be concluded that leopards are found in high densities in Sanjay Gandhi National Park and that they are using the Park as a refuge.

6.2 Prey population

The estimated wild prey densities in the study area were observed to be low and are also confined to only certain patches inside the park. Among ungulates chital showed the highest prey densities of 14.49 ± 5.2 (SE) per km. sq. inside the park. But these densities when compared to other Protected Areas in India seem to be quite low. Chital densities from Ranthambore (Bagchi *et. al.*, 2003), Nagarhole (Karanth and Nichols, 1998), Bandipur (Johnsingh 1983) and Mudumalai (Varman and Sukumar, 1995) are 31.05, 38.1, 43 and 25.03 respectively. Chital is an animal which prefers open grassland type of habitats and such habitats available in the park are highly disturbed. Sambar are present in good number inside the park with a density of 7.52 ± 1.7 (SE) per km. sq. I did not have much sightings of wild pigs on the line transects as they were majorly found to be nocturnal based on the camera trap data (Table 2). A pair of mouse deer was also photo-captured in one of the camera traps during the camera trapping conducted for leopards. After discussions with *Van Majurs* I got to know about presence of mouse deers in certain pockets of Sanjay Gandhi National Park such as Chena and Goregao areas. The high densities of primates inside the park could be due to garbage generated through tourism activities. Even though dogs are present inside the park their numbers are quite low as people staying inside the parks usually avoid keeping dogs in order to avoid leopards. But dogs are present in good numbers on the periphery of the park at a density of 17.26 ± 0.69 (SE) per km. sq. High dog densities on the periphery of the park can be explained by the presence of humans and immense amount of garbage.

6.3 Leopard's diet.

The generalist behaviour of leopards is clearly reflected in the present study. On the basis of scat analysis the leopard was observed to be feeding over a range of prey items varying in weight from 0.2 kg to 200 kg. The presence of dog, cat, domestic fowl, cattle, goat remains in the leopard's scat can be justified on the basis of the human settlements on the periphery of the park. Dog was observed to be the principal prey species for leopards in Sanjay Gandhi National Park as it showed the highest contribution in the leopard's diet in terms of biomass. Leopard's liking for dogs near villages and inhabitations has already been well documented in literature (Daniel 2009). Other studies from India outlining the importance of dogs in leopards diet are those from Maharashtra (Edgaonkar and Chellam, 2002; Athreya *et. al.* 2014) and Jammu and Kashmir (Shah *et. al.*, 2009). Primates including bonnet macaques and common langurs have good densities in the study area. As these are arboreal animals they are not easily accessible to leopard's hence they were not adequately represented in leopard's diet. There are cattle sheds present on the southern and north-eastern sides of the park. Once cattle is dead the general practice followed by the cattle owners is to dump the carcass. So there might be a possibility of a scavenging occurrence on dead livestock which was discarded. Otherwise Forest Department does not have any records of livestock depredation (S. Saste-Assistant conservator of forest *pers. comm.*). Prey remains of cat, cattle and goat have also been documented by Athreya *et. al.*, (2014) in leopard scats. Leopard diet from the same study comprises only of domestic prey in it, with the only representatives from wild being small Indian civet, mongoose and wild pigs. Relative biomass contributed by dogs in leopard's diet was found to be 39.2% in the Ahmednagar district from western Maharashtra (Athreya *et. al.* 2014). Biomass contribution of dogs from the present study is 24.26% in the leopard's diet. The present study had considerable contribution from wild ungulates and primates in the leopard's diet in terms of biomass. Although there exist two studies

(Edgaonkar and Chellam, 2002; Tiwari and Prasad, 2009) from Sanjay Gandhi National Park on food habits of leopard and comparisons could not be made with them due to difference in scale. But both the studies showed dog as the principal prey for leopards in their results. But there was a significant difference in the present study and the past two studies in representation of cervids in the leopard's diet. The present study showed about 16.83 and 15.59 percent of contribution in terms of biomass from chital and sambar in leopard's diet respectively. Whereas the previous studies showed a very minimal presence of cervids in leopard's diet. Although sambar was available in the study area in good numbers it was avoided by leopards (Figure 9) due to their preference for medium sized prey (Hayward *et. al.*, 2006). The present study just highlights the already existing fact about importance of dogs in leopard's diet.

AT

7. Conclusion

The study suggests that the leopard is dependent on both wild as well as domestic prey. This is turn is responsible for the high density of leopards shown in the study area.

8. Management of leopards in Sanjay Gandhi National Park.

Since this leopard population is residing so close to human habitations we need to know the demographic details of this population present in a human dominated landscape. Such studies should be made a part of routine monitoring of leopard populations as it would help the authorities to better understand the ecology of the leopard. The growth rate, annual turnover, precise sex ratios of leopards need to be known for better management. We need to know how far the leopards go from the park boundary, their visitation rates and their mean home range size. This can be known by radio collaring some of the leopard individuals inside the National Park.

The Sanjay Gandhi National Park is one of the National parks in India which show higher leopard density. But the National Park is highly altered and this needs to be taken care off. The human activities inside the national Park should be regulated.

Studies should be conducted in Sanjay Gandhi National Park to assess the carrying capacity of wild prey. If the prey densities are lower than the carrying capacity then efforts should be made to increase them. If not then the habitat quality should be improved.

Dogs form an important component of the leopard's ecology in Sanjay Gandhi National Park. But a constant exposure to domestic dogs by leopards also increases the risk of disease transfer. Nowell and Jackson (1996) reported a loss of about 30% of the lion population which was wiped out due to canine distemper. The dog population needs to be managed and vaccinated but a direct removal of the dog population will affect the prey availability for leopards drastically hence it needs to be well planned.

People living on the periphery of the National Park need to be educated about how to deal with leopards. They should be taught how to minimize contact with leopards by taking safety precautions.

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10. Appendix

Plate 7. Setting camera traps in the study area.



Plate 8. Camera trap image of a wild pig with the city in the background.

