STATUS AND SPATIO-TEMPORAL RANGING BEHAVIOUR OF LEOPARD (PANTHERA PARDUS) IN DACHIGAM NATIONAL PARK, SRINAGAR, JAMMU AND KASHMIR

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EXECUTIVE SUMMARY

Leopard (*Panthera pardus)* is the most widely distributed and persecuted felid amongst large cats. It is known for its ecological flexibility and found to occupy almost all habitats except for pure deserts. However, like other large carnivores, leopards are declining throughout their range due to habitat conversion, prey depletion, intense persecution and poaching for trade. In India, it largely coexists with other felid species like the tiger (*Panthera tigris*) across much of its distribution range and with lion (*Panthera leo*) and clouded leopard (*Neofelis nebulosa*) in certain areas of its distribution range. In Kashmir valley, leopard is at the top of the food chain and an apex predator and assumed to regulate prey populations. Conservation and management planning of the leopards in Kashmir valley is impeded by the paucity of reliable empirical ecological information. There has been an increase in the human leopard conflict in the valley which, if left unnoticed, will worsen the conservation prospects of this threatened felid. Hence, study was initiated by Wildlife Institute of India, Dehradun with support funding from the Department of Science and Technology (DST), Government of India, in December 2010 to December 2013 to estimate leopard population and prey abundance, to study the leopard feeding habits and to determine the ranging behavior of leopards in Dachigam National Park. This thesis is an outcome of the main study and has three main objectives. The first objective being to determine the population status of leopards; second is to study the ranging behaviour and habitat use by leopards and lastly to model habitat suitability for leopards in Dachigam National Park.

Data for density estimation of leopard was collected by means of camera trapping which was conducted during May–June, 2013 by dividing the area into a grid system of size 2 km x 2 km. Due to limited number of cameras (n=20) available, a pair of Cuddeback-attack™ digital cameras was set in each grid of 4 km^2. Density estimates were obtained from non-spatial as well as spatially explicit capture-recapture analysis methods. Relative abundance indexes were also calculated from camera trap photographs. By using the same data diel activity patterns and temporal overlap as well as probabilistic model of spatial species co-occurrence amongst mammalian species was also quantified.

A total of 378 photographs of 10 species were recorded during the whole sampling exercise of 396 trap days (after deducting the days cameras were nonfunctional). Red fox was the most commonly photographed species with 125 photo-captures. Kashmir gray langur and wild pig were least photographed species each with two captures only. A total of 14 leopard photos were obtained during the camera trapping exercise of which two male leopards (71% male captures) and one female leopard (29% female captures) were identified.

Density estimate for leopard (*Panthera pardus*) obtained from programme CAPTURE was 2.8 ± SE 1.18/100 km^2 and the SECR density obtained from software SPACECAP was 0.744 ± SE 0.18/100 km^2. The leopard density estimates, which are a first record from the state of Jammu and Kashmir, turned out to be the lowest (SECR estimates) in the country. The jungle cat and the Indian porcupine tended to be strictly nocturnal whereas the leopard cat and the red fox were primarily nocturnal and crepuscular, yellow-throated marten was diurnal. The Asiatic black bear, leopard and the hangul showed no clear pattern. We found highest temporal overlap ($\hat{\Delta}_1$ = 0.84; 95% CI = 0.54 – 0.86) between leopard and Asiatic black bear followed by pairs between red fox and leopard cat ($\hat{\Delta}_1$ = 0.83; 95% CI = 0.72 – 0.91) and jungle cat ($\hat{\Delta}_1$ = 0.82; 95% CI = 0.60 – 0.91). The lowest temporal overlap was found between yellow-throated marten and Indian porcupine ($\hat{\Delta}_1$ = 0.11; 95% CI = 0.08 – 0.20). The results from probabilistic pairwise species co-occurrence analysis suggest that out of 28 possible species pairs 25 had random associations and one pair was unclassifiable. The remaining two species pairs had positive associations of co-occurrences between leopard cat and hangul ($P_{gt} < 0.05$) and Indian porcupine and hangul ($P_{gt} < 0.05$).

In order to study ranging behaviour of leopards three leopards (one male (represented as M73) and two females (as F71 and F74)) captured and collared using GPS collars between May 2011 and July 2013. The home range sizes, home range overlap, movement patterns and habitat use for these animals were analysed. The GPS locations obtained from the collared leopards were also used for habitat use analysis using Jacob’s index. Leopards in Dachigam National Park produced largest home ranges estimates from the Indian subcontinent. Home range estimate was maximum

(100% MCP = 145 km^2; 90% FK = 130.03 km^2) for the male (M73) leopard. In case of female leopard (F74), the estimate was 100% MCP 94 km^2. This collared female (F74) produced yearlong data based on which seasonal home ranges were estimated whereas female F71 produced data only for 20 days. Seasonal homer ranges (100% MCP) for F74 leopard in increasing order is winter (41.4 km^2) < spring (48.42 km^2) < autumn (67.9 km^2) < summer (~74 km^2). 90% FK home ranges also follow the same trend as winter (40.5 km^2) < spring (43.9 km^2) < autumn (54.5 km^2) < summer (62.2 km^2). The summer home range (100% MCP) of the male (M73) was 1.96 times larger than the female leopard (F74). The 50% FK core area for the male (M73) was ~30% smaller than the 90% FK. The 50% FK core areas for female (F74) did not follow the previous seasonal pattern and showed variation as spring (10.7 km^2) < winter (13.1 km^2) < autumn (16.1 km^2) < summer (16.5 km^2). 50% FK Core areas overlap between the male (M73) and female (F74) leopards was 44.25%. The leopards showed large variation in daily distances moved during the lean season of summer. Daily displacement was longer for the male leopard (median displacement = 588 m) than the female leopard (median displacement = 367.44 m). The male leopard travelled a maximum distance of 6.75 km while the two females (F71 and F74) travelled maximum distances of 3.30 km and 9.78 km, respectively (Table 4.8). The total distance travelled by the male leopard (398.71 km) was greater than the female leopards: F74 (374.16 km) and F71 (62.91 km). In case of female leopard F74, the mean (±SE) daily distance travelled was highest during the winter season (1.171 ± 0.090 km) followed by autumn (0.933 ± 0.063 km), spring (0.842 ± 0.037 km) and summer (0.699 ± 0.037 km).

A total of seven habitat types were identified as relevant for assessing leopard habitat use. Of these, six were vegetation categories and one was human habitation category. Home ranges of each collared leopard were overlaid on the LULC map for habitat use analysis. The most common habitat types in the landscape were temperate grassland (~24%) followed by broadleaved forest (~23%), conifer/pine forest (~21%) and alpine meadow (18.5%). In the combined home range of all leopards, the area of human habitation was just 3.64 km^2. Overall, leopards preferred broadleaved forests in Dachigam landscape. The male leopard – M73 selected alpine meadows the most followed by broadleaved forests. The female leopard – F71 which was tracked for short duration selected orchard/cropland/plantation during its entire period of 20 days in Dachigam landscape. Female leopard – F74 selected broadleaved forest whereas its selection of habitats changed during summer season where it selected alpine meadows in comparison to broadleaved forest.

A total of 145 presence locations of leopard were selected spreading across the Dachigam Landscape each of these were chosen considering spatial independence as all the data layers were at the resolution of ~1 km. All environmental variable files including bioclimatic layers were prepared for suitability modelling in Dachigam landscape. Maximum entropy (MaxEnt) model was used for running the analysis. A total of 11 environmental variables which were used for running the analysis, all the eleven variables contributed 100% in explaining the distribution of the leopard in the landscape. Of these 11 variables, precipitation of the driest month followed by human influence index and terrain roughness/ruggedness contributed maximally as 25.2%, 22.6% and 14.3%, respectively. The role of each variable used for suitability prediction analysis in Dachigam landscape, examined using the jackknife test against MaxEnt prediction gain, found that the highest gain was when the precipitation in driest month was used in isolation. Therefore, this variable had the highest predictive power and had the most useful information in prediction of leopard distribution. The environmental variable that decreased the gain most when it is omitted was mean diurnal temperature range. Therefore, this variable decreased the prediction probability of leopards in Dachigam landscape and had the most information that isn't present in the other variables. Variables such as precipitation in driest month, mean diurnal temperature range, human influence index, terrain roughness and LULC categories impacted positively and influenced the leopard distribution in Dachigam landscape.

This study also provides basic information about co-occurrence of mammalian species in the community of the moist temperate forest of the Kashmir Himalaya, India. The leopard density estimate was found to be lowest (SECR estimate – 0.74 per 100 km^2) among the areas consisting leopard populations across India. The status of other ungulate species reported from the area such as Kashmir musk deer, Himalayan serow and wild pig is not known. The detection of wild pig was after a gap of three decades. This study also sheds some light on leopard activity pattern in the Dachigam NP and has revealed that this area has very poor prey base which costs leopard very high searching efforts with very less benefits. In the present scenario it cannot be ruled out that the forests of the Kashmir Himalaya including Dachigam are susceptible to or suffering through “empty forest” syndrome.

The home ranges of both male and female were found to be largest in comparison to reported ranges from elsewhere in India. The large home range estimates suggest the low availability of food resources in the study area as abundance and distribution of food resources govern the home ranges of adult females. There is seasonal variation in selecting different habitats by female leopard for which complete one year’s telemetry data in the study area is available. Overall, leopard prefers broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain. It is expected that the vegetation at the valley floor provides good cover and stealth for ambush or stalking prey to leopard benefitting it in obtaining prey as it inhabits mainly in forested habitats. the leopard distribution is positively related to areas of human influence, elevation and vegetation types. Amongst the vegetation categories, highest influence on leopard distribution is of broadleaved vegetation followed by temperate grasslands and scrubs. Preference is shown for broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain.

CHAPTER 1
INTRODUCTION

1.1 Background

Order Carnivora is divided into two sub-orders of which felids belong to the cat-branch (suborder Feloidea: the cat-like carnivores), and can be differentiated from the canids (suborder Canoidea) because of the presence of auditory bulla. Despite having a very wide range in size across the 36 extant species of wild felids consists of gigantic Siberian tiger, *P. t. altaica* (200–325 kg) to the tiny rusty-spotted cat, *Prionailurus rubiginosus* (Approx. 1 kg), of India, Nepal and Sri Lanka, there is peculiar uniformity in these species (Macdonald, Loveridge and Nowell, 2010). Almost all have strongly patterned coats, with the exception of a few (4–5) species in which adults lose the coat markings that appear in the juveniles. All cats have reduced dentition of 8-9 teeth in each jaw quadrant. Therefore, cats' behaviour by and large is remarkably similar among all the cats, thus – cats are very evidently cats (Macdonald 1992).

Felids (Cats) are at an extreme among carnivores precisely due to their habit of relying on the flesh of vertebrates (Macdonald, Loveridge and Nowell, 2010) and they need to capture, subduing and eating the prey (Kitchener, Van Valkenburgh and Yamaguchi, 2010). Moreover, due to recent evolution of most of the cats, they look similar (Kitchener, Van Valkenburgh and Yamaguchi, 2010).

1.2 Phylogeny and evolution of felids

The first felid like carnivores appeared in the Oligocene, circa 35–40 million years ago (Beninda-Emonds *et al.* 1999; Mattern and Mclennan, 2000). Members of sub-family Felinae are known to originate in the late Miocene which ultimately evolved into one of the world's most successful carnivore families, occupying most of the continents except Antarctica (Nowell and Jackson, 1996; Johnson *et al.* 2006). Earlier, Africa used to be considered as the oldest origin of pantherine fossils, but recently conducted studies on molecular phylogenies point to Asia as the oldest region of origin. This contradiction has been cleared by the recent finding of a fossil pantherine from the Tibetan Himalaya. This discovery of fossil pantherine has been estimated to be from Late Miocene and Early Pliocene age, substituting africa's ecord of oldest pantherine, thus clearing doubts and providing robust support for the Asian origin of the pantherines (Tseng *et al.* 2014). However, the pantherine cats as a whole diverged about 6.37 million years ago whereas all big cats including leopards (*Panthera pardus*) about 3.72 million years ago (Johnson *et al.* 2006).

1.3 Biogeography of felids

The wild felids inhabit all continents except the Australasia and the Antarctica, and are found on numerous islands from large (Borneo) to small (Trinidad). These felids exploit a range of diverse habitats such as boreal and tropical forests, steppe, deserts, and savannah. Specialists are tropical species with less size and 32 species have been recorded to occur in habitats consisting closed forests and woodlands (Nowell and Jackson 1996). Tropical and temperate Asian regions have the maximum number of felid species (12, with 10 found only in this biome). Europe and the cold continental regions of Asia have seven species (with four endemic species). The south-west Asia which has hot–dry conditions has seven species which are all found in Africa. The lion *P. leo* and cheetah *Acinonyx jubatus* have scanty populations in south-west Asia and the tiger *P. tigris* became extinct there several decades ago. There are only endemic cat species out of ten in the Africa.

1.4 Study species – The leopard

Studies on pantherine mitochondrial and nuclear DNA have concluded that, of the 5 members of the pantherine group, leopards were the last to diverge and were closely related with snow leopards (*Panthera unica*) (Yu and Zhang 2005). Johnson and O'Brien (1997) have placed leopards with the other big cats that are capable of roaring. The best estimates, constructed from molecular analysis, suggest the existence of a minimum of 9 recognized sub-species (Miththapala, Seidensticker and O'Brien 1996; Uphyrkina *et al.* 2001) which can be defined described as follows –

S. No.	Species	English Name	Region of occurrence
1	*Panthera pardus pardus*, Linnaeus 1758	African leopard	sub-Saharan Africa
2	*P. p. nimr*, Hemprich and Ehrenberg 1833	Arabian leopard	the Arabian Peninsula
3	*P. p. orientalis*, Schlegel 1857	Amur leopard	the Russian Far East, Korean Peninsula and Northeast China
4	*P. p. fusca*, Meyer 1794	Indian leopard	the Indian Subcontinent
5	*P. p. delacouri*, Pocock 1930	Indo-Chinese leopard	mainland Southeast Asia
6	*P. p. melas*, Cuvier 1809	Javan leopard	Java, Indonesia
7	*P. p. japonensis*, Gray 1862	North Chinese leopard	northern China
8	*P. p. saxicolor*, Pocock 1927 previously considered Caucasian leopard *P. p. ciscaucasica* Satunin 1914	Persian leopard	central Asia, the Caucasus, Turkmenistan and northern Iran
9	*P. p. kotiya*, Deraniyagala 1956	Sri Lankan leopard	Sri Lanka

The IUCN has classified the common leopard as Vulnerable (Stein *et al.* 2016). Out of the nine subspecies documented, three (Amur, Arabian, and Javan) are classified as Critically Endangered while two (Persian and Sri Lankan) are classified as Endangered (Jacobson *et al*. 2016; Stein *et al.* 2016). Recent studies (e.g. Laguardia *et al.* 2015; Rostro-Garcı´a *et al.* 2016) recommend upgrading two other subspecies, the north Chinese leopard to Critically Endangered and Indo-Chinese leopard to Endangered RedList category. The remaining two subspecies *i.e.* African and Indian leopards are both recognised as Near Threatened (Henschel *et al.* 2008).

1.4.1 Distribution of leopard

Leopard has the widest geographic distribution amongst all the *Panthera* cats (Nowell and Jackson 1996). Jacobson *et al.* (2016), in their first-ever, seminal review, have comprehensively delineated historic and current distribution of leopard. They have confirmed current leopard extant in only 25% of historic range. They recognise an overall range loss of 63–75% with some subspecies to have suffered a range loss greater than 94%. Historically, leopard occurred across ~20,000,000 km^2 in Africa whereas in Asia it ranged up to ~15,000,000 km^2 (Jacobson *et al.* 2016). However, even with their remarkable adaptability and persistence in human matrices (Athreya *et al.* 2014; Kuhn 2014), leopards have vanished from almost 48–67% of their historic range in Africa and suffer from historic range loss of over 83–87% in Asia (Jacobson *et. al.* 2016). Leopards are now extinct in 6 countries or regions they formerly occupied (Singapore, Syrian Arab Republic and Tunisia, Hong Kong, Kuwait, Libya) and their presence in 6 additional countries is very uncertain (Iraq, Kazakhastan, Lebanon, Lesotho, Mauritiana and Republic of Korea) (https://www.panthera.org/cat/leopard; accessed on 13th February, 2019). At present, leopard is distributed in over 70 countries being present in Africa, Eurasia and the Indian sub-continent **(**Henschel *et al.* 2008; Jacobson *et al.* 2016; Stein *et. al*. 2016) (Fig. 1.1).

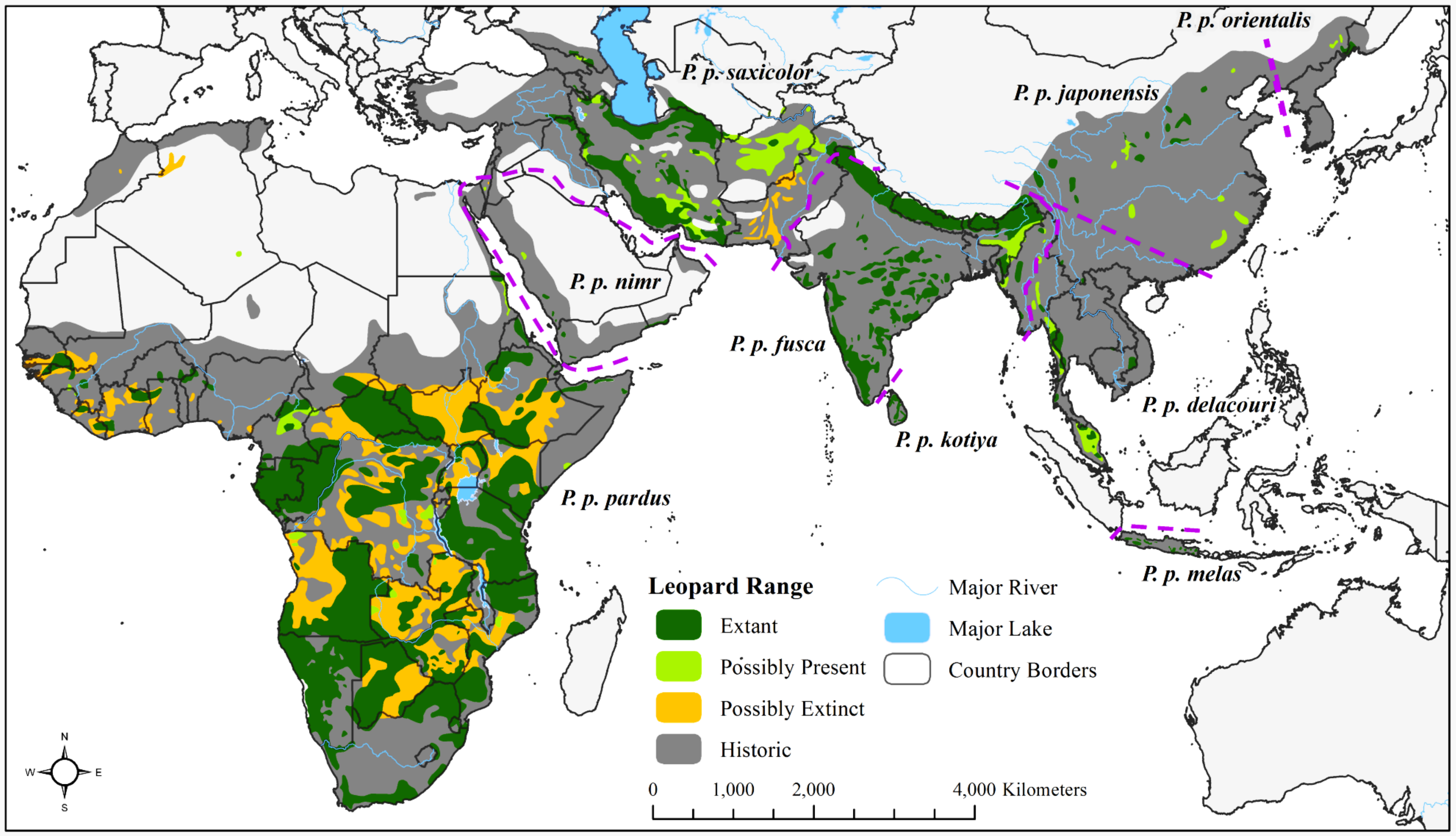


Figure 1.1 Current and historic geographic distribution range of leopard across the world (Source: Jacobson *et al.* 2016)

At local and subspecies wide scales, population and sub-species reached close to extinction. Four subspecies (*P. p. orientalis, nimr, japonensis* and *delacouri*) are known to occupy only 5% of the historic range and most common is *P. p. pardus*, found in 78 % range globally. Range of two leopard species viz., *P. p. saxicolor* and *pardus* lacks certainty (Jacobson *et al.* 2016).

In India, the leopard inhabits all forested habitats such as tropical rainforests, alpine coniferous, dry scrub, temperate deciduous, and grasslands across the country (Harrison and Bates 1991) and considered widely distributed (Athreya *et al.* 2013; Harihar *et al.* 2009). It is absent only in the arid deserts and above timber line in the Himalaya (Prater 1971). Daniel (2009) confirms leopard presence in the protected areas (PAs) of 23 states of the country with a speculation that forested areas contiguous with the PAs might hold leopard populations larger than the populations existing in the confines of the PAs.

1.4.2 Population status

Leopards, because of their widespread distribution and adaptability have long been considered to warrant low conservation priority. They are more adaptable than other carnivores (Stein *et al.* 2016), however, there number is going down across its range (Jacobson *et al.* 2016). Furthermore, until recently global population status was uncertain (Nowell and Jackson, 1996) due to difficulty in population because of leopard's low population, solitary and shy habit and large habitat needs (Rabinowitz, 1989; Nowell and Jackson, 1996). There are no reliable and robust range-wide estimates of mature individuals, IUCN categorised many Asian sub-species under critically endangered (Stein *et al.* 2016). But still many populations are believed to be increasing (Singh 2005) with likelihood of high levels of human-leopard conflict (Singh *et al.* 2007) due to several reasons such as decrease in habitat, decline in leopard prey populations, effects of translocations of problem animals near to human populated areas (Athreya *et al.* 2007; 2013). Poaching for wildlife trade has been a continuous threat to Indian leopards, for example, Raza *et al.* (2012) estimated that over a period of 10 years, four leopards per week were poached for illegal wildlife trade. Low wild prey is also causing decrease in leopard population (Datta *et al.* 2008, Selvan *et al.* 2014) demonstrating bleak future of leopard populations. The first ever scientific national census held in 2014 in India for leopards in and around Tiger habitats (excluding the northeast) estimated 7,910 mature individuals (Bhattacharya 2015). In the face of continuous threat and persecution of leopards in India, a separate assessment is highly recommended as decline in population is suspected (Stein *et al.* 2016).

In Indian subcontinent, highest leopard density estimate was recorded by Edgaonkar and Chellum (2002) in moist deciduous forests of Sanjay Gandhi National Park, India. They estimated leopard density to be 38.8 individuals/100km^2 using pugmarks of the species. This follows by a density estimate of 28.9 leopard/100km^2 by Kalle *et al.* (2011) in dry deciduous forests of Mudumalai Tiger Reserve using camera trapping. In the Himalayan ecosystems, leopard density fluctuates between 1.04 – 14.9 individual/100km^2 (Borah *et al.* 2013; Harihar *et al.* 2009; Selvan 2013; Thapa *et al.* 2014; Carter *et al.* 2015). Recently, Athreya *et al.* (2013) studied large carnivores surviving outside protected area (PA) systems in human dominated landscapes of a district in Maharashtra, and found relatively high leopard density of 4.8 individuals/100km^2.

There exists an enormous variation in density estimates across its range which can be attributed to various factors such as differences in prey and habitat availability, cover and level of persecution by humans (Karanth *et al.* 2004a,b). Non standardized methodologies also provide difference in the population status of the leopards.

1.4.3 Home range and Space use

Home range of an animal can be described as the area over which an individual animal normally walks to carry out daily routine activities such as foraging, rearing young ones, and look for mate (Burt 1943; Jewell 1966; Gittleman and Harvey 1982; Harris *et al*. 1990). However, this definition does not include any exploratory 'forays' and is therefore does not include the entire area that an animal covers during the course of its lifetime (Burt 1943; Jewell 1966; Bothma *et al.* 1997; Grimbeek 1992).

In reported home ranges of leopards from different studies across the leopard's distribution range there is a huge variation. African semi-arid ecosystems comprise largest home ranges of male leopards which exceed to over 2100 km^2 (Bothma *et al.* 1997). The home ranges of female leopards in Africa range between 12.4 km^2–488.7

km^2 (Bertram 1982; Bailey 1993; Jenny 1996; Norton and Lawson 1985; Bothma *et al.* 1997). However, generally male territories average between 30–78 km^2 and for females 15–16 km^2 in protected areas (Nowell and Jackson 1996). Norton and Lawson (1985) found leopard home ranges of 388 and 487 km^2 (for a male and female, respectively) in a mountainous terrain interspersed with farms and ranches, suggests sparse distribution of prey, hence low density of leopard.

In Asia, smallest home ranges of female leopards have been recorded to be just 5.2 km^2–6 km^2 in the sub-tropical forest ecosystem of Nepal (Seidensticker *et al.* 1990; Odden and Wegge 2005). The home range of male leopard in Asia ranges between 17 km^2–68 km^2 (Karanth and Sunquist 2000; Grassman 1999; Rabinowitz 1989; Odden and Wegge 2005). In the mountainous Himalayan ecosystem of Nepal, the ranges of the female leopards have been estimated to range 5.2 km^2–17 km^2 (Scidensticker *et. al.* 1990; Odden and Wegge 2005), whereas for male leopard it was a maximum at 50 km^2 (Odden and Wegge 2005). Recently, a study (Khan *et al.* 2018) exhibited male leopard's home range size of ~102 km^2 from western Himalaya in Pakistan. In Wilpattu National Park, Sri Lanka, the home range of adult female was estimated to range between 8 km^2–10 km^2 by Muckenhim and Eisenberg (1973). Apart from the above mentioned studies conducted in the PAs, recently Odden *et al.* (2014) studied leopard home ranges in human dominated landscapes of India and found that the male and female exhibited home range sizes between 8 to 15 km^2.

The variability in the home range sizes among the previous studies can be attributed to sexual differences, reproductive and social status, metabolic needs (Schaller 1972; Gittleman and Harvey 1982; Bailey 1993).

Any predator's spatial utilisation reflects its relationship with resources and other ecological factors, such as access to water and possible mates, human influences, cover for hunting and camouflage, prey distribution and abundance (Bailey 1993; Marker and Dickman 2005). Information pertaining to these factors can provide an indication of the importance, distribution and abundance of resources and their contribution to overall behaviour patterns (Henschel 1986). Though, the leopard is generally described as a solitary felid, but groups are formed comprising a female and her dependent offspring and between males and females who associate briefly to mate

(Bailey 1993; Bothma and Walker 1999; Sunquist and Sunquist 2002). A female leopard is expected to move according to resource availability, while male's movement is based on both receptive female(s) as well as availability of food resources. Many researchers worked on relationship between available food and size of the territory (e.g. Hixon 1980; Schoener 1981; Saitoh 1991; Bailey 1993; Odden and Wegge 2005). Thus, areas with sparser prey distribution produce extremely large home ranges resulting in predators spending more energy and time (or rather movement and activity) in search of prey.

1.4.4. Activity behaviour and movement

Leopards are generally solitary animals, shy and secretive and usually nocturnal in their behavior (Schaller 1972; Sunquist 1983; Bailey 1993). But sometimes they show boldness and return to their kill in spite of being shot at and missed. In addition, they are usually cautious and circumspect (Daniel 2009). The main social bond is between females and their offspring, although males and females do associate but for a short period during the courtships (Schaller 1972; Sunquist 1983; Bailey, 1993; Mizutani and Jewell 1998). Like other large felids, they communicate with one another using scent markings (e.g. urine spraying, scrape marking and also tree raking) and vocalizations (Eisenberg and Lockhart 1972; Ilani 1981).

Leopards are reported to crepuscular in habit (Hamilton 1976, Bailey 1993). In Kruger NP, Bailey (1993) reported high movement (especially during nights) in leopard rearing cubs. High daytime activity patterns have been recorded for leopards in thickets during the wet season when the prey also used the thickets (Bailey 1993). In Wilpattu NP, Sri Lanka, where leopards are the only large felid species, they are less nocturnal than the leopards studied elsewhere (Muckenhirn and Eisenberg, 1973). Jenny (1996) and Jenny and Zuberbühler (2005) found that leopards in the tropical rain forest were predominantly diurnally active and crepuscular than the savannah leopards and hunted only during the day time

Odden and Wegge (2005) observed pronounced sexual difference in day-to-day movements of male and female leopards. Males were less active during day unlike females having no difference in day or night movement. The males' mean diel movement distance (6.83 km) was longer than the distance moved by the female (3.5

km), but did not differ significantly (Odden and Wegge 2005). Seidensticker (1977) reported that a radio-collared female leopard rearing small cubs in the Chitwan NP spent more time in the immediate vicinity of her cubs during night than during day. The maximum distance moved by male leopards was 30.63 km (mean 16.2 km) versus 11.57 km (mean 10.96 km) for females (Martins and Harris 2013). Apart from the studies conducted in the PAs, recently Odden *et al.* (2014) studied leopards in human dominated landscapes where leopards were prominently nocturnal and their hourly step lengths averaged at 339 m during night and 60 m during the day time.

1.4.5 Functional niche

Leopards are the most successful among all the four large felids in terms of their geographic distribution and abundance. They are present in several different environments and ecosystems. They range from semi-deserts, through savannahs, tropical forests to even up to the elevations of about 5200 m above mean sea level in the Himalaya although they live below the tree line (Roberts 1977; Jackson 1984; Green 1987; Nowell and Jackson 1996). In Africa and India, leopards are sympatric with other large felids like lions and tigers, respectively by reducing spatial and food competition, using habitats not favoured by the larger felids, eating different-size prey and having different diel activity patterns (Seidensticker 1976; Bertram 1982). At other places such as mountainous regions of the South Africa and the Himalaya, where other large carnivores such as tigers, lions and dholes (*Cuon alpinus*) are absent, leopards become the apex predators regulating the prey populations thus, maintaining the ecological balance. Leopards are the most adaptable large carnivores that can survive in a wide variety of habitat types. Their flexibility is due, in part, to their catholic choice of prey items; sustenance on medium to large ungulates is supplemented by small prey items such as primates, rodents, reptiles and birds (Ilani 1981; Odden and Wegge 2005; Hayward *et al*. 2006; Lovari *et al*. 2013a,b). Studying leopard diet helps biologists and managers understand which prey is needed for their long term population viability. Furthermore, it provides insight into how the presence of leopards affects an ecosystem.

1.4.6 Threats

Leopards face multiple threats and are declining across their geographical distribution range (Ripple *et al.* 2014). The primary threats to leopards are anthropogenic and are in continuum. Several studies have identified five major threats to leopards (Jacobson *et al.* 2016) amongst which habitat loss and fragmentation (Nowell and Jackson 1996) is of grave concern as it is also the primary driver of biodiversity loss (Fahrig 2003). Low prey availability, persecution, trophy hunting, trade of body parts, and rampant killing (Datta, Anand and Naniwadekar 2008; Athreya *et al.* 2011; Raza *et al.* 2012; Qi *et al.* 2015; Stein *et al.* 2016). All of these threats, except for the unsustainable legal trophy hunting, exert pressure on leopard population across the leopard range.

Much of the leopard range is under threat due to conversion of forest lands to crop fields, thus causing a reduction in quality of available habitat, further fragmenting the rest of the habitat, and threatening self -sustaining population of leopard (Jacobson *et al.* 2016). Habitat loss in South-east Asian countries is main cause of loss of biodiversity (Sodhi *et al.* 2004) and declining range of leopard (Nowell and Jackson 1996; Rostro-Garcı´a *et al.* 2016). It is anticipated that African leopards will also face this threat in near future due to economic growth, land use change, and human population explosion (United Nations 2015; Jacobson *et al.* 2016).

Leopards also depredate on livestock causing rise in conflict with humans and often get killed for real or perceived threats to human lives and livelihoods (Stein *et al.* 2010; Athreya *et al.* 2011). Illegal trade in skins and bones of leopards is also a major threat from which leopards require better protection (Nowell 2007) and according to a recent estimate very high levels of leopard killings take place which are almost at the rate of four leopards per week for a decade (Raza *et al.* 2012). Leopards also get killed for the usage of their hides in traditional ceremonies and other body parts for Chinese traditional medicines. This illegal trade in body parts can have a substantial impact on local leopard populations (Stein *et al.* 2016).

1.4.7 Status of research effort

Previously, leopard was known to be the least studied species among the large carnivores (Nowell and Jackson 1996), but the current scenario is different and changing as several studies are being conducted on different aspects of ecology of leopard. Several studies have already been enumerated in the above sections encompassing various aspects of leopard ecology. Recently, Jacobson *et al.* (2016) in their review on leopard status and research efforts across its distribution range found skewed research effort towards the subspecies with 46% of articles focused on African leopard whereas 23% on Indian leopard. Balme *et al.* (2014) on the other hand found ~50% of articles focused on African. North Chinese, Sri Lankan and Javan each have fewer than five peer-reviewed articles (combined equalling 2.5% of all articles). In a nutshell, Jacobson *et al.* (2016) summarised that six (*P. p. orientalis, nimr, melas, kotiya,* and *japonensis*) of the nine leopard subspecies which occur across less than 5% of their historic range have received very less total research effort than the rest three subspecies which are more widely distributed.

In India, leopards have been studied addressing ecological aspects including diet, population estimation and ranging pattern (Johnsingh 1983; Karanth and Sunquist 1995; Daniel 1996; Edgaonkar and Chellam 1998; Ramakrishnan *et al*. 1999; Sankar and Johnsingh 2002; Chauhan *et al*. 2005; Qureshi and Edgoankar 2006; Maheshwari 2006; Andheria *et al*. 2008; Arivazhagan *et al*. 2008; Edgaonkar 2008; Sankar *et al*. 2008; Chauhan 2008; Harihar *et al*. 2009b; Riddhika 2009; Wegge *et al*. 2009; Wang and Macdonald 2009; Ramesh *et al*. 2009; Majumder 2011; Kalle *et al*. 2011; Mondal 2012; Borah *et al.* 2013; Athreya *et al*. 2014), human-leopard conflicts (Athreya and Belsare 2007; Goyal and Chauhan 2006; Kumar 2011).

1.4.8 Previous studies on leopard in Kashmir including Dachigam National Park

Kashmir valley is very rich in biodiversity owing to the unique ecosystem coupled with geographic location being situated in western Himalayan region and being one of the biodiversity hotspots of the world. But active and continuous research and monitoring programs on wildlife and biodiversity as a whole have always been at the back foot due to border issues between India and Pakistan, insurgency, armed conflict and political instability in the region (Akbar 2002; Bhatnagar *et al.* 2009). Nevertheless, several studies have been conducted from time to time on various species and aspects e.g. on ecological aspects of hangul (*Cervus hanglu* ssp. *hanglu*, formerly *C. elaphus hanglu*) by Schaller (1969), Kurt (1977; 1978; 1979), Shah *et al*. (1983), Ahmad (2006), Ahmad *et al*. (2009), Mukesh *et al*. (2013; 2015); on markhor (*Capra falconeri*) by Bhatnagar et al. (2009), Ahmad *et al.* (2017); on avifaunal elements by Katti (1989), Ahmad (1999), Wani (2012). A long term monitoring program was initiated by the Wildlife Institute of India (WII) to study ecological aspects of the Asiatic Black Bear (*Ursus thibetanus*) which also looked into spatial organization of the black bears through satellite telemetry (Charoo 2012; Sharma 2012; Sathyakumar *et al*. 2013). Despite having fair amount of research studies carried out on different faunal elements, amount of ecological research on leopard has not been much and mostly dealt with human-leopard conflict as apparent from the studies Iqbal *et al*. (2005), Singh *et al*. (2007), Choudhury *et al.* (2008).

With this background, present study was initiated to collect empirical ecological information to aid in management of the leopard population in this biodiversity rich landscape. This study attempts to study the status, ranging pattern and habitat suitability of leopard in Dachigam National Park. These are prerequisites to develop the conservation strategy for the species and subsequent management planning and legislations. This study considers the Indian subspecies of leopard *Panthera pardus fusca* and all observations in the present study pertain to this subspecies only. This species was first described by Friedrich Albrecht Anton Meyer in 1794. Formerly Kashmir Leopard (*Panthera pardus millardi*, Pocock 1930) was considered as a separate sub-species but it was later on clubbed with *Panthera pardus fusca* (Miththapala *et. al.* 1996).

1.4.9 Objectives of the study

The present study considering some ecological aspects of leopard in Dachigam National Park was carried out with the following objectives:

1. To determine the population status of leopards in the Dachigam National Park

2. To study the ranging patterns and habitat use in relation to land use/land cover (LULC) pattern

3. To develop the habitat suitability model for leopards in relation to LULC pattern

1.4.10 Study period

The study was conducted from December 2010 to December 2013. This period covered four different seasons which are well marked – December to February is considered as winter, March to May as spring season, June to August as summer season and September to November as autumn season. This study was a part of a research project, “Ecology of leopard *Panthera pardus* in relation to prey abundance and land use pattern in Kashmir Valley” initiated by Wildlife Institute of India, Dehradun. Department of Science and Technology, Govt. Of India supported with fund for the study. All field equipments and logistic support required for this study were provided by the Wildlife Institute of India, Dehradun.

1.4.11 Organisation of the thesis

This thesis has been organized into six chapters which are as follows:

Chapter 1 provides a general introduction, describes the background of this study, details in ecological aspects of leopard and describes the need of this study, the study objectives and the study period of the study.

Chapter 2 deals with descriptive account of the study area, which includes the history, topography, climate, vegetation and available fauna in the study area.

Chapter 3 deals with the status of leopard in the study area. This chapter presents first ever leopard density estimates for the study area.

Chapter 4 deals with the ranging pattern and movement of the leopard and its habitat use in relation to LULC pattern in the study area and its surroundings.

Chapter 5 attempts to develop habitat suitability model for the leopard in relation to LULC pattern of the study area and its surroundings.

Chapter 6 discusses conclusions of this study and provides management recommendations based on the findings of this study.

CHAPTER 2
STUDY AREA

2.1 The Himalaya

Mountains are globally important environmental resources that encompass biologically rich landscapes with complex climate and diverse weather regions. The Himalaya is the youngest, most dynamic yet most fragile mountain ecosystem in the world. Though it has enormous biological, ecological, geo-hydrological, socio-cultural and aesthetic significance, it is being depleted at an alarming pace.

The formation of the Himalaya resulted in new barriers and corridors, which influenced the dispersal of flora and fauna and development of high degree of endemism. The Himalaya is the meeting point of three biogeographic zones namely Indo-Malayan, Africo-tropical and Palaearctic and provides various habitats that have been occupied by many primitive as well as newly evolved species (Mani 1974). The location, topography and climate of this complex system have endowed it with rich and diverse life forms. The interesting patterns of biogeography characterized by the high degree of endemism and localized distribution of certain species have resulted from the temporal and spatial variation in the physical conditions (Mani 1978; Singh and Singh 1987). This high degree of endemism is very much relevant for several rare, endangered and economically important flora and fauna. These mountains are responsible for the abundant rainfall which ensue prosperity of the people living in the Indo-Gangetic plains as they impede the northward flow of the monsoon clouds and their geographic positions form the watershed for the rivers flowing in northern India. However, the burgeoning human population and associated land use changes and development activities in the Himalaya along with recent alterations in the economy and growing market forces have led to the reduction in the forest cover of these vital watershed areas of India and concurrently degraded a large extent of the prime wildlife habitats.

2.2 Biogeographic zones of the Himalaya

Rodgers and Panwar (1988) have categorised the whole Himalaya region into five biotic provinces *viz*. **(a)** *Trans – Himalaya* (1A-1D; comprising of Aksai Chin Plateau and cold deserts of Ladakh region of the J&K, Lahaul and Spiti, of the Himachal Pradesh (HP), Gangotri region of the Uttarakhand and the North Sikkim), **(b)** *North-west – Himalaya* (2A; J&K and HP), **(c)** *Western – Himalaya* (2B; HP and Uttarakhand), **(d)** *Central – Himalaya* (2C; Sikkim and Darjeeling districts of West Bengal) and **(e)** *East – Himalaya* (2D; Arunachal Pradesh). Each of these provinces is endowed with its own distinctive floral and faunal diversity.

2.3 The Jammu and Kashmir State

The state of Jammu and Kashmir (hereafter J&K) is located in the north western extremity of the Himalayan biodiversity hotspot. It lies between 32° 10' and 37° 10'N latitudes and 72° 30' and 80° 30'E longitudes. Covering a total area of about 2, 22,236 km^2 (Hussain 2002), (including 1, 20,849 km^2 under the occupation of Pakistan and China), the state is further divided into three provinces *viz*. Jammu (26, 293 km^2), Ladakh (59, 146 km^2) and Kashmir Valley (15, 948 km^2) (Anonymous 2010), with each province differing markedly from the other in its climate, vegetation and culture.

These provinces appear as a unified natural system within which it contains a vast and extremely rich geographic, physiographic, ethnic, demographic, linguistic and cultural diversity. With about 19.95% of the total geographical area (falling under the Indian side of the line of control (LoC)) covered by forests (Anonymous 2009), that consists mostly of coniferous, broad leaved, deciduous and other evergreen woody elements, the state is divided into three floristic regions: alpine desert flora of Ladakh, subtropical flora of Jammu and predominantly temperate flora of Kashmir. Geologically, the rock formations belong to three broad groups: the Pir Panjal which includes the outer hills, plains and middle mountains; the Zanskar which embraces almost whole of the eastern region from Spiti to Lahul and Karakoram in north and the tertiary groups which involve the valley of Kashmir and other river valleys (Wadia 1953). Agriculture is the main stay of economy as three quarters of the population residing here is directly or indirectly dependent on this sector (Anonymous 2010).

2.4 The Kashmir Valley

The valley of Kashmir was formed by the thrust between the Himalayan sub-continental plate and the rest of Asia plate that led to folding and faulting and the Himalayan mountain chain was formed. The Kashmir valley runs northwest to southeast and gets oval shape which gives it a clearly defined physical boundary. The region is drained by river Jhelum (*Veth* in Kashmiri), its tributaries and numerous other fast moving snow-fed streams with the mighty Jhelum cutting through Pir Panjal at the Baramullah gap. The rock formations are varied and belong to all age groups from Achaean complexes to recent alluvium. Floristically the region is very rich and harbours an amazing diversity. The vast areas covered by grasslands and meadowlands further add to its aesthetic splendour and resource profusion. These grasslands spread across a broad altitudinal and latitudinal gradient and are present nearly across all breadth of Kashmir valley.

2.5 The Dachigam National Park

2.5.1 Location

The Dachigam National Park (hereafter Dachigam NP) is situated between 34° 05'N – 34° 11'N and 74° 54'E – 75° 09'E (Fig. 2.1) and the area falls under jurisdictions of three districts Srinagar, Anantnag and Pulwama (Naqash and Sharma 2011). Its area comes in the Himalayan high lands and Bio-geographic zone 2A. It is 21 km north-east to Srinagar, situated in Zabarwan mountain range of the Great Himalaya.

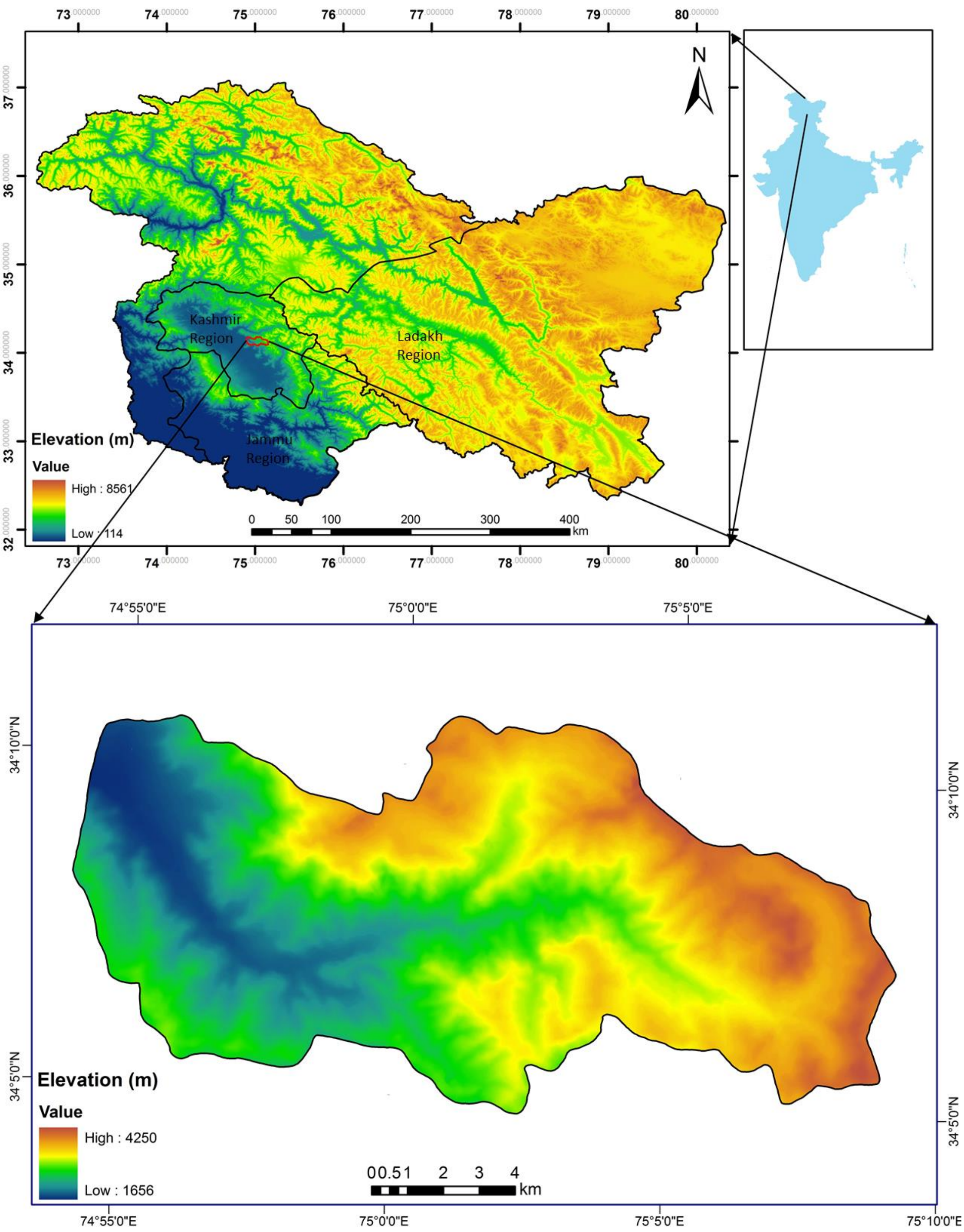


Figure 2.1 Digital elevation model of J&K state showing three provinces and study area

2.5.2 Terrain

The terrain in the Dachigam NP is a rugged and steep mountains separated with deep valleys. The altitudinal gradients vary from 1,650 to >4,000 m. A range of aspects and slopes supporting a variety of vegetation types is presented by the series of undulations (Naqash and Sharma 2011). Several conservation reserves around the Dachigam NP form a contiguous Dachigam landscape (Fig. 2.2).

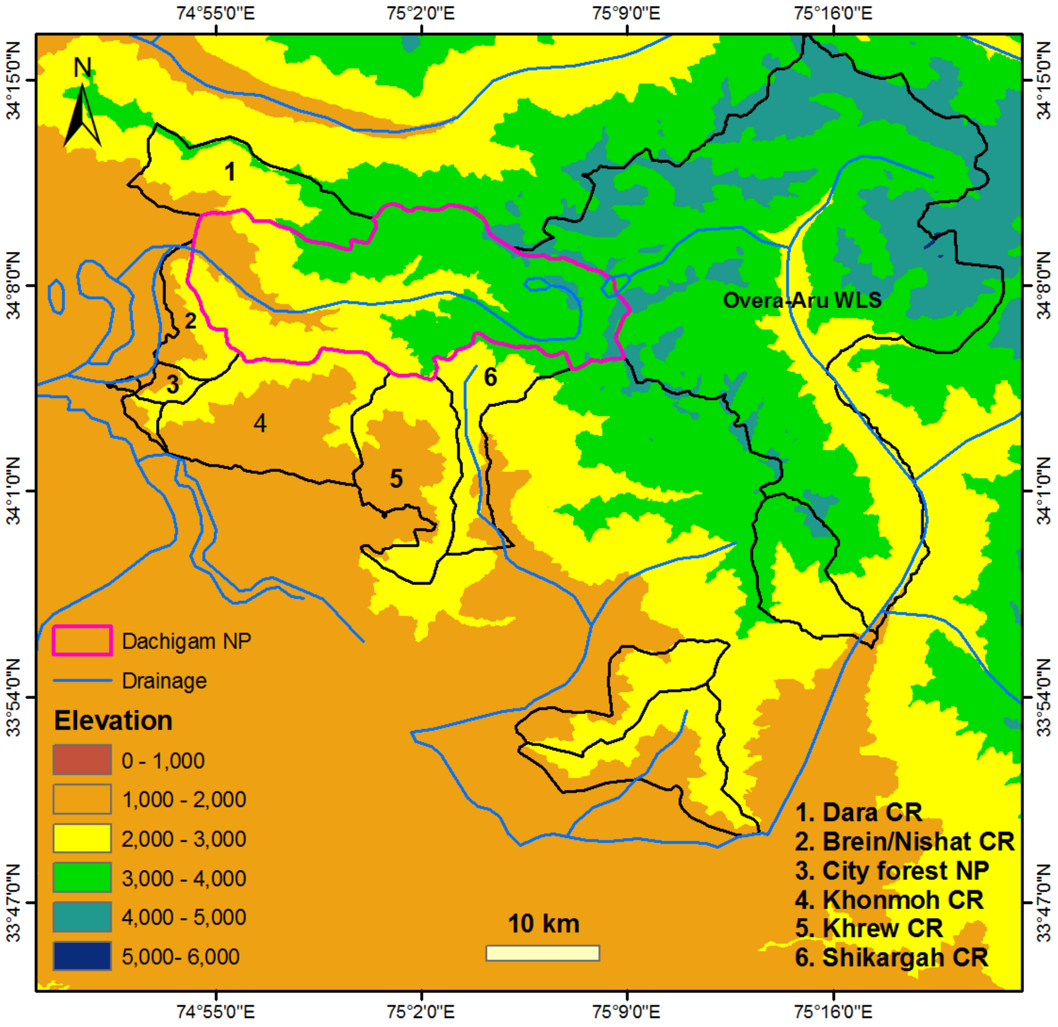
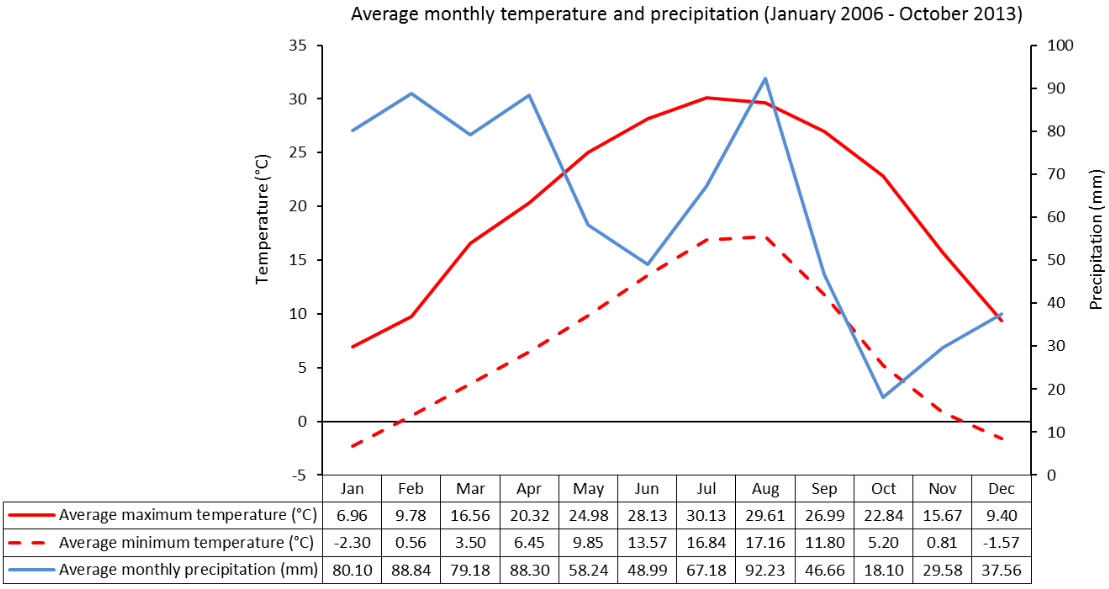


Figure 2.2 Dachigam NP and other adjoining Protected Areas (PAs) in the landscape

2.5.3 Climate

Sub-Mediterranean to typically temperate type of climate occurs in the area with high degrees of variation in precipitation and dryness. The main source of precipitation is snow which occurs during winter and in some higher parts melts by June. The park also serves as the catchment area of the famous Dal Lake and has received (during 2006–2013) an average annual rainfall of 734.9 mm (range = 577.2–1020.4 mm) (as per data obtained, for the duration January 2006 through October 2013, from nearest meteorology station at Sher-e-Kashmir University of Agricultural Science and Technology, SKUAST, Shalimar, Srinagar and situated 2 km south-west of Dachigam boundary). There is no definite rainy season, but four distinct seasons are recognised in the valley: autumn (September–November), summer (June–August), spring (March–May) and winter (December–February). The average maximum temperature recorded during summer was 29.6 °C while the minimum during winter was -2.3 °C (Fig. 2.3). The minimum and maximum temperatures inside the Dachigam NP are expected to be lower than outside.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum temperature (°C)	6.96	9.78	16.56	20.32	24.98	28.13	30.13	29.61	26.99	22.84	15.67	9.40
Average minimum temperature (°C)	-2.30	0.56	3.50	6.45	9.85	13.57	16.84	17.16	11.80	5.20	0.81	-1.57
Average monthly precipitation (mm)	80.10	88.84	79.18	88.30	58.24	48.99	67.18	92.23	46.66	18.10	29.58	37.56

Figure 2.3 Average monthly temperature (C) and precipitation recorded at nearest weather station (SKUAST, Shalimar) during 2006 and 2013

2.5.4 Vegetation

Champion and Seth (1968) have described the vegetation of Dachigam as typical of Himalayan moist temperate forest; alpine forest type and sub-alpine forest can be classified into following types:

1. Moist Temperate deciduous forest
2. Parrotiopsis scrub forest
3. Western Himalayan low level blue pine forest
4. Western mixed coniferous forest
5. Deciduous alpine scrub
6. Western Himalayan sub-alpine birch - rhododendron forest
7. Dwarf juniper scrub
8. Dry temperate scrub
9. Alpine pastures.

A detailed vegetation study was also carried out by Singh and Kachroo (1978) in Lower Dachigam. The dominant species in order of frequency constituting the flora of Dachigam are; Compositae; Gramineae; Rosaceae; Labiatae; Leguminaceae; Cruciferae; Umbelliferae; Boraginaceae; Caryophyllaceae and Cyperaceae.

2.5.5 Fauna

Like other Himalayan ecosystems Dachigam National Park supports diverse faunal elements the Dachigam NP supports several mammal species having high conservation value, which include the hangul (*Cervus hangul* spp. *hanglu*), Kashmir musk deer (*Moschus cupreus*), Himalayan Serow (*Capricornis thar*) and snow leopard (*Uncia uncia*). Other species found in the Park include Asiatic black bear (*Ursus thibetanus*), leopard (*Panthera pardus*), Himalayan grey langur (S*emnopithecus ajax*), rhesus macaque (*Macaca mulatta*), red fox (*Vulpus vulpes*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), leopard cat (*Prionailurus bengalensis*), long-tailed marmot (*Marmota caudata*), common otter (*Lutra lutra*), yellow-throated marten (*Martes flavigula*), Himalayan weasel (*Mustela sibirica*) and Indian porcupine (*Hystrix indica*). A few species like serow and wild boar (*Sus scrofa*) were recorded after a gap of *c*. 20 and 30 years, respectively, during the present study as well as in the recent camera trapping exercises (Sathyakumar *et al*. 2013; Ahmad *et al*. 2013). Similarly, small Indian civet (*Viverricula indica*) has also been recorded very recently for the first time as a range extension (Charoo *et al*. 2010). Besides, the park inhabits a good diversity of insects, reptiles and avifauna (~250 bird species) (Naqash and Sharma 2011).

CHAPTER 3

DENSITY OF LEOPARD, ACTIVITY AND CO-OCCURRENCE WITH OTHER MAMMALS

3.1 Introduction

Carnivore density and distribution is largely governed by a variety of ecological, environmental and anthropogenic factors. Of these, prey availability and abundance pose the main constraints and are positively correlated with the carnivore density (Carbone and Gittleman 2002; Karanth *et al*. 2004). Suitable habitat is also basic requirement of large carnivores which can provide cover for hunting and denning sites for rearing their young to females (Hayward *et al*. 2006; Mizutani and Jewell 1998). Anthropogenic factors limiting carnivore density include habitat loss (Ray *et al*. 2005), decline of prey densities (Datta *et al*. 2008, Henschel *et al*. 2011), human persecution (Balme *et al*. 2010), poaching for body parts (Raza *et al*. 2012) and unsustainable trophy hunting (Packer *et al*. 2011). Widespread and rampant alteration of forests and carnivore habitat for anthropogenic activities has resulted in extensive habitat loss for many large carnivores including leopard. Little is known about the status of large mammals especially carnivores across the rugged Himalayan landscape owing to limited number of studies (e.g. Bashir *et al*. 2014; Carter *et al*. 2015). There is no study pertaining to the status of the leopard from the western Himalaya which marks the northern most limit of the leopard (*P. p. fusca*) distribution in India.

Similarly, information pertaining to how species coexist is of paramount importance in understanding community diversity (Chesson et al. 2000, HilleRisLambers *et al*. 2012). Coexisting mammal species often avoid interspecific competition by partitioning resources along time, food and space resulting in niche differentiation (Schoener 1974a, b). Understanding the species’ niche differentiation helps scientists and managers understand the capacity of species to coexist thereby benefitting conservation and management of ecological communities (HilleRisLambers *et al*. 2012). In terms of time and space, spatially coexisting sympatric species conspicuously synchronize their activity peaks to coincide with the hours of daylight, darkness or twilight and circadian rhythms leading to partitioning of resources structured among different sympatric species accordingly (Hayward and Slotow 2009). Activity patterns of terrestrial mammals can be classified as diurnal (active during the day), nocturnal (active during darkness), crepuscular (active mostly during twilight) and cathemeral (active during both daylight and darkness hours) (Bennie *et al*. 2014). Activity patterns vary across regions and seasons even within the same species but there are many factors affect activity patterns at local scale such as day length (Bennie *et al*. 2014), temperature (Bennie *et al*. 2014), precipitation (HilleRisLambers *et al*. 2012), moonlight (Kotler *et al*. 2010; Kronfeld-Schor *et al*. 2013), prey-predator or competitive interactions (Schmitt and Holbrook 1986; Case and Bolger 1991; Johnsingh 1992; Linkie and Ridout 2011; Ramesh *et al*. 2012), and human activities (Carter *et al*. 2015). To overcome these challenges, Camera-trap surveys have received growing attention for the past two decades mainly because it is cost effective, non-invasive to animals and produces information representing whole population in a given time frame. This survey method has also been used to monitor the activity patterns elsewhere (van Schaik and Griffiths 1996; Azlan and Sharma 2006; Akbaba and Ayaz 2012; Ramesh *et al*. 2012).

In the Indian sub-continent, studies pertaining to coexistence and resource partitioning between predators considering space (e.g. Karanth and Sunquist 2000; Sankar and Johnsingh 2002; Andheria *et al*. 2007; Ramesh 2010) and time (e.g. Ramesh *et al*. 2012; Ross *et al*. 2013) have largely concentrated in the tropical forest ecosystems thereby leaving a void in understanding about other ecosystems specially the rugged, mountainous and temperate ecosystems. Little is known about the activity behavior of mammals especially carnivores across the Himalayan landscape owing to limited number of studies (e.g. Bashir *et al*. 2014; Carter *et al*. 2015).

The Jammu and Kashmir region, in particular, has been into political instability since 1948 due to border issues between India and Pakistan (Akbar 2002). Later on, with the eruption of insurgency in 1989 and increase in the military presence in the region, protection of wildlife became a low priority. Moreover, the declaration of protected areas in the region could not even facilitate conservation action and research on the status and distribution of several species in the region was taken a back seat (Bhatnagar *et al*. 2009) which led to creation of a knowledge gap (Mir *et al*. 2015).

In this chapter, I present the first record of leopard density from a Himalayan moist-temperate forest of the Dachigam National Park, India, using camera traps. Although, the work was focused on estimating the density of leopard, I have also provided relative abundances of other species encountered during the camera trapping exercise. I have also examined activity patterns of species encountered and species co-occurrence across space and time. This information contributes to an understanding of an ecosystem where leopard plays an important role of top predator. This would inform the managers and help them in developing more appropriate management and conservation strategies for the forests in other similar mountainous regions and ecosystems.

3.2 Methodology

3.2.1 Camera Trapping

Data for density estimation of leopard was collected by means of camera trapping which was conducted during May–June, 2013 by dividing the area into a grid system of size 2 km x 2 km. Due to limited number of cameras (n=20) available, a pair of Cuddeback-attack™ digital cameras was set in each grid of 4 km^2. The camera trap locations were selected based on presence of leopard sign, accessibility, terrain features, animal trails and *nallahs* (seasonal drainages). To ensure that all individual leopards were potentially exposed to trapping, an inter-camera trap location distance of 1–2 km was maintained. Each camera trap location had two camera units facing each other, fixed at locations judged to be optimal leopard travel routes. It was not possible to follow the prescription of setting paired camera traps 3.5 m away from the main trail everywhere, at a height of 45 cm to simultaneously photograph either flank of an animal that passes through (Karanth 1995; Karanth and Nichols 2002), because most of the camera trap sites fell on very steep and narrow trails leaving little space for setting one camera, let alone two. Most of the camera traps were set on trees growing from the lower side of the trails. Sometimes the space for even one camera was so limited that I was compelled to orient the camera traps at an angle toward or away from the trail to increase the view. Despite the constraints on camera trap placement, these narrow trails had the advantage of channeling animal movements into the camera’s field of view. The cameras were typically kept active for 24 h at a given location and set to take consecutive images (1 min picture interval) when triggered. Capture times for each species were assumed as a random sample of activity of the species, so that the likelihood of getting a photograph increases in proportion to how active the species is at that time of day. In order to maintain statistical independence and to reduce bias caused by repeat detections of the same animal, one record of each species per half an hour per camera site was considered as an independent detection and subsequent records were eliminated (O’Brien *et al*. 2003). Camera traps were checked every other day to record the number of exposures, to change the batteries if needed and to check proper functioning of the cameras. In total 20 grids were sampled for a period of 40 days (20 days each for two sampling blocks) (Fig. 3.1) to meet the underlying assumption of population closure i.e. the sampling period is short enough so that no births, deaths, or emigration/immigration occur during the sampling period (Karanth and Nichols 2002, Williams *et al*. 2002). The closure assumption was tested using program CLOSE TEST (Stanley and Burnham 1999). Individual leopards were identified from photos based on their pelage marking (rosette) patterns of their flanks. I used the flank that had maximum number of unique individuals for abundance estimation of leopard to avoid the possibility of double counting an individual. Individual capture histories were created in “X matrix format” for each individual by assigning either “1” or “0” if the individual was captured on each occasion (Otis *et al*. 1978), where each trap day represented a separate capture occasion.

3.2.2 Density estimation

There are two different approaches for estimation of animal density from photographic capture recapture data. The first approach is relatively old and a non-spatial method of density estimation. It can be considered as an *ad hoc* or conventional capture-recapture (CR) model (Otis *et al*. 1978; Karanth and Nichols 1998) that relies on capture-frequency data derived from photographed animals to estimate population size, and uses distances between locations of recaptures to obtain the effective area sampled for estimating density. The other approach is spatially explicit capture-recapture (SECR) method of abundance estimation which is based on point process models that incorporate information on capture location directly into the modeling and the estimation of capture probabilities. This method is considered more robust because it obtains estimates of population density unbiased by edge effects, incomplete detection and heterogeneous capture probabilities and eliminates the need for the *ad hoc* estimation of the sampling area (Efford 2004; Borchers and Efford 2008).

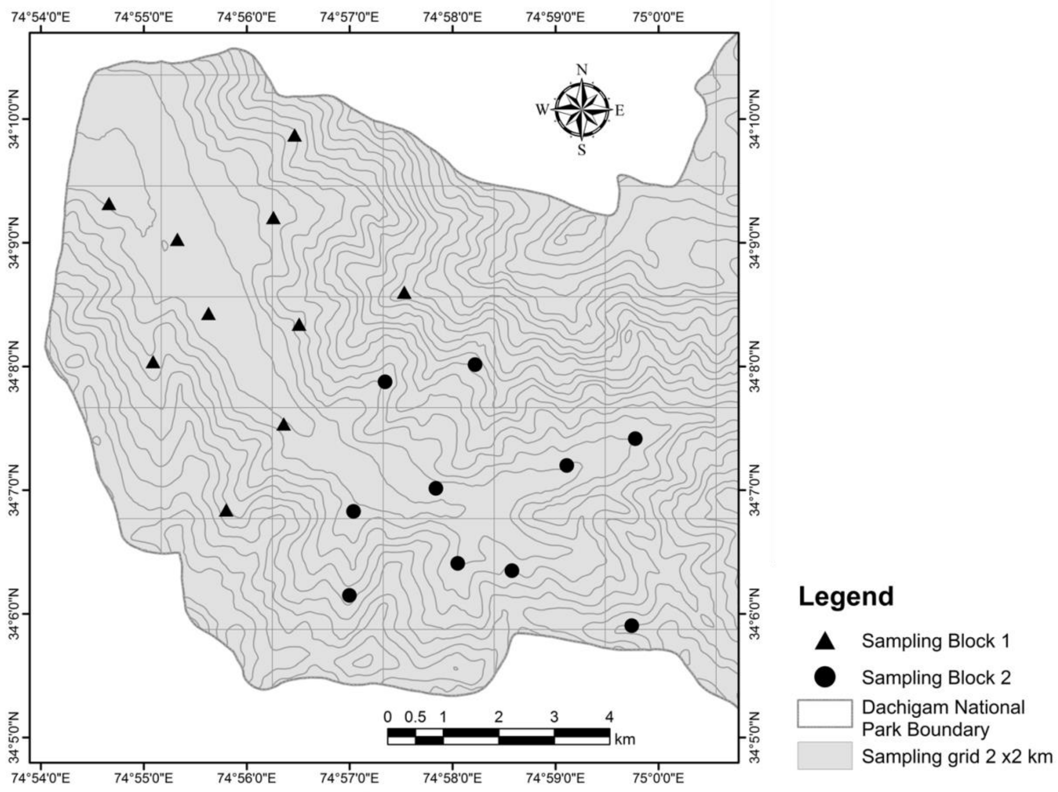


Figure 3.1 Location of the camera traps in the sampling blocks in the study area (Lower Dachigam) Dachigam NP, India

3.2.2.1 Non-spatial density estimation

For comparisons and consistency with previous non-spatial camera trap surveys of leopards (Balme *et al*. 2009b; Harihar 2009; Wang and Macdonald 2009) I first used the program CAPTURE (Rexstad and Burnham 1992) to estimate the leopard abundance. The capture history data from the two blocks were combined for density estimation. I retained the 40 sampling days as such considering each day as a single occasion. Abundance computation was based on different possible models provided by the CAPTURE for closed populations. The models were compared based on expected effects of individual heterogeneity in capture probability (Model M(h)), behavioural responses to trapping (Model M(b)), and changes in capture probability among sampling occasions (Model M(t)) (Karanth and Nichols 1998). The null model M(0) assumes that capture probability is not affected by any of these factors. As suggested by Karanth and Nichols (1998), I rejected the null model because the model assumption was likely to be violated due to territorial behaviour and trap response. I estimated the effective sampling area (for density estimates) by adding a circular buffer around each camera trap location equal to half the average mean maximum distance between locations of individuals photo-captured more than once (Henschel and Ray 2003; Balme *et al*. 2009b).

3.2.2.2 Density estimation using spatially explicit model

For more reliable estimation of leopard densities I preferred the recently developed spatially explicit capture-recapture (SECR) models. Of the two types of SECR models available, I preferred the Bayesian model (Royle *et al*. 2009a, b) over the likelihood based model (Borchers and Efford 2008) because the former offers non-asymptotic inferences which are more appropriate for small samples of capture data typical of photo-capture studies (Gopalaswamy *et al*. 2012). I used the Bayesian estimator SPACECAP (Gopalaswamy *et al*. 2012) version 1.1.0 in R version 3.4.0 (R core team 2017). SPACECAP makes use of three input files: 1) detection history (information on animal identity, trap location and sampling occasion), 2) trap deployment (location of camera-traps, sampling occasions and camera function details) and 3) potential home-range centres file (a mesh of potential leopard home-range centres located in areas of suitable leopard habitat; these are demarcated by a 1 for suitable, and a 0 for non-suitable). SPACECAP then combines the surveyed area comprising the camera trap array with an extended area surrounding it, which is known as the "state-space" of the underlying point process ‘S’. This state-space is represented by a large number of equally spaced points in the form of a very fine mesh which are visualized as representing all possible potential activity centres (or home range centres) of all the animals in the population being surveyed (Gopalaswamy *et al*. 2012). The state space area which consists the outer camera trap polygon and a large buffer area ‘S’ was created using ArcGIS 9.3 (ESRI, Redlands, USA) and was made up of UTM coordinates of potential home range centres created as equally spaced points and an associated column indicating habitat suitability at each point. This Spatial Bayesian method incorporates data augmentation to deal with unobserved capture histories. I generated systematic home range centres in an area contained within 8 km buffer (larger than mean maximum distance moved, MMDM; Karanth and Nichols 1998) around camera traps (Fig. 3.2). The large buffer around the sampled area was used to ensure inclusion of all individual home ranges within a reach of cameras (Royle and Dorazio 2008). I analysed the data with buffer increment of 1 km and population was augmented with more than double the estimated leopard population. This was done until the density estimates stabilized as this Bayesian SECR method was found to be extremely sensitive to the buffer width and augmentation size (Kalle *et al*. 2011).

Finally, using ArcGIS 9.3, numerous equally spaced points (0.5 km) representing home range centres (each pixel size = 0.25 km^2) were generated for this extended area (Gopalaswamy *et al*. 2014). For the state-space file (the buffered area including the camera polygon) the area was set at 0.25 km^2. Habitat thought not suitable for leopards was removed from the analysis. The areas considered unsuitable for leopard were removed from the analysis that included elevations above tree line i.e. 3800 m above sea level, large flat crop fields that were away from the study area (> 1 km), and provided no hunting cover for leopards, though I retained those fields which were on the fringe of the study area and fell under 1 km distance (Mir 2016), dense human settlements of main city, and water bodies.

The following model definitions were used for the analysis: trap response absent, spatial capture–recapture, half-normal detection function and Bernoulli’s encounter model. The number of Markov-Chain Monte Carlo (MCMC) iterations was set at 100,000 with a burn-in period of 20,000 iterations and a thinning rate of 10. Chain convergence was assessed via examination of z score values produced by the Geweke diagnostic statistic in SPACECAP. Z scores should be between -1.6 to +1.6 implying that the MCMC analysis has run long enough and the chains have converged. A Bayesian P-value is produced by SPACECAP allowing for assessment of the adequacy of the model, values close to 0 or 1 imply that the model is inadequate (Gopalaswamy *et al*. 2014).

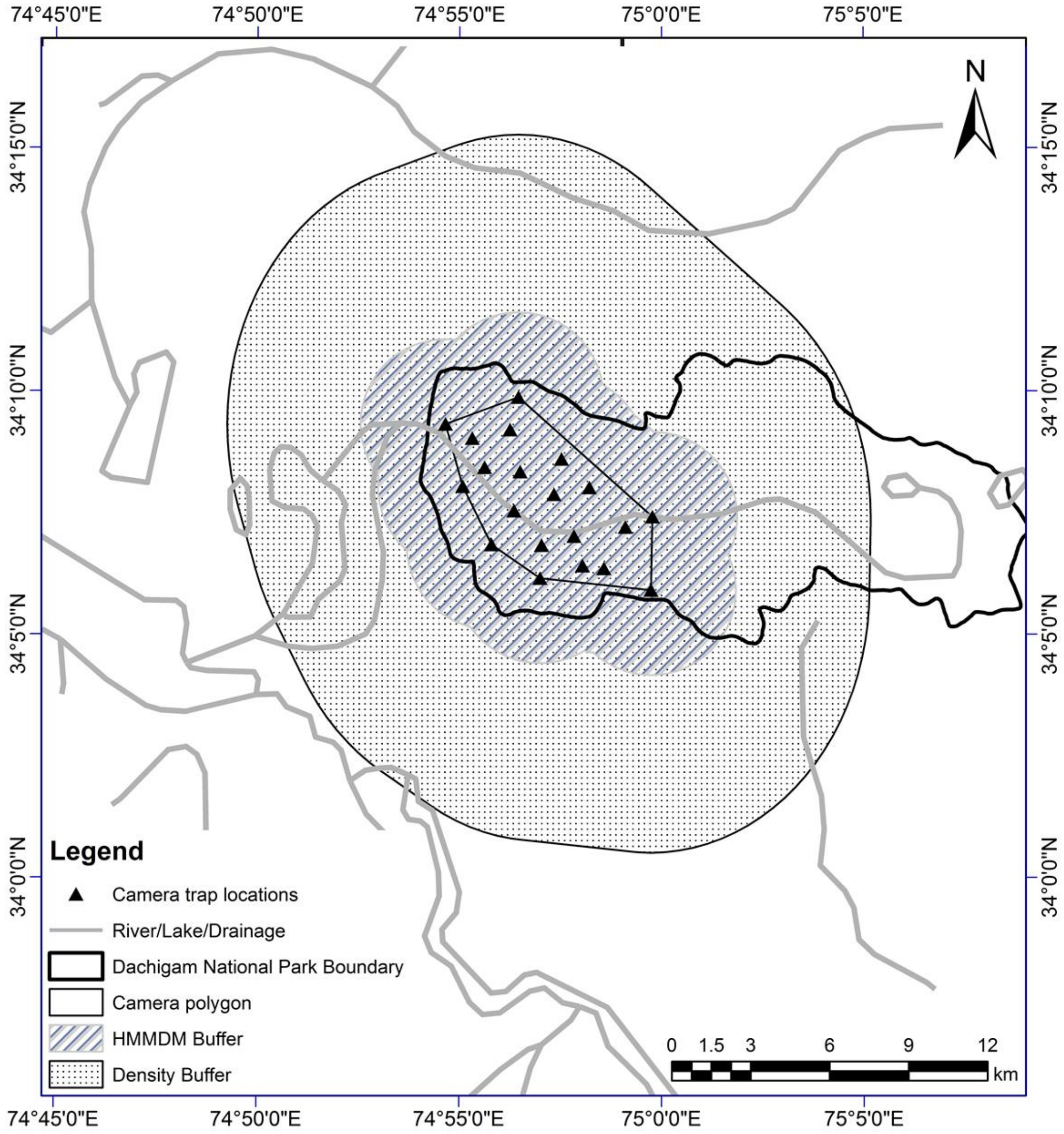


Figure 3.2 Camera traps locations with camera polygon, HMMDM (1/2MMDM) and the density buffer of 10 km (buffer width at which density stabilized) width in Dachigam National Park

3.2.3 Relative abundance of species encountered

Relative abundance indices from camera trap surveys have been shown to be directly related to independently derived density estimates of the species (O'Brien *et al*. 2003) therefore, relative abundance index were calculated from camera trap photographs taken during the survey. To calculate species abundance, each photograph of an animal was identified to species level and the time and date recorded, with the photo then classified as an independent or dependent event. An independent event was defined as consecutive photos of different species or consecutive photographs of individuals of the same species taken more than half an hour apart (O'Brien *et al*. 2003) as mentioned above. The relative abundance index (RAI) equalled the number of days required to obtain a photograph of each species. This index measured effort and was expected to decrease as density increased with a score of 0 indicating that the species was captured on the day the camera trap survey began, required low capture effort and existed at a high density on the study site. Species with higher RAI scores took a greater capture effort to obtain a photograph and therefore signified a lower density (Carbone *et al*. 2001; O'Brien *et al*. 2003). Encounter rates (number of signs encountered per km) of leopard signs such as scat, pug mark, scrape and rake marks were also used for relative abundance estimation for leopard.

3.2.4 Diel activity patterns

Animal activity rhythms are known to match sun/moon related rhythms as circadian rhythms therefore, activity patterns can be understood to synchronise in accordance with the daylight and night hours (Kronfeld-Schor *et al*. 2013). Thus, animals can be broadly categorised into two main categories either nocturnal (active in night) or diurnal (active in day light), but some are active at the dawn and dusk, representing bimodal activity peaks or crepuscular pattern. Researchers (e.g. Weckel *et al*. 2006; Harmsen *et al*. 2011; Gerber *et al*. 2012; Ross *et al*. 2013) have arbitrarily defined the crepuscular time range (usually 1 to 1.5 h) band before and after local sunrise and sunset timings, respectively. Therefore, I defined crepuscular activity time bands according to local sunrise and sunset timings *i.e.* the civil twilight time at dawn and at dusk, respectively. According to Hut *et al*. (2013), in the Northern Hemisphere, ~80% of the change of sunlight intensity takes place during the civil and nautical twilight timings. Civil twilight is defined as the time when the sun is between 6 and 0 degrees below the horizon while the nautical twilight is defined as the time when the sun is between 12 and 6 degrees below the horizon. Therefore, I obtained the civil and nautical twilight times as well as the local sunrise and sunset timings from Thorsen (2008) and both the nautical and the civil twilights were used to categorize activity times. Thus, the crepuscular activity time band covers civil and nautical twilight times i.e. the whole time period when the sun is between 0 and 12 degrees below the horizon. The activity between local sunrise and sunset timings was considered as diurnal whereas the nocturnal activity was considered to be falling between astronomical twilight's (i.e. the time when the sun is between 18 and 12 degrees below the horizon) start in the evening till its end in the morning.

As discussed above, mostly animal activities are likely to be a function of light intensity and thus of the sun's position: time of sunrise and zenith or sunset. The clock time of sunrises, sunsets (hereafter sun time) differs according to the latitude, longitude and date of the year making patterns of behaviour to differ if analysed by clock time rather than by the deviation from sun time. Therefore, I standardized the observations by transforming the clock-recorded time of each detection to the relative sun time corresponding to the local sunrise and sunset times (Nouvellet *et al*. 2012). I further examined species' selectivity to time periods by comparing use to availability of each time period (Manly *et al*. 2002). To see if species' activity was predominately classified as crepuscular, diurnal, or nocturnal, I calculated selection ratios of use to availability to each time period by each species following Manly *et al*. (2002):

$$w_i = o_i / p_i$$

where w_i is the selection ratio for period i; o_i is the proportion of detections in period i and p_i is the elapsed time in period i as a proportion of total elapsed camera trap time. Elapsed times were calculated by summing over all camera trapping days and over all sites. Values of $w_i > 1$ indicate that the time period is selectively used more than availability whereas $w_i < 1$ indicates that the time period is avoided (Gerber *et al*. 2012). I used χ^2 tests to determine if species used the three time periods non-randomly. I regarded the detections in crepuscular, diurnal and nocturnal periods as a multinomial distribution and the probability in each class was determined by the length of that period. I calculated the length of periods as sum of all camera trapping days at all sites. Resource selection analysis was performed in program R (R Development Core Team 2016) using the 'adehabitat' package (Calenge 2006).

3.2.5 Temporal overlap

I quantified the overlap for all species pairs, using the *coefficient of overlap*,$\hat{\Delta}$, which ranges from 0 (no overlap) to 1 (complete overlap) to measure the extent of overlap between two kernel density estimates (i.e., daily activity patterns of two species compared) (Ridout and Linkie 2009). Overlap was defined as the area under the curve formed by taking the minimum of the two kernel density estimates at each point in time. Specifically, I used the overlap coefficient $\hat{\Delta}_1$ as recommended by Ridout and Linkie (2009) in cases of low sample sizes (Meredith and Ridout 2014). I used 1000 bootstrap samples to obtain percentile 95% confidence interval (CI) of $\hat{\Delta}_1$ (Linkie and Ridout 2011). The calculated $\hat{\Delta}_1$ was compared between carnivores as well as between carnivores and potential prey species. Temporal overlap analyses were performed in program R (R Development Core Team 2016) using the ‘overlap’ package (Meredith and Ridout 2014).

3.2.6 Species co-occurrence patterns

I tested the potential co-occurrence patterns between species pairs by using probabilistic models to test for statistically significant pairwise patterns of species co-occurrence (Veech 2013). This model allows one to calculate the probability (P) that two species co-occur at a frequency either less than (P_{lt}) or greater than (P_{gt}) the observed frequency of co-occurrence. The model is based on calculating P_j, the probability that two species co-occur at exactly j sites (sampled camera stations). Thus, if $P_{lt} < 0.05$, two species have a negative co-occurrence and if $P_{gt} < 0.05$ then there is positive co-occurrence between the two species. The probabilistic pairwise species co-occurence analysis was performed in program R (R Development Core Team 2016) using the ‘cooccur’ package (Griffith *et al*. 2016).

3.3 Results

3.3.1 Camera Trapping

A total of 378 photographs of 10 species were recorded during the whole sampling exercise of 396 trap days (after deducting the days cameras were nonfunctional). Red fox was the most commonly photographed species with 125 photo-captures. Kashmir gray langur and wild pig were least photographed species each with two captures only.

3.3.2 Density estimation

A total of 14 leopard photos were obtained during the camera trapping exercise of which two male leopards (71% male captures) and one female leopard (29% female captures) were identified.

3.3.2.1 Non-spatial density estimation

The closure test of Otis *et al*. (1978) suggested no violation of permanent population closure (Z = 999, p = 2.00). Similarly, the test of Stanley and Burnham (1999), which incorporates time variation in recapture probability, suggested population closure was achieved (χ^2 = 1.00, p = 1.00) for the sampling period.

The null model (M(0)) was ranked first with the highest discriminant criterion of 1.00, followed by the heterogeneity model (M(h) = 0.83). I regarded M(h) model as the most appropriate because it accounts for ecological reasoning of individual heterogeneity in capture probability as mentioned in Karanth and Nichols (1998). The average capture probability was 0.074 using the jackknife estimator, providing me with a population size of 4 leopards (SE = 1.65). Two individuals were photographed more than once while one male could not be recaptured. This gave a mean maximum distance moved (MMDM) estimate of 6.447 km (SE = 2.159 km) moved between the camera traps. Therefore, with an effectively sampled area of 140 km^2, I obtained leopard density of 2.85 ± 1.17 (SE) per 100 km^2 (Table 3.1). I also calculated density using half mean maximum distance moved (MMDM) to get the density estimate of 5.71 ± 2.35 (SE) per 100 km^2. I also used average home range radius (HRR = 6.17 km), calculated from the average home ranges of a male (145 km^2) and a female (94 km^2) leopards collared in the study area and to be discussed in the next chapter, to estimate the effective trapping area (ETA) (Table 3.1). The density estimate using HRR got reduced to 1.31 ± 0.54 100 km^{-2}. Density estimates obtained using MMDM, HRR and spatial likelihood approaches are considered to be more close to actual density estimates (Sharma *et al*. 2009).

Table 3.1 Density estimates for leopard using different methods in Dachigam National Park

Best Model	**Mt+1**	**P hat**	**N (± SE)**	**95% CI**	**Method**	**ETA (km^{-2})**	**Density (± SE; per 100 km^2)**
M_h (Jackknife)	3	0.074	4.00 (± 1.65)	L = 4 U = 12	MMDM	317	1.26 ± 0.52
					1/2MMDM	140	2.85 ± 1.17
					HRR	305	1.31 ± 0.54

3.3.2.2 Density estimation using spatially explicit model

The posterior SECR summaries obtained from model fit with the half-normal detection function are provided in Table 3.2. The leopard density stabilized at 10 km buffer width therefore, I chose to select the estimate at 10 km buffer as the final density estimate. The leopard density at 8 km buffer was 0.96 ± 0.17/km^2 and at 10 km buffer was 0.74 ± 0.18/km^2, i.e., a reduction of ~22% in density (Table 3.2). The models were of an adequate fit as the Bayesian P-values of the models ranged from 0.83 to 0.86. The negative exponential model was tested for convergence with Geweke test which indicated that all model parameters converged with z scores falling between 1.64 and -1.64 (sigma = -1.427; lam0 = 0.899; psi = -0.268; N = -0.383).

Since, the spatially explicit CR methods are more reliable, the inferences are based on SECR results rather than conventional CR analyses. I have kept the results from non-spatial conventional *ad hoc* CR analyses only for comparisons with earlier studies that used the approach.

Table 3.2 Posterior summaries from Bayesian spatially explicit capture-recapture (SECR) of the model parameters implemented in SPACECAP. The derived parameters are $\lambda0$ which is the intercept of expected encounter frequency, σ is the range parameter of the species, Ψ is the ratio of the number of animals present within the state space "S" to the maximum allowable number, N super is the population size for the state space S, D = Density is N super divided by S presented per 100 km^2.

Parameters	**Posterior mean**	**Posterior SD**	**95% HPD level**		**Z scores**
			Lower	**Upper**	
Density	0.744	0.187	0.674	1.124	
σ	55578.724	48234.670	2642.794	158123.767	-1.427
$\lambda0$	0.011	0.007	0.003	0.019	0.899
Ψ	0.287	0.125	0.069	0.522	-0.268
N super	3.312	0.834	3.000	5.000	-0.383

3.3.3 Relative abundance of species encountered

A total of 378 photographs of 10 species were recorded during the whole sampling exercise out of which red fox was the most commonly photographed species with 125 photo-captures (Table 3.3). Kashmir gray langur and wild pig both were captured least number of times (n=2, each).

Table 3.3 Different species photographed over 40 days in May–June 2013 in the Dachigam National Park. Species' conservation status in the Schedules of the Indian Wildlife (Protection) Act 1972 and the IUCN status have been provided. Capture frequencies expressed as relative abundance index (RAI: the number of days required to obtain a photograph of a species i.e. total sampling effort divided by total number of independent photographs).

Species	**Conservation Status**		**Total number of photo-captures**	**RAI**
	IUCN	**WPA**		
Red fox	LC	II	125	3.16
Leopard cat	LC	I	64	6.18
Asiatic black bear	VU	I	55	7.20
Indian porcupine	LC	IV	46	8.61
Hangul	CR	I	30	13.20
Yellow-throated marten	LC	II	27	14.67
Leopard	VU	I	14	28.28
Jungle cat	LC	II	13	30.46
Kashmir gray langur	EN	II	2	198.00
Wild pig	LC	III	2	198.00

3.3.4 Diel activity patterns

Daily activity patterns of all eight species detected in the study area are presented in Fig. 3.3. All the species except the Asiatic black bear, leopard and hangul exhibited non-random use of diurnal, nocturnal, and crepuscular periods (Table 3.4). The jungle cat, was detected infrequently during the diurnal (P = 0.000) and crepuscular (P = 0.000) periods and detected more than expected during the nocturnal period (P < 0.001). The leopard cat was detected less than expected during the diurnal period (P = 0.000) and more than expected during the crepuscular (P = 0.012) and nocturnal (P =

0.000) periods. Similarly, the red fox, it was detected less than expected during the crepuscular (*P* = 0.947) and diurnal (*P* = 0.000) periods and more than expected during the nocturnal (*P* = 0.000) hours. Yellow-throated marten was detected during the diurnal hours (*P* = 0.000) only with not a single detection during the crepuscular and nocturnal periods. For the Indian porcupine, it was detected mostly during the nocturnal hours (*P* = 0.000) while detecting it infrequently during the crepuscular (*P* = 0.633) and diurnal (*P* = 0.000) hours.

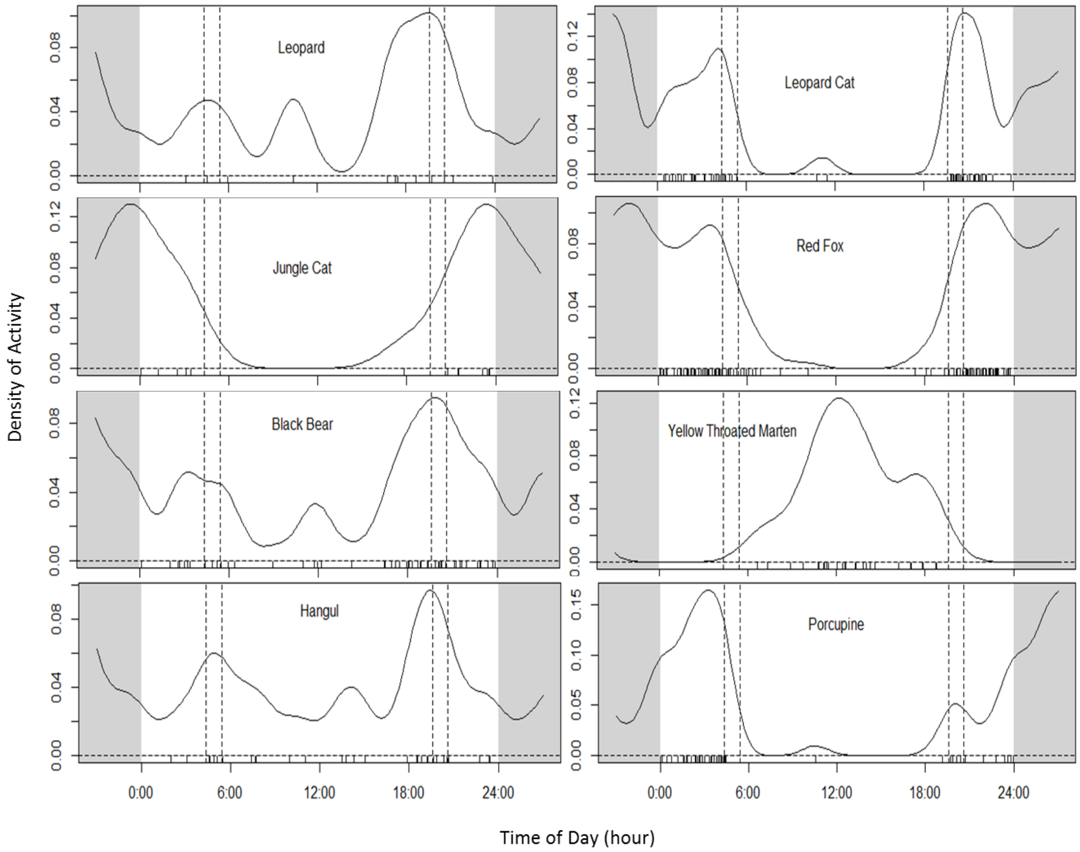


Figure 3.3 Temporal activity patterns of the species recorded in Dachigam NP during the study period. The four dotted vertical lines indicate start of nautical twilight, sunrise, sunset and end of nautical twilight, respectively.

Table 3.4 Number of detections *n* (selection ratio *w*) and the random use test of the diurnal, nocturnal and crepuscular periods given their availability by the mammals photo-captured during May – June 2013, in the Dachigam NP, India

Species	***n* (*w*) in time periods**			**Random use test (χ^2, df = 2)**
	Diurnal	**Nocturnal**	**Crepuscular**	
Asiatic black bear	25 (0.919)	19 (0.983)	11 (1.297)	0.87, $P = 0.646$
Leopard	7 (1.011)	3 (0.610)	4 (1.853)	2.12, $P = 0.345$
Jungle cat	1 (0.156)	12 (2.627)	0 (0.000)	19.4, $P < 0.001$
Leopard cat	2 (0.063)	43 (1.912)	19 (1.926)	69.61, $P < 0.001$
Red fox	13 (0.210)	93 (2.118)	19 (0.986)	98.47, $P < 0.001$
Yellow-throated marten	27 (2.022)	0 (0.000)	0 (0.000)	38.02, $P < 0.001$
Indian porcupine	1 (0.044)	39 (2.413)	6 (0.846)	60.45, $P < 0.001$
Hangul	15 (1.011)	7 (0.664)	8 (1.730)	3.37, $P = 0.185$

3.3.5 Temporal overlap

Highest overlap was found between Asiatic black bear and hangul with an overlap coefficient, $\hat{\Delta}_1 = 0.81$ followed by leopard and hangul ($\hat{\Delta}_1 = 0.79$). On the other hand, least overlap ($\hat{\Delta}_1 = 0.47$) was found between hangul and yellow-throated marten (Fig. 3.4a). Similarly, highest coefficient value was for red fox and Indian porcupine temporal overlap ($\hat{\Delta}_1 = 0.72$), followed by leopard cat and Indian porcupine ($\hat{\Delta}_1 = 0.70$; Fig. 3.4b). Amongst carnivore species, highest temporal overlap was found between leopard and Asiatic black bear ($\hat{\Delta}_1 = 0.84$), followed by red fox and jungle cat ($\hat{\Delta}_1 = 0.82$), whereas the least overlap among carnivores was between yellow-throated marten and leopard cat ($\hat{\Delta}_1 = 0.12$; Table. 3.5).

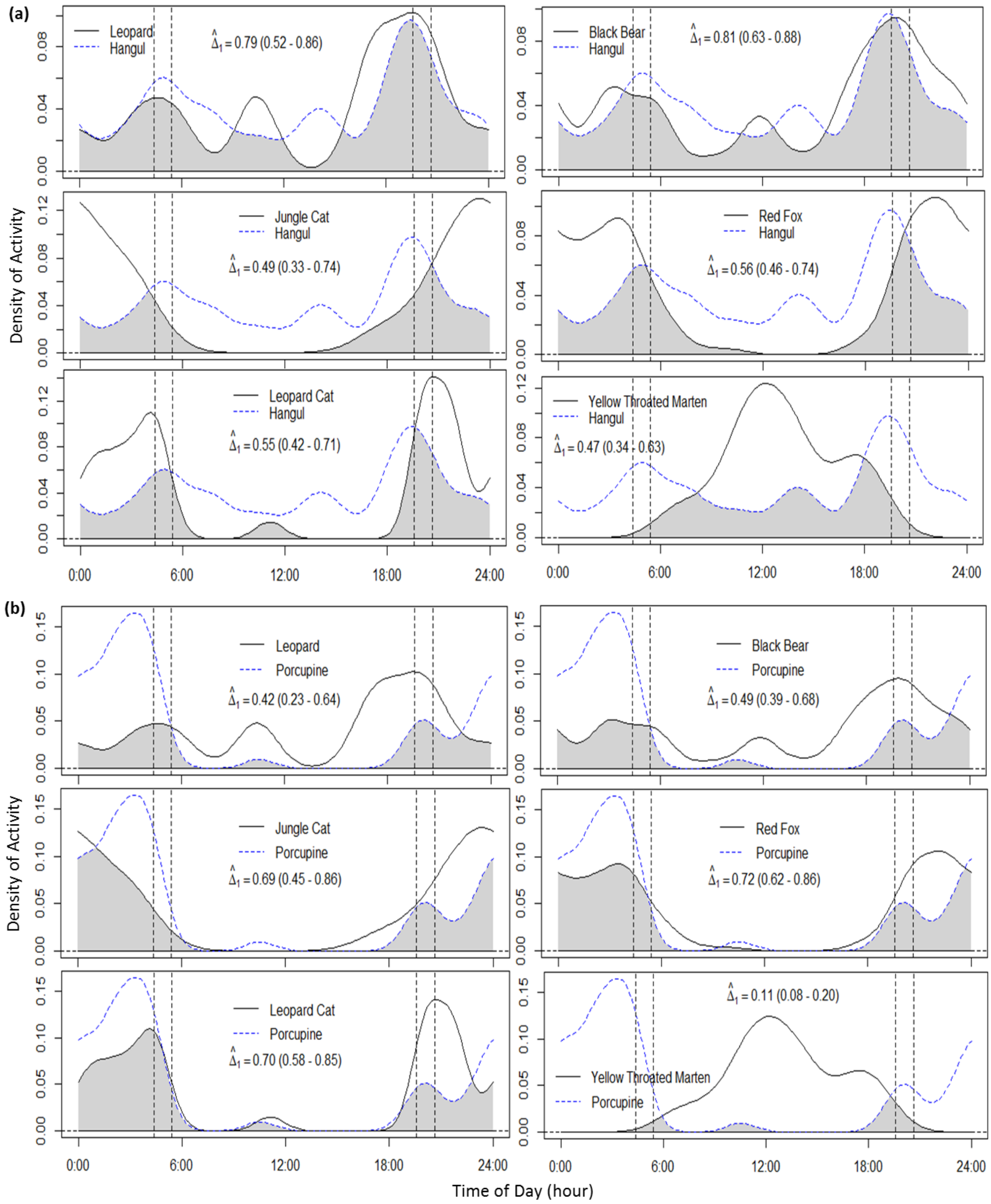


Figure 3.4 Temporal overlap (shaded area) between six carnivore species and herbivore species (a; hangul and b; Indian porcupine) considered as prey. Coefficient of overlap ($\widehat{\Delta_1}$) given for each pair along with percentile 95% CI given in parentheses. The four dotted vertical lines indicate start of nautical twilight, sunrise, sunset and end of nautical twilight, respectively.

Table 3.5 Temporal overlaps and species co-occurrence patterns between the species pairs. Temporal overlaps (upper half of the table in light gray) between the species pairs with overlap coefficient values ($\hat{\Delta}_1$) given on top and below are the percentile 95% confidence intervals given in parentheses. The species are sorted from highly carnivorous (leopard/leopard cat) to herbivorous (porcupine). High temporal overlaps ($\hat{\Delta}_1 > 0.75$) are bold. The lower half of the table (dark gray) presents standardized effect sizes (differences between expected and observed frequency of co-occurrence) for easy comparisons among studies and methods (Griffith *et al*. 2016). These standardized values are bounded from -1 to 1, with positive values indicating positive associations and negative values indicate negative associations. Statistically significant values are bold ($P_{lt} < 0.05$ or $P_{gt} < 0.05$).

	Leopard cat	**Jungle cat**	**Red fox**	**Asiatic black bear**	**Yellow - throated marten**	**Hangul**	**Indian Porcupine**	
	0.55 (0.34 - 0.72)	0.49 (0.25 - 0.74)	0.55 (0.33 - 0.74)	**0.84** (0.54 - 0.86)	0.46 (0.27 - 0.67)	**0.79** (0.52 - 0.86)	0.42 (0.23 - 0.64)	**Leopard**
Jungle Cat	0.040	0.70 (0.52 - 0.86)	**0.83** (0.72 - 0.91)	0.63 (0.54 - 0.77)	0.12 (0.11 - 0.21)	0.55 (0.42 - 0.71)	0.70 (0.58 - 0.85)	**Leopard cat**
Red Fox	0.060	0.050	**0.82** (0.60 - 0.91)	0.60 (0.41 - 0.78)	0.15 (0.06 - 0.34)	0.49 (0.33 - 0.74)	0.69 (0.45 - 0.86)	**Jungle cat**
Asiatic black bear	0.060	0.000	-0.010	0.66 (0.54 - 0.78)	0.15 (0.14 - 0.23)	0.56 (0.46 - 0.74)	0.72 (0.62 - 0.86)	**Red fox**
Yellow-throated marten	0.025	0.060	0.040	-0.010	0.40 (0.30 - 0.58)	**0.81** (0.63 - 0.88)	0.49 (0.39 - 0.68)	**Asiatic black bear**
Hangul	**0.140**	0.010	0.070	0.020	0.060	0.47 (0.34 - 0.63)	0.11 (0.08 - 0.20)	**Yellow-throated marten**
Indian Porcupine	0.110	0.050	0.090	-0.010	-0.010	**0.120**	0.45 (0.33 - 0.64)	**Hangul**
Leopard	0.055	0.040	0.080	0.080	-0.005	0.000	0.030	

3.3.6 Species co-occurrence patterns

The results (Table 3.5) from the probabilistic pairwise co-occurrence analysis suggest that 25 of the 28 total classifiable species pairs were ‘truly random’ associations as none of the 25 species pairs exhibited significantly negative or positive co-occurrence patterns at the study sites ($P_{lt} > 0.05$, $P_{gt} > 0.05$). The significant non-random associations which were positive were only two in which hangul exhibited significantly positive co-occurrence patterns with the leopard cat ($P_{gt} = 0.012$) and the Indian porcupine ($P_{gt} = 0.039$). The remaining species pair (Indian porcupine-leopard cat) was deemed unclassifiable ($P_{lt} > 0.05$, $P_{gt} = 0.052$).

3.4 Discussion

This study provides first information pertaining to co-existence in mammalian community of the moist-temperate forest of the Kashmir Himalaya, India, however with sample size limitations. Although I initially aimed to collect data on leopard for longer periods covering seasons but constraints like limited number of cameras and security concerns hampered the overall sampling duration. Other sympatric mammals such as the ‘endangered’ Kashmir gray langur and wild pig (which reappeared after a long gap of 30 years during the sampling period; Ahmad *et al*. 2013) were also recorded but could not be included in the analysis due to very low detections. In rugged terrain of the mountainous regions like this study area, camera trapping can be a more cost-effective method than other survey methods. Camera trapping can be more efficient in terms of both finance and human effort and provide detailed biological information on diel activity patterns.

3.4.1 Density of leopard

This study is a first in documenting leopard density estimates from the moist temperate region of Kashmir in western Himalaya. In Indian sub-continent only a few studies have been conducted in the mountainous terrains of the Himalaya (Wang and Macdonald 2009; Harihar *et al*. 2009; 2011; Selvan 2013) and none from the Kashmir valley which marks the northern most limit of leopard (*P. p. fusca*) distribution in India (Jacobson *et al*. 2016). Leopard co-exists with the tiger in most of the protected areas across its distribution therefore, the information pertained to leopard ecology is generally a by catch as most of the studies are tiger centric and mostly deals with abundance estimation (Kalle *et al*. 2011; Harihar *et al*. 2011; Selvan *et al*. 2013; Jhala *et al*. 2015). Recently, a few studies have targeted leopards to study their ecology and movement patterns outside the protected area systems in the human dominated landscapes (Athreya *et al*. 2013; Odden *et al*. 2014).

For the sake of comparison with other studies which did not employ SCR method I used non-spatial, *ad hoc* density estimates. The density estimate (2.8 ± 1.18 leopards/100km^2) is the lowest adult leopard population density recorded in India (Table 3.6). Similar low density values have also been reported from other regions of the Himalaya like Bhutan (1.04 ± 0.01 leopards/100km^2; Wang and Macdonald 2009) and Pakke Tiger Reserve (2.9 ± 1.13 leopards/100km^2; Selvan 2014) (Table 3.6). There is a huge variation in leopard density estimates across India the highest recorded density being 28.9 ± 7.2 leopards/100km^2 from tropical forests of Mudumalai (Kalle *et al*. 2011).

Table 3.6 Comparison of leopard densities (non-spatial and spatial with SE in parentheses) and the prey biomass in some protected areas of the Indian sub-continent.

Protected Area	**Habitat Type**	**Prey Biomass (kg/km^2)**	**Density (±SE) (leopards/100 km^2)**	
			Non-spatial	**Spatial**
Jigme Singye Wangchuk	Broadleaf to coniferous forest	379[a]	1.04 (0.01)[b]	–
Dachigam	Moist temperate forest	872[c]	2.8 (1.18)[d]	0.74 (0.18)[d]
Pakke	Tropical semi-evergreen forest	2183[e]	2.9 (1.13)[e]	2.82 (1.20)[e]
Chitwan	Alluvial grassland and moist woodland	6966[f]	4.34 (1.46)[f]	3.45 (0.49)[f]

Parsa	Subtropical dry deciduous forest	5227[g]	5.61 (1.30)[h]	3.48 (0.83)[h]
Manas	Alluvial grassland and moist woodland	–	11.30 (2.9)[i]	3.40 (0.82)[i]
Chilla	Moist and dry deciduous forest	6916[j]	14.9 (6.9)[k]	9.76 (3.50)[l]
Mudumalai	Subtropical dry deciduous forest	8365[m]	28.9 (7.2)[n]	13.17 (3.15)[n]

a–Wang 2010; b–Wang and Macdonald 2009; c–Mir 2016; d–Present study; e–Selvan 2013; f–Thapa 2011; g–adapted from Thapa 2011 (assumed to be similar to lowest biomass recorded in Chitwan); h–Thapa *et al*. 2014; i–Borah *et al*. 2014; j–Harihar 2005; k–Harihar *et al*. 2009, l–Harihar *et al*. 2011; m–Ramesh *et al*. 2009; n–Kalle *et al*. 2011.

The density estimate obtained via Bayesian SECR (0.74 leopards per 100 km^2) turns out to be very low in comparison to leopard density calculated from the conventional non-spatial capture-recapture method. The estimates obtained through spatial capture-recapture methods are known to be lower than the ad hoc non-spatial methods (Gopalaswamy *et al*. 2012; Noss *et al*. 2012). A decrease of about 25–50% in leopard density estimates has been recorded in some studies (see Harihar *et al*. 2009; Harihar *et al*. 2011; Kalle *et al*. 2011; Athreya *et al*. 2013; Thapa *et al*. 2014; Braczkowski *et al*. 2016). Yet, the use of SCR is better and recommended because the spatially explicit methods are not biased by an informal estimation of an effective survey area (Borchers and Efford 2008; Royle *et al*. 2009a, b; Noss *et al*. 2012). It is important to recognise however, that survey design and analysis can also be the factors that may bias density estimates. One such factor that might have biased the density estimates was a smaller camera trap polygon of 35 km^2. It would have been appropriate to have a larger trapping area (Karanth and Nichols 1998; Jhala *et al*. 2008) preferably of the size of the largest home range of a male leopard (Tobler and Powell 2013) or several times larger than the average home range (known or estimated) of the target species (Noss *et al*. 2012). Nevertheless, SECR models have been shown to produce unbiased density estimates even when the camera polygon size is small (Sollmann *et al*. 2011; Tobler and Powell 2013) but further validation will be required to check the stability of the estimate. Using sex as covariates in the SECR analysis can be a second consideration for future work. Sex and age are reported to influence the movement and detection parameters and therefore, density (Gray and Prum 2012; Sollmann *et al*. 2011; Tobler and Powell 2013). There is no facility in SPACECAP to use these as covariates. Males and females have heterogeneous capture probabilities thus biasing camera trapping data towards the sex with the greater capture probability. In order to remove this bias, one option would be to estimate the densities for males and females separately if sample sizes are adequate (Foster and Harmsen 2012) which was not the case for this study. Since, SECR models with sex covariates have shown that not accounting for sex could result in an underestimation of the true density estimate (Tobler and Powell 2013) which was unknown, therefore I cannot infer the degree of biasness of the estimates. Future studies should look forward to include this aspect in order to improve the precision of density estimates through the inclusion of sex as covariates.

Carnivore abundance is known to be regulated by the abundance of prey (Carbone and Gittleman 2002). Similarly, variation in leopard density is partially due to differences in biomass and abundances of prey (Carbone and Gittleman 2002; Karanth *et al*. 2004). Leopards preferentially feed upon animals in the range of 10 and 40 kg that live in small herds and occupy dense habitat (Hayward *et al*. 2006). This range of prey biomass is not available in the Dachigam NP. In a parallel study in the same study area on leopard diet and prey abundance (Mir 2016) leopards are found to be mostly dependent on small rodents and the study area does not support adequate prey base to sustain a large leopard population. The only ungulate that got photographed easily was hangul but even this species is not that abundant (~218 odd individuals, Charoo *et al*. 2011). The status of other ungulate species reported from the area (Kashmir musk deer, Himalayan serow and wild pig) is not known, not even photographed during the present survey except for the wild pig which was recorded after a gap of three decades (Ahmad *et al*. 2013. The Jammu and Kashmir region has been going through armed insurgency and political instability for the past three decades (Akbar 2002) which are a major threat to local biodiversity (Hanson *et al*. 2009). All this impacts negatively on the biodiversity with increased pressures from illegal killing and natural resource extraction, very low investment in conservation, and displacement of people (Hart *et al*. 1997; McNeely 2003; Loucks *et al*. 2008) resulting in large declines in the population and distribution of large mammal species. Densities of large cats in particular have been found to get decreased owing to both direct mortality from hunting and the collapse of prey populations (Gray and Prum 2012). Owing to the present scenario it cannot be ruled out that the forests of the Kashmir Himalaya including the present study area are susceptible to or suffering through "empty forest" syndrome (Karanth *et al*. 2004; Datta *et al*. 2008). Recently, similar results have been shown by Shehzad *et al*. (2014) in similar ecosystem of western Himalaya in Pakistan.

3.4.2 Activity pattern and co-occurrence of species

The large mammals in this study are found to be active both day and night indicating no clear cut selection from the three diel categories and thus, can be understood to have cathemeral pattern of activity. This could be attributed, at least partially, to the energy requirements imposed by their large body sizes which require being active more time (van Schaik and Griffiths 1996). I explore plausible justifications pertaining to this behaviour in each case of the three species. In case of hangul, it showed firstly, two distinct activity peaks in the twilights around dawn and dusk which is consistent with studies conducted in the temperate ecosystems (Georgii & Schröder 1983, Boyce *et al*. 2010, Ensing *et al*. 2014). Secondly, I assume that hangul (as ~73% were females) has more energy requirements during the sampling period, which marks the onset of the fawning (Prater 1980), due to which it is compelled to remain active during daylight hours. Finally and most importantly, it has to trade-off, by remaining active 24 h period, between minimizing predation risk while maximising the food intake to supplement energy requirements and this is in agreement with what has been reported by Ensing *et al*. (2014). On the other hand, it is well known that some predators such as cats hunt primarily by auditory and visual cues (Sunquist and Sunquist 2002) and therefore, synchronise their activities in accordance with the activity pattern of their prey species. This is the case of leopard which in forest ecosystems has a diurnal activity pattern matching with that of prey activity (Jenny and Zuberbuhler 2005). Leopard activity pattern is similar to that of hangul in my study at least for the sampling duration when pregnant hangul females are more susceptible to get killed. This study on ecological aspects of leopard in the Dachigam NP has revealed that this area has very poor prey base which costs leopard very high searching efforts (e.g. largest home range sizes; next chapter) and very low benefits (Habib *et al*. 2014). This prey scarcity ultimately forces the leopard to spend great amount of energy in search efforts across time and space thus, resulting cathemeral activity. In case of Asiatic black bear, it is also diurnally active throughout the summer in the study area (Prater 1980) so as to compensate for the energy lost during the previous winter season. It has to spend sufficient amount of time in search of food resources under high intra-specific competition (for vegetal food/and animal matter) as well as inter-specific competition with other carnivores (for animal matter). Since, the study area harbours very high Asiatic black bear densities [1.3–1.8 bears/km^2 (Saberwal 1989); 48/100 km^2 (Sathyakumar *et al*. 2013)].

This study finds the two small cats (leopard cat and the jungle cat) to be primarily nocturnal which is consistent with other studies only in case of leopard cat (Prater 1980; Grassman 2000; Lynam *et al*. 2013; Mukherjee 2013), nevertheless there are studies contradicting nocturnality of leopard cats (Rabinowitz 1990; Azlan and Sharma 2006, Austin *et al*. 2007). Jungle cat is diurnal and crepuscular and is reported to even kill the nocturnal Indian porcupines (Prater 1980). Here in this study, jungle cat was found to be strictly nocturnal as has been reported by Majumder *et al*. (2011). According to several studies (Harmsen *et al*. 2011, Bashir *et al*. 2014) the daily activity of many felids is correlated with the activity pattern of their prey. The main reason of these small cats being nocturnal in the study area could be that small mammals such rodents, which is their main potential prey, are generally nocturnal (Prater 1980; Bashir *et al*. 2014) although I could not quantify this aspect through camera trapping.

The only canid species recorded during this study was red fox. The red fox is a generalist predator which utilizes the resources according to their availability and hence, considered as opportunistic in behaviour (Webbon *et al*. 2006, Dell'Arte *et al*. 2007). According to Nowak (1999), it has nocturnal and crepuscular activity behaviour which the present results also confirm. Like the two small felids, the red fox too predominantly depends on rodents in this study area (~50%; Bora 2012). In the study area, yellow-throated marten was active during diurnal hours completely and has been suggested as 'primarily diurnal' by Nowak (1999), but can hunt both by day and night (Prater 1980). It is also known to attack young deer also (Prater 1980) due to which its predation potential on hangul fawns can be anticipated during the sampling period, at least, which coincides with the onset of hangul fawning (Prater 1980). On the other hand, Indian porcupine is mainly a nocturnal species with little activity during the twilight (crepuscular). The Indian porcupine has been described as a nocturnal species (Menon 2014).

The activity timings varied amongst different sympatric carnivore species in the study area. Among large carnivores, leopard was active almost equally during light and dark (night and crepuscular hours) periods of the day. The results show that activity patterns of both leopard and Asiatic black bear match with hangul activity resulting in very high values of temporal overlap coefficients.

I found no statistically significant spatial co-occurrence patterns amongst the species pairs. Except for the two pairs (hangul-leopard cat and hangul-Indian porcupine) which were positively associated, all other 26 pairs analysed were random i.e. no positive or negative associations shown. Therefore, the spatial niche differentiation among the species in the study area is not a determining factor in the area. The species have to differentiate on other two dimensions of niche at least i.e. time and diet. In case of time the species pairs which had high temporal overlap also had difference on their general diet patterns (carnivore, omnivore or herbivore). Thus, I can assume that species co-occurrence in the study area may be regulated by partitioning the ecological niches or resources at a finer scale; therefore, further studies are needed to determine the factors controlling their co-occurrence and potential interactions at a micro-scale.

I recognise drawbacks of small data sets for some species and short span of time but owing to the importance of the species and the ecosystem, every bit of information is crucial for the management which should be interpreted with caution. Moreover, according to Ramesh *et al*. (2012), camera traps are effective in recording spatio-temporal patterns with certain limitations, like the inability to account for detection probability which varies with species. For surveying large carnivores, cameras are placed along trails and roads which affect the ungulate capture rates (Ramesh *et al*. 2012). This ecosystem consists an unbalanced number of species comprising several small to large predators and an important ungulate species hangul which is numerically small in population (~218 odd individuals, Charoo *et al*. 2011) and high conservation status (Mukesh *et al*. 2015). Moreover, there are other ungulate species with unknown population status owing to their very low abundance, thus, further studies are needed in order to explicitly understand the coexistence patterns within this community.

CHAPTER 4

RANGING PATTERN, MOVEMENT AND HABITAT USE OF LEOPARD

4.1 Introduction

Home range of an animal can be defined as the area over which an individual animal normally travels in pursuit of its daily routine activities such as searching for food, caring for young and mating (Harris *et al*. 1990). However, this definition does not include any exploratory ‘forays’ (e.g. by sub-adults or transient leopards) and therefore, does not include the entire area that an animal covers during the course of its lifetime (Burt 1943; Jewell 1966; Bothma *et al.* 1997; Grimbeek 1992). Any predator’s spatial utilisation reflects its relationship with resources and other ecological factors, such as access to water and possible mates, human influences, cover for hunting and camouflage, prey distribution and abundance (Bailey 1993; Marker and Dickman 2005).

Obtaining information pertaining to home range size is vital and helps in developing conservation and management strategies as it provides crucial and robust information on the spatial and habitat requirement of predators and indicates the utilization pattern of the landscape (Simcharoen *et al*. 2008), the overall behaviour patterns of the predator (Henschel 1986) as well as mortality and factors affecting it (Hunter *et al*. 2003; Nilsen *et al*. 2008).

4.1.1 Leopard home ranges and movement

Leopards are generally described as solitary felids with groups and associations generally taking place between males and females to mate and between a female and her dependent offspring (Bailey 1993; Bothma and Walker 1999; Sunquist and Sunquist 2002). Usually male leopards have larger home ranges in comparison to female leopards. Home ranges of the same sex, males particularly, seldom overlap (Bailey 1993; Schaller 1972). Transient individuals such as sub-adults that have not yet dispersed from their natal areas can also be found within the ranges of resident animals. Similarly, old or young leopards that are passing through to find and establish their own territory can be found in vacant home ranges or areas (Bailey 1993).

There are a number of different behavioural and ecological factors that govern and affect the home range size. Usually, availability of reproductively active females govern the adult male home range sizes, thus males have larger home ranges than the females ranges. This is in particular to maximise access to more number of reproductively active females and mating opportunities (Bailey 1993; Marker and Dickman 2005). Larger body size of males and accompanying more energy requirements force large home ranges of male in comparison to females (Carbone and Gittleman 2002). Distribution and abundance of food resources and availability of safe areas for rearing young generally determine adult female home ranges (Sunquist and Sunquist 1989 Bailey 1993; Marker and Dickman 2005). In case of solitary felids, availability of hunting cover and inter and intra-specific competition can also affect the home range size such as (Gittleman and Harvey 1982).

This non-random pattern of overlaps of individual home ranges is suggests that some form of social congruence exists among felid species; this has been classified as ‘spatial groups’ (Macdonald *et al.* 2010b). These spatial groups, or the spatial organisation within the groups, can be characterised by the extent of overlap within and between the home ranges of adult and sub-adult females and males (Bailey 1993; Macdonald *et al.* 2010b). The socio-spatial organisation of these home ranges is majorly determined by the territoriality of the resident leopards. According to Etkin (1967), territoriality can be defined as any behaviour by an animal that tends to confine the movements of that animal to a particular locality. The socio-spatial behaviour is an important factor to study, particularly in areas where leopards are persecuted such as in India (Raza *et al.* 2012). It is observed that if males are perpetually persecuted in an area, females of that area are not able to rear cubs successfully because of the high rate of male turnover and incursions (Balme *et al.* 2010a). Therefore, the home range sizes and ranging patterns of leopards are important factors in any conservation management planning.

Leopards have highly variable home range sizes throughout their distribution. African semi-arid ecosystems comprise largest home ranges of male leopards which exceed to over 2100 km^2 (Bothma *et al.* 1997). The home ranges of female leopards in Africa range between 12.4 km^2–488.7 km^2 (Bertram 1982; Bailey 1993; Jenny 1996; Norton and Lawson 1985; Bothma *et al.* 1997). However, generally male territories average between 30–78 km^2 and 15–16 km^2 are common for females in protected areas (Nowell and Jackson 1996). Norton and Lawson (1985) found leopard home ranges of 388 and 487 km^2 (for a male and female, respectively) in a mountainous terrain interspersed with farms and ranches, suggesting both severely reduced prey availability and low leopard density.

With limited number of studies from South Asian countries, home range sizes differ greatly even within these (Table 4.1). Female leopards have shown smallest home range sizes ranging 5.2 km^2–6 km^2 in the sub-tropical forest ecosystem of Nepal (Seidensticker *et al.* 1990; Odden and Wegge 2005). The home range of male leopard in Asia ranges between 17 km^2–68 km^2 (Karanth and Sunquist 2000; Grassman 1999; Rabinowitz 1989; Odden and Wegge 2005; Habib *unpublished data*). In the mountainous Himalayan ecosystem of Nepal, the ranges of the female leopards have been estimated to range 5.2 km^2–17 km^2 (Scidensticker *et. al.* 1990; Odden and Wegge 2005), whereas for male leopard it was a maximum at 50 km^2 (Odden and Wegge 2005). Recently, a study (Khan *et al.* 2018) exhibited male leopard's home range size of ~102 km^2 from western Himalaya in Pakistan. In Wilpattu National Park, Sri Lanka, the home range of adult female was estimated to range between 8 km^2–10 km^2 by Muckenhim and Eisenberg (1973). Apart from the above mentioned studies conducted in the PAs, recently Odden *et al.* (2014) studied leopard home ranges in human dominated landscapes of India and found that the male and female exhibited home range sizes between 8 to 15 km^2.

The variability in the home range sizes among the previous studies can be attributed to sexual differences, reproductive and social status, metabolic needs, differences in the spatial distribution of food resources, as the density and movement of prey are essential determinants of predator behavior (Schaller 1972; Gittleman and Harvey 1982; Bailey 1993).

Table 4.1 Estimated home range sizes (km^2) of radio-collared leopards in South Asia. (NP = National Park; PA = Protected Area; WLS = Wildlife Sanctuary)

Study area	**Habitat / Forest Type**	**Sample size (n)**	**Home range size (100% MCP; km^2)**		**Reference**
			Male	**Female**	
Dachigam NP, India	Moist Temperate	3	145	94	This study
Ayubia NP, Pakistan	Temperate, tropical and sub-tropical	1	102.2	-	Khan *et al.* 2018
Outside PA system in Maharashtra and Himachal Pradesh, India	Human dominated landscape	5	42	65	Odden *et al.* 2014
				11	
			8	15	
Sariska TR, India	Tropical dry deciduous	2	84.3*	-	Mondal *et al.* 2013
			63.2*		
Bardia NP, Nepal	Subtropical	3	50.4	17.1	Odden and Wegge 2005
			20.1		
Nagarhole NP, India	Tropical deciduous	2	26.3**	-	Karanth and Sunquist 2000
			17.1**		
Kaeng Krachan NP, Thailand	Tropical	3	17.3	8.8	Grassman 1999
			18.0		
Royal Chitwan NP, Nepal	Subtropical	3	-	7.0	Seidensticker *et al.* 1990
				6.0	
				13.0	
Huai kha khaeng WLS, Thailand	Tropical	2	27.0	11.4	Rabinowitz 1989

* - Problem animal; ** - 95% MCP;

Leopards are generally solitary animals, shy and secretive and usually nocturnal in their behavior (Schaller 1972; Sunquist 1983; Bailey 1993). But sometimes they show boldness and return to their kill in spite of being shot at and missed. In addition, they are usually cautious and circumspect (Daniel 2009). The main social bond is between females and their offspring, although males and females do associate but for a short period during the courtships (Schaller 1972; Sunquist 1983; Bailey, 1993; Mizutani and Jewell 1998). Like other large felids, they communicate with one another using scent markings (e.g. urine spraying, scrape marking and also tree raking) and vocalizations (Eisenberg and Lockhart 1972; Ilani 1981).

Leopards are reported to be most active between dusk to dawn hunting prey during this time using their keen hearing and vision (Bailey 1993). The highest rates of daytime activity were recorded for leopards in thorn thickets during the wet season, when the main prey also used the thickets (Bailey 1993). In Wilpattu NP, Sri Lanka, where leopards are the only large felid species, they are less nocturnal than the leopards studied elsewhere (Muckenhirn and Eisenberg, 1973). Jenny (1996) and Jenny and Zuberbühler (2005) found that leopards in the tropical rain forest were predominantly diurnally and crepuscularly active than the savannah leopards and hunted only during the day, though they often moved at night.

Odden and Wegge (2005) observed pronounced sexual difference in day-to-day movements of male and female leopards. The males were found to be less active than the female during day-time. Moreover, the female moved similar distances during day and night, whereas, males moved mainly at night. The males’ mean diel movement distance (6.83 km) was longer than the distance moved by the female (3.5 km), but did not differ significantly (Odden and Wegge 2005). Seidensticker (1977) reported that a radio-collared female leopard rearing small cubs in the Chitwan NP spent more time in the immediate vicinity of her cubs during night than during day. In the South African Cederberg Mountains, an open rocky habitat with low human impact and no competing predators, leopards were predominantly nocturnal, mainly hunting diurnal prey species. The maximum distance moved by male leopards was 30.63 km (mean 16.2 km) versus 11.57 km (mean 10.96 km) for females (Martins and Harris 2013). Apart from the studies conducted in the PAs, recently Odden *et al.* (2014) studied leopards in human dominated landscapes and found that the movement patterns were conspicuously nocturnal, with average hourly step lengths of 339 m during the night and 60 m during the day.

As has been mentioned above that environmental and behavioural patterns influence leopard home ranges, another important consideration when comparing studies is the home range estimation method used. The conventional Minimum Convex Polygon (MCP) estimator is still used in home range estimations. The 100% MCP estimator is mainly used for easy comparisons with other studies. But there are several weaknesses in this estimator such as its sensitivity to the number of location fixes, sampling duration and autocorrelation (Harris *et al.* 1990; Swihart and Slade 1997; Seaman *et al.* 1999; Laver and Kelly 2008). The Kernel Utilisation Distribution (Kernel UD), also known as the Kernel Density Estimator (KDE), is more robust, accurate, reliable, efficient and unbiased estimator recommended for home range studies (Worton 1989; Seaman and Powell 1996; Swihart and Slade 1997; Seaman *et al.* 1999; Odden and Wegge 2005; Börger *et al.* 2006; Laver and Kelly 2008; Nilsen *et al*. 2008). However, the KDE also has its problems when attempting to compare home ranges between different studies; the main weakness being the selection of a smoothing factor (also known as the bandwidth or h value) which varies in each study (Laver and Kelly 2008) as different studies use different smoothing factors. The smoothing factor greatly influences home range estimates because it can be calculated in a number of ways, and depends on the telemetry data sample size (Seaman *et al.* 1999; Laver and Kelly 2008). Therefore, it is better to add as much supplemental information on the methods used, and the environmental factors affecting the area should be mentioned in home range studies in order to make more meaningful comparisons, and to replicate studies (Marker and Dickman 2005a).

4.1.2 Habitat use by leopard

Leopards are the most successful among all the four large felids in terms of their geographic distribution and abundance. They occupy variable environments as different as open and semi-arid deserts, savannahs, tropical forests reflecting thei broadness of their ecological niche (Nowell and Jackson 1996). They have been recorded even up to the elevations of 5200 m above mean sea level in the Himalaya (Jackson 1984; Stein *et al*. 2016) but mostly living below the tree line (Roberts 1977; Green 1987). In Africa and India, leopards are sympatric with other large felids like lions and tigers, respectively by reducing spatial and food competition, using habitats not favoured by the larger felids, eating different-size prey and having different diel activity patterns (Seidensticker 1976; Bertram 1982). At other places such as mountainous regions of the South Africa and the Himalaya, where other large carnivores such as tigers, lions and dholes (*Cuon alpinus*) are absent, leopards become the apex predators regulating the prey populations thus, maintaining the ecological balance. Leopards are the most adaptable large carnivores that can survive in a wide variety of habitat types. Their flexibility is due, in part, to their catholic choice of prey items; sustenance on medium to large ungulates is supplemented by small prey items such as primates, rodents, reptiles and birds (Ilani 1981; Odden and Wegge 2005; Hayward *et al*. 2006; Lovari *et al*. 2013).

Although there a few studies on leopard home ranges from Indian subcontinent (Table 4.1) but there is no published home range data for leopard from the moist temperate region of western Himalaya particularly from the state of Jammu and Kashmir. As mentioned in previous chapter, the density estimates of leopards in this study area are likely to be lower than other parts of the country because of the low prey base even though there is quality habitat available. The main reason could be more than two decades of armed insurgency and conflict and political instability in the region (Akbar 2002; Bhatnagar *et al.* 2009). These factors together with human-leopard conflict in the region (Singh *et al*. 2007; Mir 2016) can have significant implications for setting of reliable management and conservation strategies. Thus, robust home range estimates and a sound understanding of leopard spatial and habitat requirements are required, not only within the protected area (PA) system but also in areas outside of PA system.

4.1.3 Objectives

With this background three adult leopards (one male and two females) were captured using customised collapsible metallic drop door box trap/cages and collared with GPS collars during the study period. The main objectives of this exercise were:

- to study ranging and movement pattern of leopards across time and space in the study area

- to study habitat use by leopards in space and time in the study area

4.2 Methodology

The whole exercise of capturing, collaring and tracking of leopards was conducted from May 2011 to July 2013. It was intended that four leopards were to be captured and collared, however, due to time constraints only three leopards (one male and two females) were captured. The home range sizes, home range overlap, movement patterns and habitat use for these animals were analysed.

4.2.1 Capture and immobilisation

In order to obtain the data for home range estimates, live capture of leopards was necessary so as to attach GPS collars. Large carnivores can be captured using a variety of techniques. There are several techniques which are used for leopard capture of which box trap or cage trapping is most common (Hamilton 1976; Norton and Henley 1987; Bailey 1993; Karanth and Sunquist 2000; Marker and Dickman 2005a; Simcharoen *et al*. 2008; Odden *et al*. 2014; Khan *et al*. 2018). Other commonly used techniques include free-darting (Bertram 1982; Steyn 2007; Balme 2009) and soft-hold foot-snaring (Frank *et al.* 2003; Balme 2009; Sikes *et al.* 2011). The main aim of every capture procedure should be to minimise the stress on the animal, whilst maximising the safety of any personnel involved (Tribe and Spielman 1996; Sikes *et al.* 2011). Therefore, all leopard capture and immobilisation procedures were conducted in the presence of wildlife veterinarian and other personnel of the J&K state Department of Wildlife Protection.

Leopards were captured using customised collapsible metallic drop door box traps/cages with a separate bait compartment to keep the bait alive and safe. Once a leopard was caught in the cage, the wildlife veterinarian present administered the combination of Ketamine hydrochloride (@5 mg/kg body weight) and Xylazine hydrochloride (@1.5 mg/kg body weight) to the captured leopards following Deka *et al*. (2012). This drug combination has been used previously on leopards and was effective and safe for the purpose of immobilisation of leopards for radio collaring studies (Jayaprakash *et al*. 2001; Belsare and Athreya 2010; Deka *et al*. 2012).

Once the drug had taken full effect and the leopard was fully immobilised, it was removed from the cage, weighed, and then placed on a tarpaulin or clean surface in the shade in a position that allowed it to breathe easily, usually in lateral recumbency (Deka *et al*. 2012). A blindfold (moist towel or cloth) was placed over the eyes to prevent any damage from excessive exposure and respiratory rate, temperature, and heart rate were monitored throughout the immobilisation procedure (Deka *et al*. 2012). Following this, Vectronics GPS plus collars were fitted on the captured leopards keeping in mind to leave a gap large enough to slide one's hand under each collar whilst still fitting tight enough to prevent from being shed or moving around excessively (causing chafing) when the animal moved. Leopards were aged, based on their size and body condition and wear and tear of their teeth (Bailey 1993; Stander 1997). Claws were checked for possible damage sustained whilst the leopard was contained in the cage and treated. After finishing the entire collar fitting procedures, health and morphological measurements the leopards were left undisturbed until they started showing signs of recovery and regaining consciousness.

4.2.2 GPS telemetry equipment

GPS Plus collars (Vectronic Aerospace GmbH) were used to collect location data from the collared leopards. Each collar offered to measure and store on board the position of the animal, ambient temperature profile of the collar and the activity of the collared animal. All the data was stored in the on-board non-volatile memory and was downloaded via cable, VHF/UHF link, or satellite.

The GPS Plus collar records an animal's position as with the GPS sensor, determined by the co-ordinates estimated by the satellites. Each collar recorded date and time, co-ordinates, altitude, ambient temperature, positional dilution of precision (DOP) and navigation status as quality information and information about the satellites used for positioning. The DOP is a measure of precision which is determined by the number and position of satellites used to record each positional fix. A PDOP value higher than five is rated as moderate to poor, and values of five or less are rated as good to excellent. The data were stored on the collars and downloaded via a handheld UHF receiver where from the data were exported to computer and saved in Microsoft Excel spreadsheets format. The handheld UHF receiver searches for any GPS collars within range (approximately 1 km) via the UHF signal. When a collar falls within this range, its data are stored on UHF receiver.

The number of fixes that one sets the collars to record, and the upload interval scheduled, determine the battery life of the collars, therefore a trade-off is needed between a suitable number of fixes and a battery life. GPS collars were scheduled to log GPS fixes five times a day at variable intervals set using three schedule rules (cyclic, discrete and rollover) provided by Vectronic Aerospace. A minimum time interval of two hours was kept between two consecutive GPS positions recorded by the collars.

4.2.3 Home range analysis

Although there are several analytical methods to estimate home ranges of individuals (Nilsen *et al*. 2008), two of them are most commonly used – the Minimum Convex Polygon (MCP) (Mohr 1947) and Kernel Density Estimation (KDE) (Worton 1989). MCP is the simplest and also the most widely used home range estimator of the two methods, however it is mainly used for comparative purposes only.

4.2.3.1 Minimum convex polygon (MCP)

MCP involves calculating the area enclosed by the imaginary lines that join the outermost telemetry points recorded by the collared animal. The area of the convex polygon thus created is then measured and represents the individual’s observed home range (Mohr 1947). The boundary of the calculated 100% MCP encompasses all location fixes used in the home range estimation and also includes the occasional sorties that an animal makes outside its core area. The resulting range size is strongly influenced by these outlying fixes and may also include large areas of unused space (Harris *et al*. 1990; Kenward 2001). Therefore, 95% MCP was also calculated in order to reduce the biasness caused by delineating all locations forming 100% MCP (Karanth and Sunquist 2000).

4.2.3.2 Kernel density estimation (KDE)

KDE is a contouring method which creates isopleths of intensity of home range usage by calculating the mean influence of data points at a range of grid intersections. Isopleths which are created by this method specify the amount of time an individual spends within a contour (e.g. 95%, 75%, 50%) and comprises a fixed percentage of the utilisation concentration of the location data used (Hemson *et al*. 2005). KDE offers a more accurate picture of spatial utilisation as it allows the inclusion of multiple activity centres as outlying data fixes are not used to create home range boundaries. It is also less affected by peripheral points and excludes unused areas of the home ranges (Hemson *et al*. 2005).

4.2.3.3 Autocorrelation

Autocorrelation in general results at the violation of the statistical assumption of independence between pairs of observed points. In other words, it is the lack of independence between consecutive telemetry locations at certain distances in time or space. This lack of independence indicates that the individual being tracked did not have time to move far enough before it was relocated or it displayed a repeated movement pattern (Swihart and Slade 1985; Legendre 1993). Independence of successive animal locations is a basic assumption of many statistical methods of home range analysis such as KDE and dependence of observations may underestimate true home range size (Swihart and Slade 1985).

It is well known that animals typically move in a non-random manner thus animal telemetry data is often strongly auto-correlated, particularly when frequent position fixes have been collected (Solla *et al.* 1999). Swihart and Slade (1985) recommend restricting the sampling regime based on results from pilot studies as frequent monitoring of individuals severely jeopardises the validity of the independence assumption. Another more common technique of eliminating autocorrelation has been to subsample the datasets (Worton 1989). But sub-sampling datasets not only reduces the sample size but also reduces the biological significance of the data as has been argued by Solla *et al.* (1999) and Börger *et al.* (2006). Similarly, having an adequate sample size is considered to be more important than independence between observations (Reynolds and Laundre 1990; Otis and White 1999). Thus, in an attempt to reduce autocorrelation in this study, the scheduled GPS fixes of the collars were set to log at minimum interval of two hours, resulting in a total of five fixes per day in order to monitor the leopards' diel movements. Despite being generally regarded as nocturnal, leopards are reported to be often active during the day (Bailey 1993;

Bothma and Walker 1999). Thus, all GPS fixes logged by the collars were used in the home range analyses.

4.2.4 Habitat use by leopard

Habitat mapping was done following Sharma *et al*. (2010). The Global landsat 8 data with resolution of 30 m was used to generate false color composite classification of the habitat types identified. Habitat map for the Dachigam landscape was generated by adopting hybrid method of classification in GIS domain using ArcGIS 10.2.2 and ERDAS 10.1 with an accuracy of 82%. Habitat selection by the leopard was estimated by Jacob's preference index calculated as:

$$D = \frac{R - P}{R + P - 2RP}$$

Where R is the ratio of the locations found in a specific habitat type to the total number of locations and P is the ratio of the area of a specific habitat to the total size of the home range (Jacobs 1974). The value of selectivity (D) varies from -1 (avoided) through 0 (indifference) to +1 (preferred habitat).

4.3 Results

4.3.1 Capture and immobilisation

A total of three adult leopards (2 females and 1 male) were captured using drop door mechanism cages between March 2012 to July 2013 with an average capturing effort of 150 trap days per individual (Table 4.2). Details pertaining to morphological measurements taken and are presented in Table 4.3.

Table 4.2 Leopard capturing success using drop door cage traps in Dachigam National Park.

Time Duration	**Capturing Technique**	**Numbers**	**Effort (Trap Nights)**	**Bait Type**	**Success**
May – June 2011	Foot-hold snares	4	120	-	NO
July – August 2011	Drop door cage	1	25	Live + Rotten Meat	NO
February – March 2012	Drop door cage	3	75	Live	YES
April – May 2012	Drop door cage	2	50	Live	YES **
October – November 2012	Drop door cage	2	50	Live	YES
February – April 2013	Drop door cage	2	80	Live	NO
June – July 2013	Drop door cage	2	50	Live	YES

**Recapture of same female leopard that was captured in March 2012

Table 4.3 Morphometric details of leopards captured and collared during the study period in Dachigam National Park.

Collared animal ID	**Date of capture**	**Sex**	**Body weight (kg)**	**Body length (cm)**	**Tail length (cm)**	**Total body length (cm)**	**Neck girth (cm)**	**Chest girth (cm)**	**Girth at abdomen (cm)**	**Shoulder height (cm)**	**Total Length (L) Total Width (W) (cm)**	
											Front paw	**Rear paw**
F 74	18.03.2012	Female	39	107	76	183	48	70.6	91.4	61	L = 7.7 W = 7.5	L = 7.9 W = 7.6
F 71	11.11.2012	Female	38	91	33	124	50.8	76.2	50.8	63	L = 7.69 W = 6.11	L = 7.9 W = 5.9
M 73	05.07.2013	Male	65	105	100	205	52	85	90	65	L = 10.62 W = 8.44	L = 8.38 W = 6.94
F[#]	25.01.2012	Female	41	118	86	204	46	-	75	64	L = 8.3 W = 6.8	L = 7.26 W = 6.24

[#] This female leopard was a conflicting animal captured by the Deptt. of Wildlife Protection, J&K, Staff from a nearby locality. It could not be collared because of severe injury in one of her hind feet.

4.3.2 Home range analysis

The collars deployed on the leopards worked well with variable success rates (Table 4.4). The collars were set to take 5-7 GPS fixes in 24 hours except the collar F71 where it was set to fix every 2 hours. But this female lost contact after 20 days and only 170 locations could be generated successfully through this individual (Table 4.4).

Table 4.4 Number of GPS locations successfully fixed by the collars and duration of data collection in Dachigam National Park

Collared Animal ID	**Date of Deployment**	**No. of Days**	**GPS Fix Attempts**	**Successful Fixes**	**Success Rate (%)**
F 74	18.03.2012	438	2973	2321	78.06
F 71	11.11.2012	20	175	170	97.14
M 73	05.07.2013	78	694	546	78.67

4.3.2.1 Minimum convex polygon (MCP)

The 100% MCPs are shown in Fig. 4.1 (a-b), the male leopard M73 has the largest home range of ~145 km^2 (Fig. 4.1a) which was recorded during the summer season. Overall 100% MCP home range for the female F74 was 94 km^2, whereas the seasonal variation in home range size was recorded the during summer season with a maximum of ~74 km^2 (Table 4.5). The summer home range (100% MCP) of the male was 1.96 times larger than the female leopard. The least home range (~41.4 km^2; 100% MCP) came up during the winter season. The increasing trend represented by the ranges (100% MCPs) of this female was winter < spring (48.42 km^2) < autumn (67.9 km^2) < summer (Fig. 4.1b). Incremental analysis calculated that asymptotes were reached at 150 for female – F71, at 800 for female – F74 and at 500 for male – M73 (Fig. 4.2). This variation in number of locations to asymptote shows leopards different socio-biology and exploratory movements.

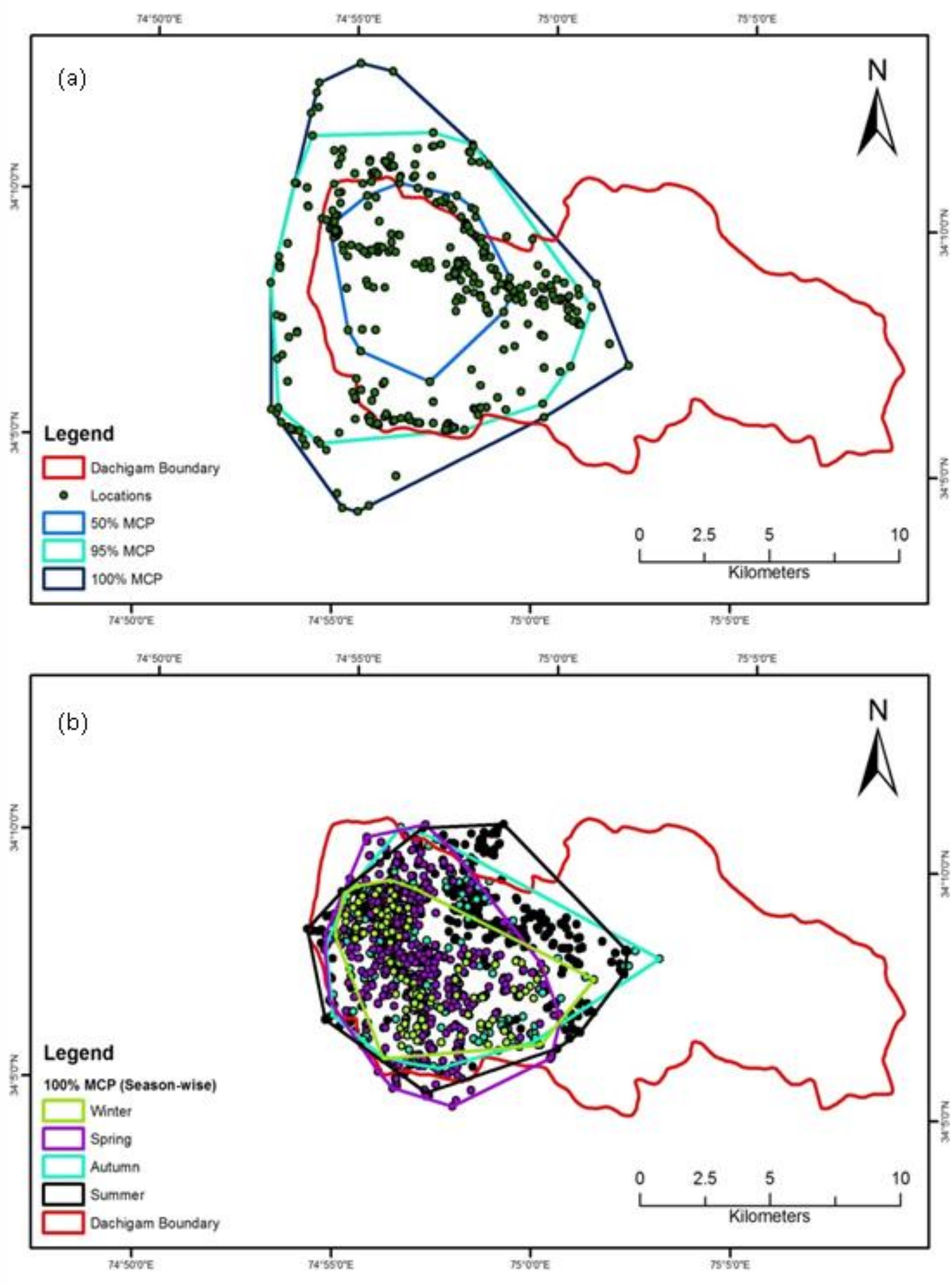


Figure 4.1 100% MCP home range of male (a) M73; and (b) seasonal home ranges of the female leopard (F74) in the Dachigam National Park

Table 4.5 100% MCP home range estimates of collared leopards in Dachigam National Park

Leopard ID	**100% MCP**
M73	**145** km^2
F71	**14** km^2
F74	**94** km^2
Winter	41.4 km^2
Spring	48.4 km^2
Summer	74.0 km^2
Autumn	67.9 km^2

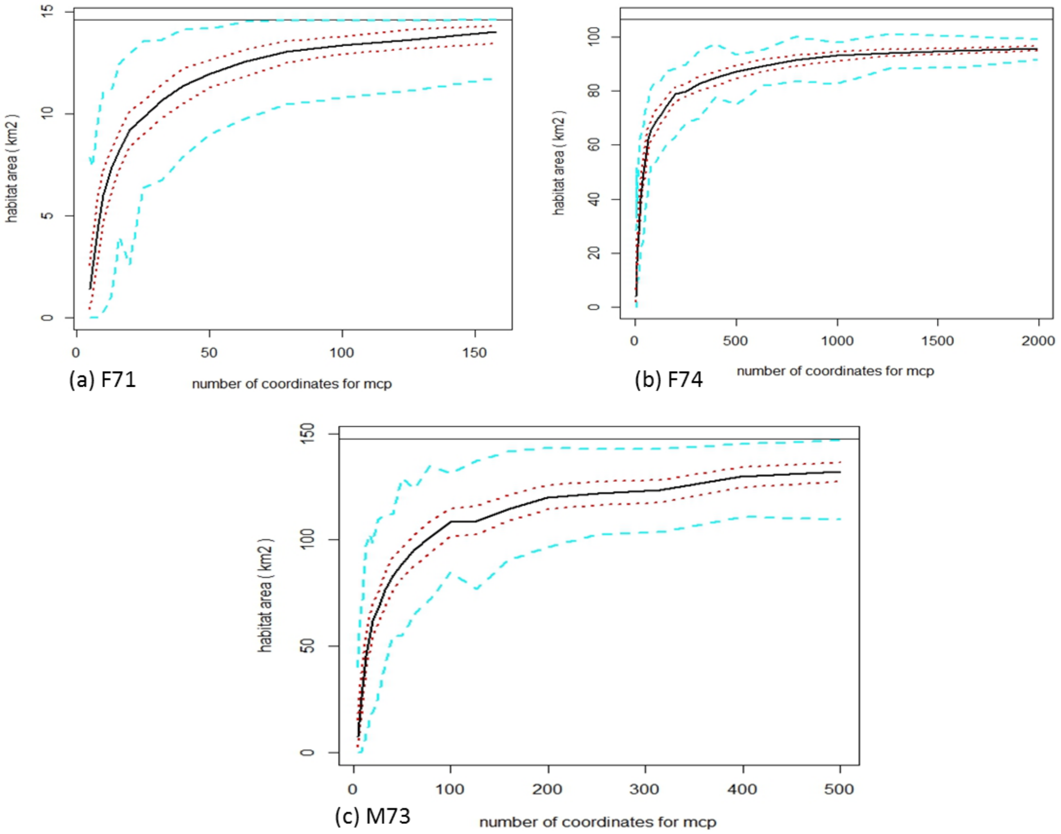


Figure 4.2 100% MCP incremental analysis shows variable levels of asymptotes achieved at variable number of locations by three GPS collared leopards in Dachigam National Park; (a) female – F71, (b) female – F74, (c) male – M73

4.3.2.2 Kernel density estimation (KDE)

The 90% and 50% fixed kernel home ranges are tabulated in Table 4.6. For female - F74, during winter season the 90% and 50% fixed kernel intensity of use areas are just ~40 km^2 and ~13 km^2, respectively whereas, these sizes got maximum during winters when 90% fixed kernel area increases to become ~62 km^2 and 50% fixed kernel becomes ~16 km^2 (Fig. 4.3a-b). Since, for the male summer data is available only, the 90% fixed kernel area turns out to be ~130 km^2 while 50% fixed kernel area is just ~37 km^2 (Fig. 4.3a-b). The maximum overlap of 44.25% was represented between male and female (M73 – F74) in the 50% fixed kernel core areas (Table 4.7). While minimum overlap in the 50% fixed kernel cores was 13.7% which was observed between the two females (F71 – F74) (Table 4.7).

Table 4.6 Home Ranges (Fixed Kernel; FK) of the three Collared Leopards (F = Female; M = Male) in Dachigam National Park.

	90% FK (km^{-2})			**50% FK (km^{-2})**		
Animal ID	**F 71**	**M 73**	**F 74**	**F 71**	**M 73**	**F 74**
Spring	-	-	43.90	-	-	10.69
Summer	-	130.03	62.26	-	37.97	16.48
Autumn	11.44	-	54.59	-	-	16.10
Winter	-	-	40.52	-	-	13.14

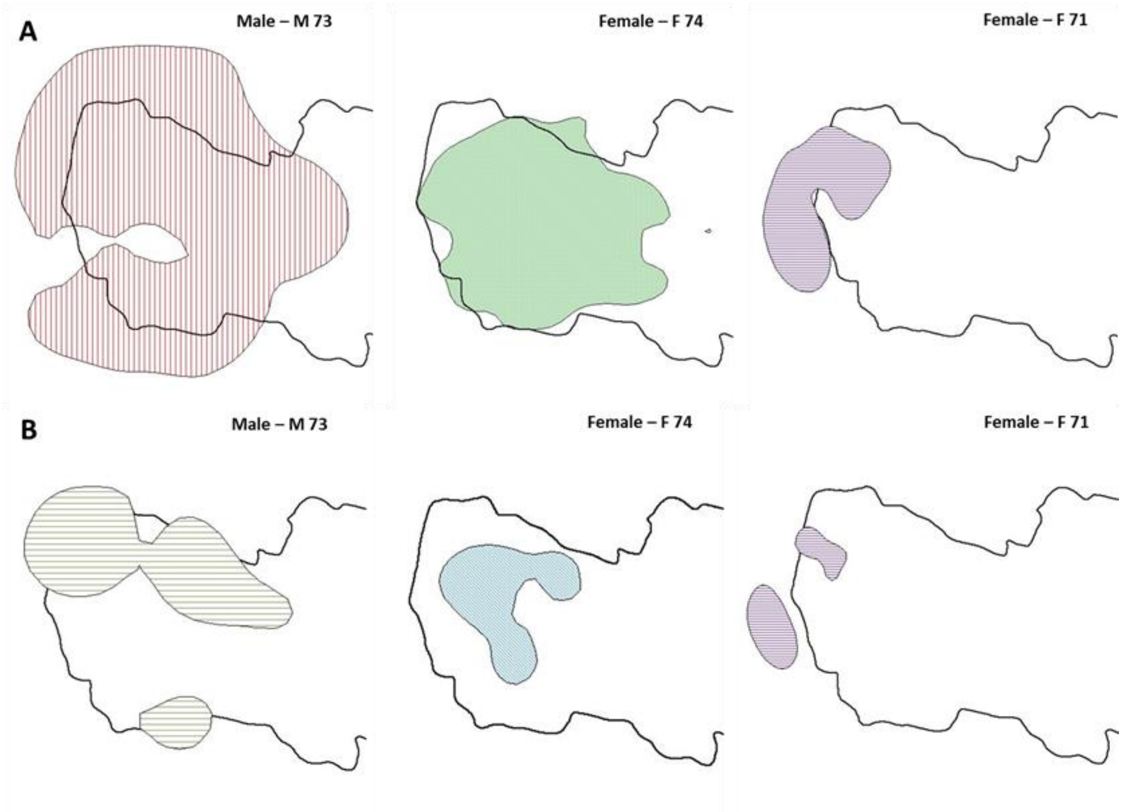


Figure 4.3 (a) 90% Fixed Kernel home ranges of leopards; and (b) 50% Fixed Kernel home ranges of leopards in Dachigam National Park

Table 4.7 Percentage overlap in 50% Fixed Kernel core areas of the leopards in Dachigam National Park

Collared Leopard ID	**50% Fixed Kernel Overlap (%)**		
	M 73	**F 71**	**F 74**
M 73	-	17.9	44.25
F 71	-	-	13.7

4.3.4 Daily distance moved

The leopards show large variation in daily distances moved (Fig. 4.4) during the lean season of summer. Daily displacements of the leopards were not normally distributed (Kolmogorov-Smirnov Test) for the male: M73 (D = 0.119, df = 105, *p* = 0.001), female: F71 (D = 0.191, df = 105, *p* = 0.000) and female: F74 (D = 0.092, df = 105, *p* = 0.029). Daily displacement was longer for the male leopard (median displacement = 588 m) than the female leopard (median displacement = 367.44 m) (Table 4.8). The male leopard travelled a maximum distance of 6.75 km while the two females (F71 and F74) travelled maximum distances of 3.30 km and 9.78 km, respectively (Table 4.8). The total distance travelled by the male leopard (398.71 km) was greater than the female leopards: F74 (374.16 km) and F71 (62.91 km). In case of female leopard F74, the mean (±SE) daily distance travelled was highest during the winter season (1.171 ± 0.090 km) followed by autumn (0.933 ± 0.063 km), spring (0.842 ± 0.037 km) and summer (0.699 ± 0.037 km).

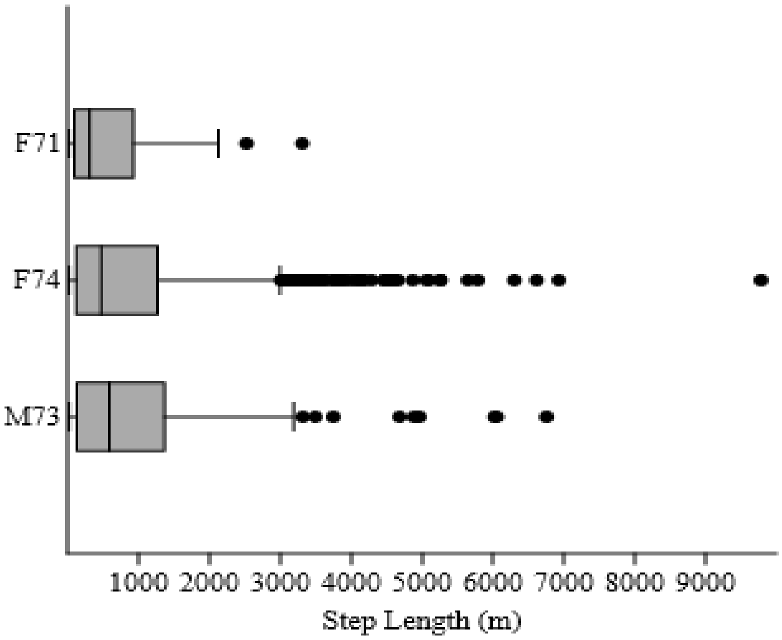


Figure 4.4 Daily displacements (m) of the three leopards in Dachigam National Park. For comparison summer data of female F71 is used. Error bars indicate the 75th and 25th percentiles, the line inside each box indicates the median, and lines represent the maxima and minima.

Table 4.8 Descriptive statistics of the distances moved between GPS fixes per day for the three collared leopards. The total distance travelled during the tracking period and the number of GPS locations used in analysis for each leopard is also presented.

Leopard ID	**Daily distance moved between GPS fixes (km)**			**Total distance travelled (km)**	**Number of Fixes used**
	Maximum	**Median**	**Mean (± SE)**		
M73	6.75	0.588	0.895 ± 0.046	398.71	78
F71	3.30	0.309	0.599 ± 0.064	62.91	105
F74 (Overall)	9.78	0.479	0.855 ± 0.025	1475.53	1725
F74 (Seasonal)					
Winter	6.93	0.664	1.171 ± 0.090	248.45	212
Spring	6.29	0.506	0.842 ± 0.037	552.40	656
Summer	5.64	0.367	0.699 ± 0.037	374.16	535
Autumn	9.78	0.528	0.933 ± 0.063	300.52	322

4.3.5 Habitat use by leopard

A total of seven habitat types were identified as relevant for assessing leopard habitat use. Of these, six were vegetation categories and one was human habitation category (Table 4.9). The final output map of habitats classified in Dachigam landscape is provided in Fig. 4.5 below. Home ranges of each collared leopard were overlaid on the LULC map for habitat use analysis.

Total available habitat within all the leopards’ home ranges combined together is provided in Table 4.10. The most common habitat types in the landscape were temperate grassland (~24%) followed by broadleaved forest (~23%), conifer/pine forest (~21%) and alpine meadow (18.5%). In the combined home range of all leopards, the area of human habitation was just 3.64 km^2. Overall, leopards preferred broadleaved forests in Dachigam landscape as depicted in Fig. 4.6. The male leopard

– M73 selected alpine meadows the most followed by broadleaved forests (Fig. 4.7). The female leopard – F71 which was tracked for short duration selected orchard/cropland/plantation during its entire period of 20 days in Dachigam landscape (Fig. 4.8). Female leopard – F74 selected broadleaved forest (Fig. 4.9) whereas its selection of habitats changed during summer season (Fig. 4.10) where it selected alpine meadows in comparison to broadleaved forest.

Table 4.9 Habitat types classified to assess habitat use by leopard in Dachigam landscape

Habitat Type	**Characteristics**
Alpine Meadow	This habitat category is found to comprise several grass species as well as *Juniperus recurva*. This habitat type starts from 3300 m in the upper Dachigam area and in adjoining areas of the Dachigam landscape
Conifer/Pine Forest	This habitat comprises mainly confer species *Pinus wallichiana* it associates with other species as well including *Parrotiopsis jacquemontiana* at the lower elevations (starting at ~1900 m) and *Taxus wallichiana*, *Picea smithiana*, *Abies pindrow* and *Betula utilis* at higher elevations up to 3300 m

Broadleaved Forest	This type of habitat mainly found at valley bottom between 1700 m to 1900 m with dominating species *Parrotiopsis jacquemontiana*. This habitat also comprises riverine vegetation found along the vicinity of Dachigam main *nallah* and the seasonal drainages where other broadleaved associates such as *Morus alba*, *Quercus robur*, *Aesculus indica*, *Prunus cerasifera*, *P. tremantosa* etc. are found.
Temperate Grassland	This habitat mainly comprises *Parrotiopsis jacquemontiana* and *Prunus armeniaca* as main tree species. This habitat usually spreads from 1900 m to 2900 m elevation.
Fallow Land	This habitat type was identified outside the protected area system of Dachigam National Park. This was actually the croplands which were not being cultivated.
Orchard/Cropland/Plantation	This habitat type was important as most of the orchards were on the periphery of the park. Mostly, cherry was cultivated in these orchards which were on the PA boundary and crops or plantation in areas at some distances from the boundary.

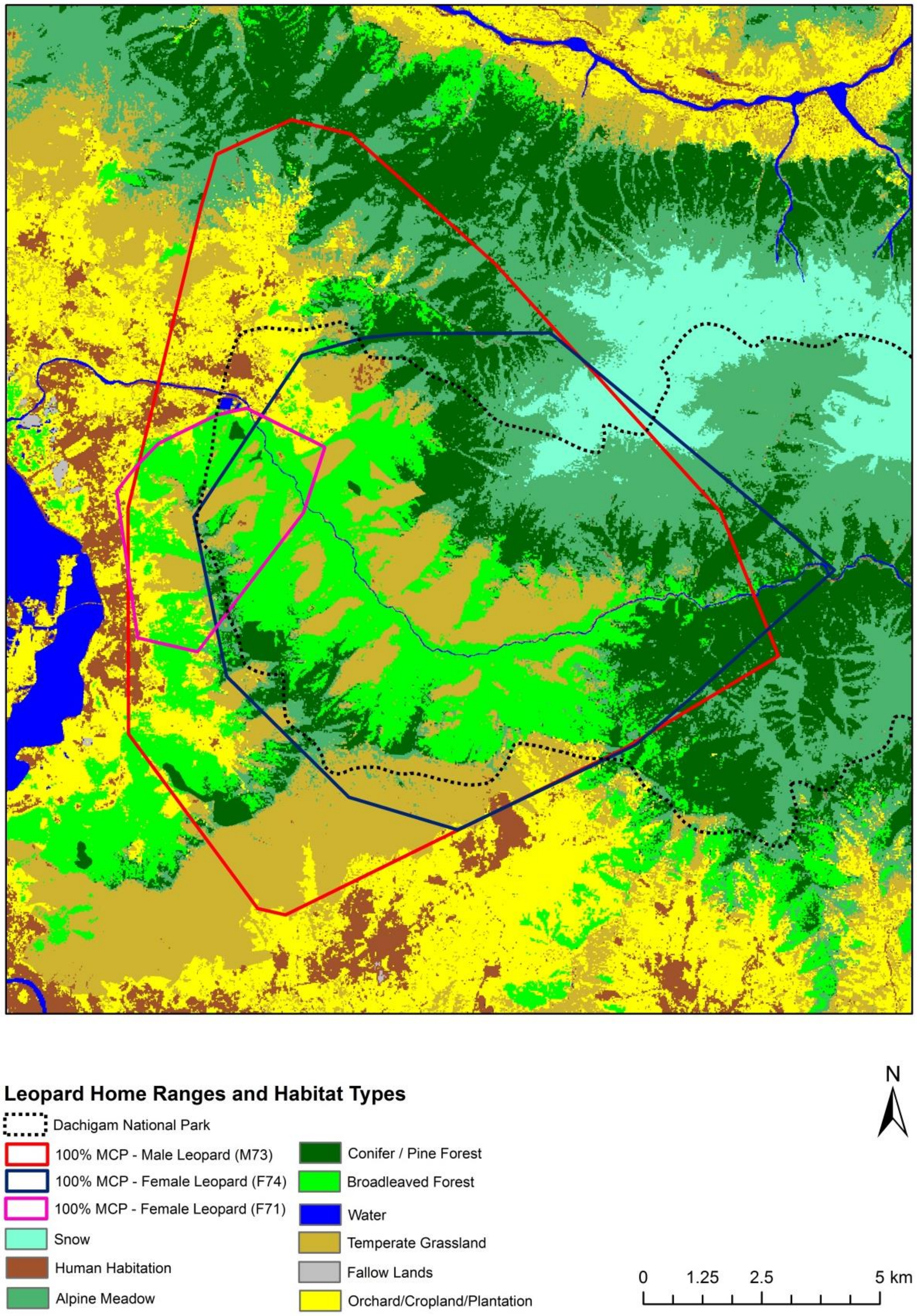


Figure 4.5 Different habitat types of Dachigam landscape with the 100% MCPs of three GPS collared leopards.

Table 4.10 Habitat types classified and their areas available for leopards when data for all combined in Dachigam landscape

Habitat Class	**Area (km^2)**
Temperate Grassland	35.844
Broadleaved Forest	34.811
Conifer/Pine Forest	31.661
Alpine Meadow	27.743
Orchard/Cropland/Plantation	16.163
Human Habitation	3.645
Fallow Land	0.005

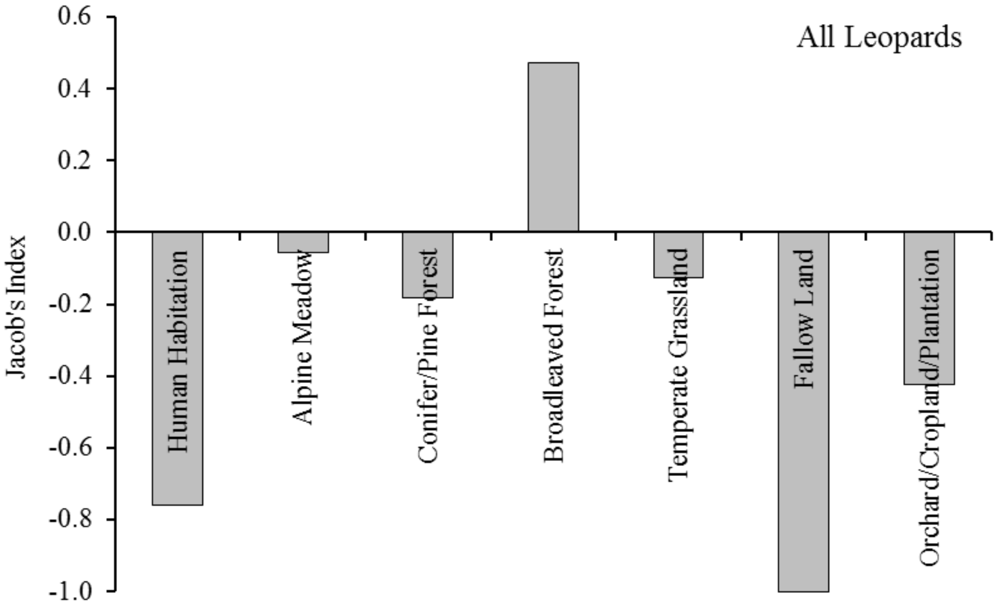


Figure 4.6 Jacob’s index of habitat preference by all three GPS collared leopards put together in Dachigam landscape

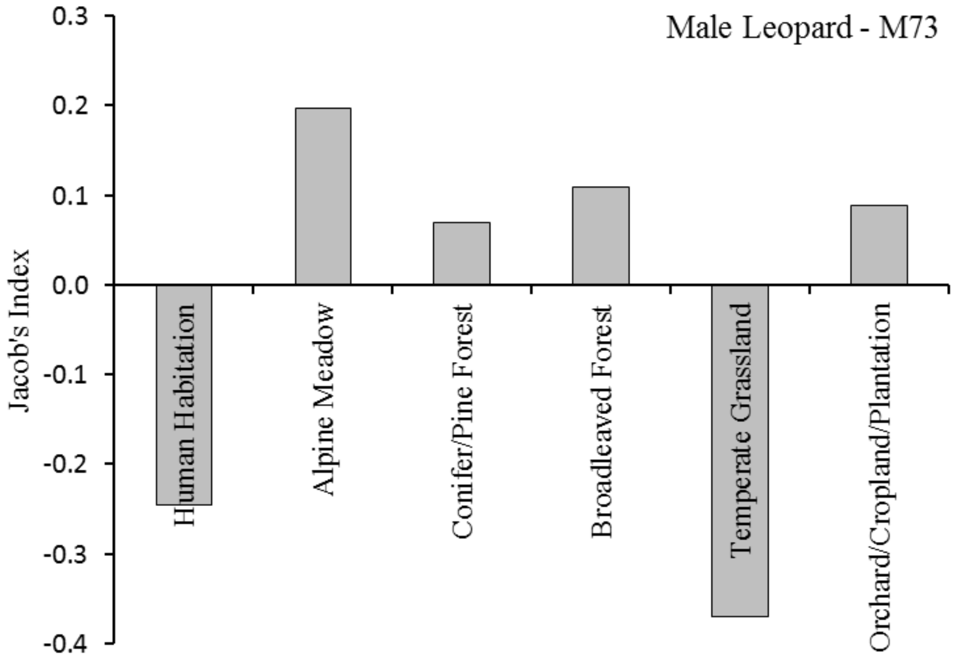


Figure 4.7 Jacob’s index of habitat preference by male GPS collared leopard (M73) in Dachigam landscape

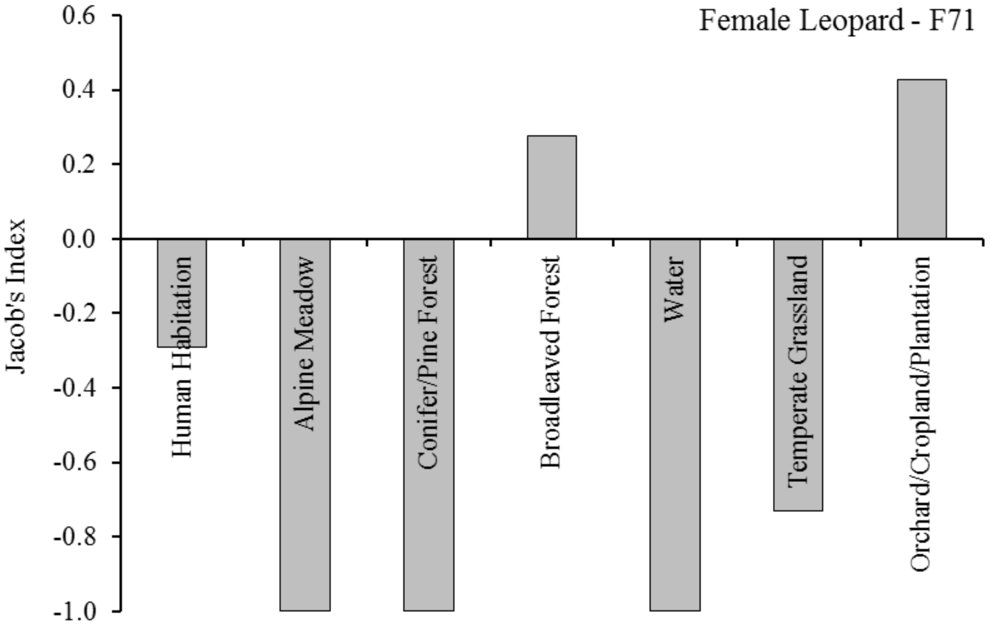


Figure 4.8 Jacob’s index of habitat preference by female GPS collared leopard (F71) in Dachigam landscape

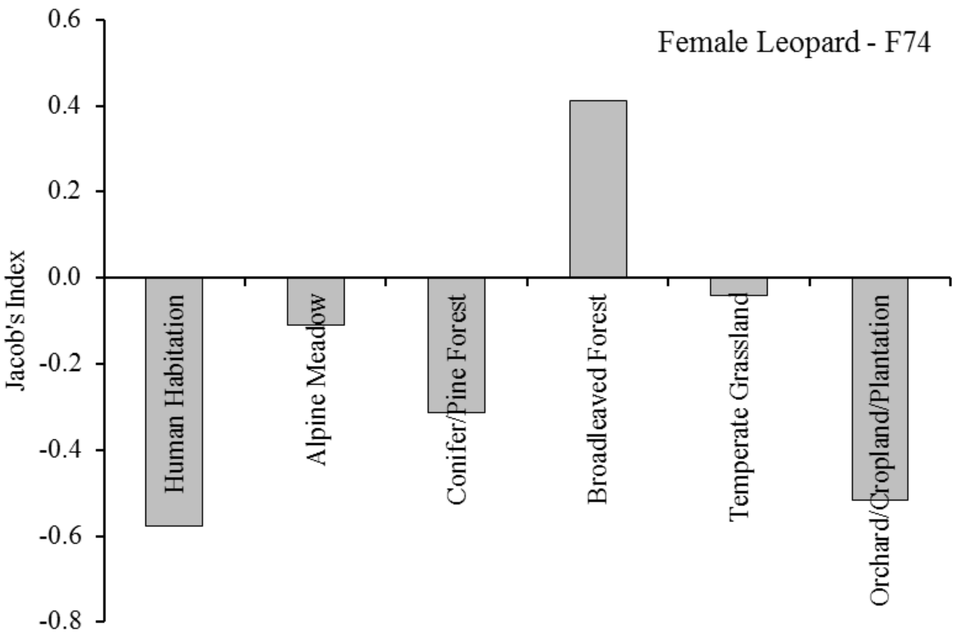


Figure 4.9 Jacob's index of habitat preference by female GPS collared leopard (F74) in Dachigam landscape

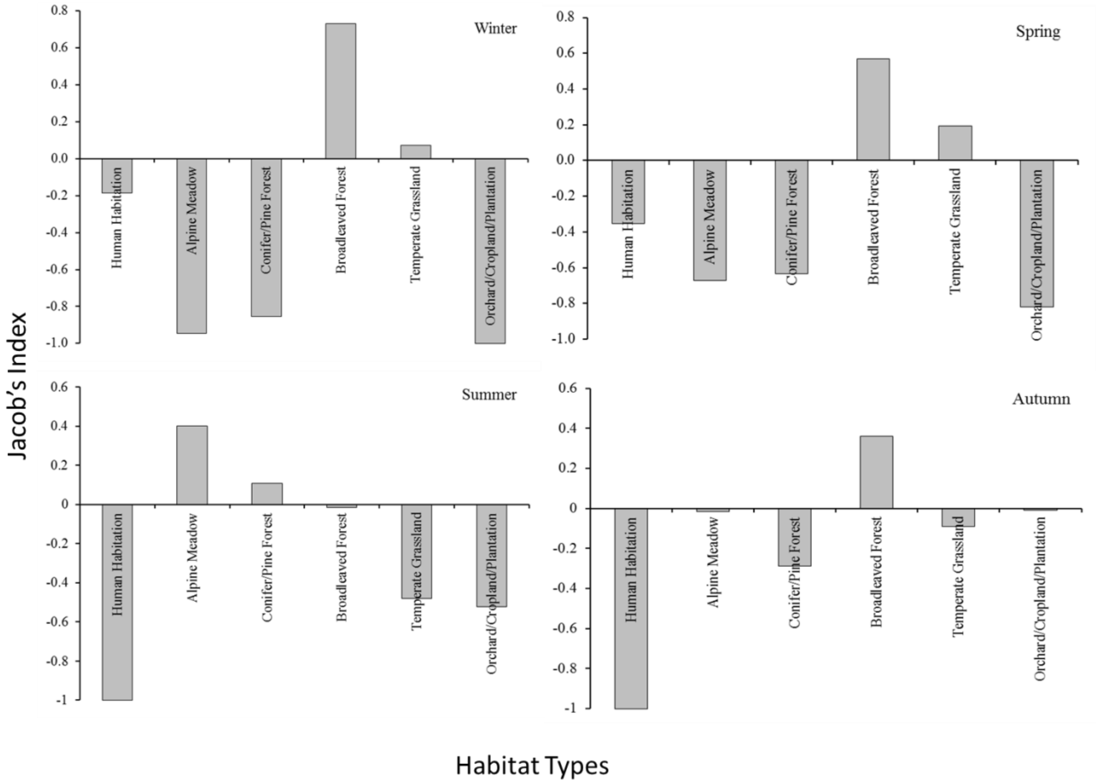


Figure 4.10 Jacob's index of seasonal habitat preference by female GPS collared leopard (F74) in Dachigam landscape

4.4 Discussion

In large territorial carnivores, there is an inverse relationship between food availability and home range size (Schoener 1981; Gittleman and Harvey 1982; Saitoh 1991). This relationship is quite evident from the studies conducted elsewhere in the dry arid areas of the African continent, where prey scarcity forces the carnivores to travel longer distances to forage and thus, large home range sizes which range from 160 km^2 to 2182.4 km^2 (e.g. Norton and Lawson 1985; Grimbeek 1992; Bothma *et al*. 1997; Stander *et al*. 1997; Marker and Dickman 2005; Swanepoel 2008; McManus 2009; Chase-Grey 2011). On the other hand, this study presents largest home ranges in the south-east Asian countries (Table 4.1). Even, the estimates of home ranges of this study are much larger than the studies conducted in similar Himalayan ecosystems (e.g. Seidensticker *et al*. 1990; Odden and Wegge 2005). This large difference in the home range sizes can be attributed to low prey availability in this study area which is considered to influence the home range sizes in carnivores. The basic social organisation of solitary felids is governed by the limiting resource; which is food for females and access to females for the males. This type of organisation is a common feature among leopards throughout their distribution range (Odden and Wegge 2005) and is more pronounced in the study areas like those of Africa where home ranges are typically very large. Thus, males expand their ranges proportionally more than females in areas where resources are more sparsely distributed and hence, the cost of traversing larger home ranges cannot be a determinant factor of shaping leopard communities (Odden and Wegge 2005).

In this study the female has large home range in comparison to other studies conducted elsewhere which represents the low food availability in our area. Seasonally also, the maximum home range turned out to be during the summer season when the potential large prey hangul and langur move to higher elevations in search of suitable food. During the winter season, climatic conditions (like snow) limit the movement of the animals to lower elevations only; that is why the home range during this season is the smallest in size.

The difference in day-to-day movement of the two sexes (male: female) was 1.6:1, and thus, similar to the sexual difference in range size (1.9:1). This could be due to longer distances moved by males every day in order to regularly frequent all parts of its territory and can be attributed to more linear movement pattern of the male. Moreover, female (F74) travelled more distance during the winter season in search of potential prey when its home range size was the least, while on the other hand, lesser distances were covered during summer when home range got maximum in size due comparatively more availability of smaller mammalian prey during this period.

Selection of habitat in species is based on the principle of increased fitness, survival and reproductive success. This study focused on habitat use by leopard by using GPS locations from collared leopards. There is seasonal variation in selecting different habitats by female leopard for which complete one year's telemetry data in the study area is available. Overall, leopard prefers broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain. It is expected that the vegetation at the valley floor provides good cover and stealth for ambush or stalking prey to leopard benefitting it in obtaining prey (Gittleman and Harvey 1982; Karanth and Sunquist 1995; 2000) as it inhabits mainly in forested habitats (Karanth 2013). In the study area leopards appear to cope with temporal and spatial variation in resources as its diet fluctuates with season (Mir 2016).

CHAPTER 5

HABITAT SUITABILITY MODELLING FOR LEOPARD

5.1 Introduction

Climate change is found to be a greatest imminent threat to biodiversity across the biomes (Millennium Ecosystem Assessment 2005) therefore, predicting its impacts on species are a top conservation priority (Thuiller *et al.* 2008). Species distribution modeling is a common tool used by conservationists to evaluate and predict suitable habitat for a range of wildlife species including mammals, birds, reptiles, insects, and plants, at scales ranging from local to continental to global. The species distribution modeling was developed as an approach to predict the distribution of a species in geographic space and to predict the spatial coverage of particular species distribution including the regions where no data is available (Stockwell DRB, Peterson AT 2002). Therefore, these spatial predicting models are essential for species conservation and management, especially for endangered species like Himalayan brown bear (Rodríguez *et al.* 2007). The species distribution modeling are recognized as an important tool to assess the status of protected areas, locate the areas of conservation priority, analyze the impacts of climate change species distribution and serve as a guide for efficient field data collection on rare and endangered species (Rushton *et al.* 2005; Guisan and Thuiller 2005; Papes 2007; Zimmermann *et al.* 2010). Species distribution modeling is also essential for other issues like prediction of exotic species invasions (Oliveira *et al.* 2010), to monitor the decline of native species (Osborne *et al.* 2001), to analyze the range extensions of recovering species (Corsi *et al.* 1999) and probability estimates of species' long-term persistence (Cabeza *et al.* 2004). The distribution models basically relate the field observations to environmental factors which are independent variables, based on statistically or theoretically derived response surfaces (Guisan and Zimmerman 2000). Therefore, the fundamental components of every distribution model are the environmental variables, the resulting habitat suitability values (dependent variables) and the functional processes that link the two (Corsi *et al.* 2000). Field observations of a species of interest can be simple presences, presence-absence or abundances and are usually collected through systematic sampling techniques or from observations collected opportunistically

(Graham *et al*. 2004). The environmental variables can have a direct or indirect impact on the distribution of a species and can be categorized into three main types; limiting factors, disturbances and resources. A wide variety of distribution models have been developed (like, generalized linear model, principal component analysis, classification and regression trees, redundancy analysis, Ecological Niche Factor Analysis (ENFA), Maximal entropy method (MaxEnt), and Genetic Algorithm for Rule-set Production (GARP) etc. and applied successfully over the past decade. The success of the models depends critically on the available data and the models can be selected on the basis of set of criteria. Generally, the predictive models recognize a qualitative or quantitative relationship between species occurrences and a number of meteo-climatic, geomorphological variables and information on land use and anthropogenic disturbance and vegetation cover (Austin *et al*. 1990; Hortal *et al*. 2005). The distribution models can be made from presence/absence data of a species (Osborne and Tigar, 1992; Brito *et al*. 1999; Carroll *et al*. 1999). However, it is necessary to have previously distinguished true absences (Araújo *et al*. 2005). Presence data usually correspond to the true presence of the species. On the other hand, absences could be due to an insufficient sampling effort (Hortal *et al*. 2005). Hence, false absences are fairly common than false presences. Thus, these inaccurate data should be removed from distributional maps (Palmer *et al*. 2003) in order to assure the reliability of absences (Anderson 2003). There are various other ways available to estimate potential distributions when data on absences are not reliable, such as BioMapper software (Hirzel *et al*. 2004a), MaxEnt (Phillips *et al*. 2006). These techniques provide a useful alternative that relies solely on information about presences of the species (Hirzel *et al*. 2001; 2002; Hortal *et al*. 2005).

5.2 Methodology

5.2.1 Leopard distribution data

A total of 145 presence locations of leopard were selected spreading across the Dachigam Landscape each of these were chosen considering spatial independence as all the data layers were at the resolution of ~1 km. Therefore, each record was almost 1 km from the other record. The occurrence points were selected from the GPS telemetry data, locations obtained from camera trap survey, confirmed records of signs collected during surveys. These data points were well spread across the study area and comprised natural trails, ridges and *nallahs*.

5.2.2 Environmental data

All environmental variable files were prepared in ArcGIS 10.3. The extent of analysis was a rectangle bounding the Western Himalaya. The resolution was 1 km^2 based on the climate raster resolution, which was the coarsest of map layers. Files were modified to have the same extent and snapped to the same base raster and converted to .asc files by using *circuitscape* tool in ArcGIS 10.3 for use in MaxEnt.

5.2.3 Climate

Climate is expected to play a major role in impacting species distributions in extreme environments such as Himalayan regions (Araujo and Guisan 2006). The climate data were obtained from World Climate (http://www.worldclim.org) (Table 5.1), which has a set of nineteen bioclimatic variables with 1 km resolution (Hijmans *et al*. 2005). These bioclimatic variables are interpolated from monthly data collected at weather stations globally between 1950 to 2000 which cover annual, seasonal and extreme temperatures and precipitation (Hijmans *et al*. 2005; Graham and Hijmans 2006).

5.2.4 Anthropogenic disturbance

Anthropogenic disturbance was assumed to negatively impact the distribution of leopard. As a proxy for anthropogenic disturbance, Human Influence Index (HII) was obtained from SEDAC. HII was created from nine global data layers - population density, human land use and infrastructure (built-up areas, night time lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers) based on 2004 data. Index values range from zero indicating no impact to 64 indicating maximum human influence.

5.2.5 Topography

Elevation and measures derived from it were considered likely to exert a major influence on the distribution of leopard in Dachigam landscape and assumed to restrict distribution on higher elevations. A digital elevation model (DEM) layer was obtained from the Shuttle Radar Topography Mission (SRTM) version 4 (Jarvis *et al*. 2008). The DEM was used to calculate the following topographic complexity indices in ArcGIS 10.3, slope, roughness, compound topographic index and slope position index.

5.2.6 LULC categories

The LULC used in previous chapter has nine classes which are presented below along with the category codes used in the suitability modelling.

Category Code	LULC type
7	Snow
8	Human habitation
9	Alpine meadow
10	Conifer/Pine forest
12	Broadleaved forest
14	Water
15	Temperate grassland
25	Fallow lands
27	Orchard/Cropland/Plantation

5.2.7 Correlation

Maxent is fairly robust to correlated variables (Elith *et al*. 2006), but correlations can result in misleading interpretations of variables contribution to the model and also cause uncertainties to the model due to high degree of correlation among the variables (Heikkinen *et al*. 2006; Peterson and Nazakawa 2008; Ahmadzadeh *et al*. 2013; Boria *et al*. 2014). All the variables were tested for correlation using Spearman's rho in ENMTools software 3.5. If two variables had correlations (r_s) equal to or greater than 0.75, only one was selected for the model as per the requirement of the species. The variables that were tested for correlation and those that were retained after deleting correlated variables.

Table 5.1 List of all environmental variables selected and actually used (represented as ‘Yes’) in analysis and developing the prediction model.

Variables	**Unit**	**Used in final models**
Bio1 Annual Mean Temperature	degree C	Yes
Bio2 Mean Diurnal Temperature Range	degree C	Yes
Bio3 Isothermality (Bio2/Bio7*100)	Value 0 to 100	No
Bio4 Temperature Seasonality (SD*100)	%	No
Bio5 Max Temperature of Warmest Month	degree C	No
Bio6 Min Temperature of Coldest Month	degree C	No
Bio7 Temperature Annual Range (Bio5-Bio6)	degree C	No
Bio8 Mean Temperature of Wettest Quarter	degree C	No
Bio9 Mean Temperature of Driest Quarter	degree C	No
Bio10 Mean Temperature of Warmest Quarter	degree C	No
Bio11 Mean Temperature of Coldest Quarter	degree C	No
Bio12 Annual Precipitation	mm	No
Bio13 Precipitation of Wettest Month	mm	No
Bio14 Precipitation of Driest Month	mm	Yes
Bio15 Precipitation Seasonality (CV)	%	Yes
Bio16 Precipitation of Wettest Quarter	mm	No
Bio17 Precipitation of Driest Quarter	mm	No
Bio18 Precipitation of Warmest Quarter	mm	No
Bio19 Precipitation of Coldest Quarter	mm	No
LULC Land Use/Land Cover	Categories	Yes
Compound topographic index	Value 5.92 to 21.56	Yes
Slope position index	Value -138 to 146	Yes
Roughness	Value 0 to 32614.61	Yes
Aspect	Value 0 to 359	Yes
Human Influence Index (HII)	Value 0 to 64	Yes

5.2.8 Building the predictive models

MaxEnt algorithm (Phillips *et al*. 2006) was used to determine the potential distribution of leopard across the landscape. Although many algorithms are available, MaxEnt algorithm was used based on their high predictive power and its capability of performing well on presence only data. MaxEnt is a machine learning method used to predict the potential distribution of species, based on the principle of maximum entropy (Phillips *et al*. 2006). MaxEnt predicts the spatial distribution of species under the most discrete scenario assuming all the environment constraints affecting species presence were taken into consideration during the calculations (Phillips *et al*. 2006 and Elith *et al*. 2011).

Five models were developed and each model was run using 90% of presence records as training and the remaining 10% for testing, and 5000 iterations with a bootstrap replicate strategy; other parameters were a 1.0 x 10-5 convergence threshold; logistic output format; and linear/quadratic regularization values with hinge and threshold features. The best model was selected on the basis of AUC value.

5.3 Results

The AUC score (± SD) was high for the MaxEnt predicted model for the training data used for prediction (0.956 ± 0.005) which is much > 0.75 to indicate model’s prediction ability (Philips and Dudik 2008). There was no overfitting around the presence point data as the standard deviation was low (0.005).

The percent contribution and permutation importance of each environmental variable which affects the leopard distribution the most in Dachigam landscape are presented in Table 5.2. The eleven variables contributed 100% in explaining the distribution of the leopard in the landscape. Of these 11 variables, precipitation of the driest month followed by human influence index and terrain roughness/ruggedness contributed maximally as 25.2%, 22.6% and 14.3%, respectively (Table 5.2).

The role of each variable used for suitability prediction analysis in Dachigam landscape, examined using the jackknife test against MaxEnt prediction gain, found that the highest gain was when the precipitation in driest month (bio_14_tif) was used in isolation (Fig. 5.1). Therefore, this variable has the highest predictive power and has the most useful information in prediction of leopard distribution. The environmental variable that decreased the gain most when it is omitted is mean diurnal temperature range (bio_2_tif). Therefore, this variable decreased the prediction probability of leopards in Dachigam landscape and had the most information that isn't present in the other variables (Fig. 5.1).

The effects of each of the environmental variables used in the final MaxEnt prediction model are presented in the form of response curves (Fig. 5.2). Variables, as mentioned above, such as precipitation in driest month, mean diurnal temperature range, human influence index, terrain roughness and LULC categories are positively impacting and influence the leopard distribution in Dachigam landscape. A composite habitat suitability map for leopards in Dachigam landscape obtained from the MaxEnt is presented in Fig. 5.3.

Table 5.2 Environmental variables used and their percent contribution in prediction modelling for leopard in Dachigam landscape

Code used	**Variable**	**Percent contribution**	**Permutation importance**
bio_14_tif	Precipitation of Driest Month	25.2	19.6
hii_tif	Human Influence Index	22.6	9
Roughness_tif	Terrain Roughness/Ruggedness	14.3	4.1
Lulc_tif	Land Use/Land Cover	8	0.7
bio_15_tif	Precipitation Seasonality (CV)	7.1	1.7
bio_1_tif	Annual Mean Temperature	6.7	31.9

bio_2_tif	Mean Diurnal Range (Mean of monthly (max temp - min temp))	6.1	28.5
Elev_tif	Elevation	3.6	2.7
Spi_tif	Slope Position Index	2.4	0.7
Cti_tif	Compound Topographic Index	2.4	0.6
Aspect_tif	Aspect	1.7	0.4

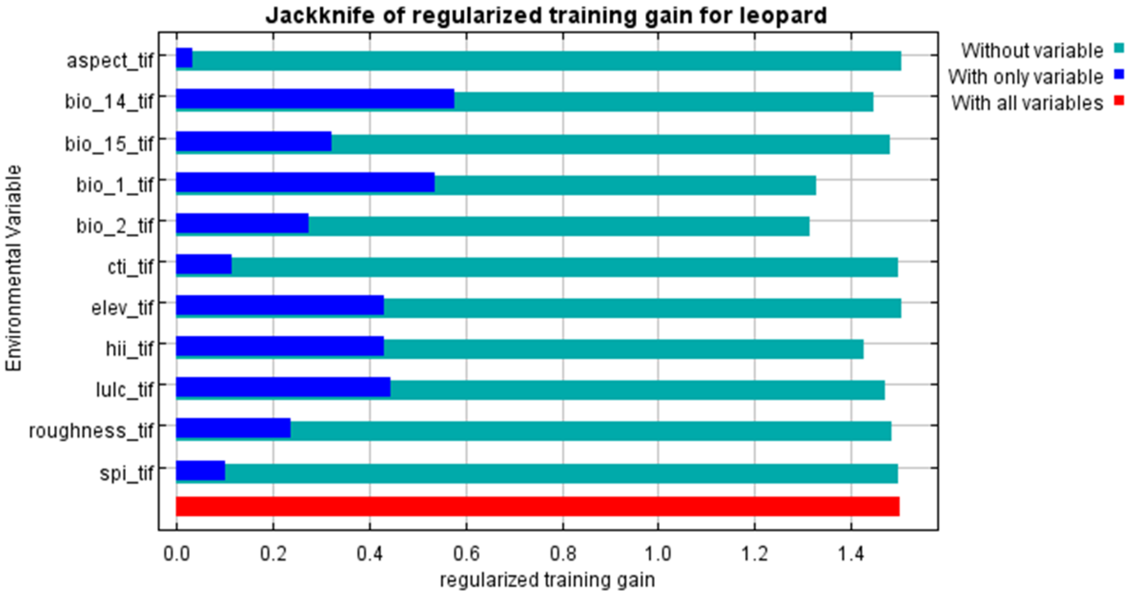


Figure 5.1 The Jackknife test for evaluating the relative importance of environmental variables for leopard in Dachigam landscape

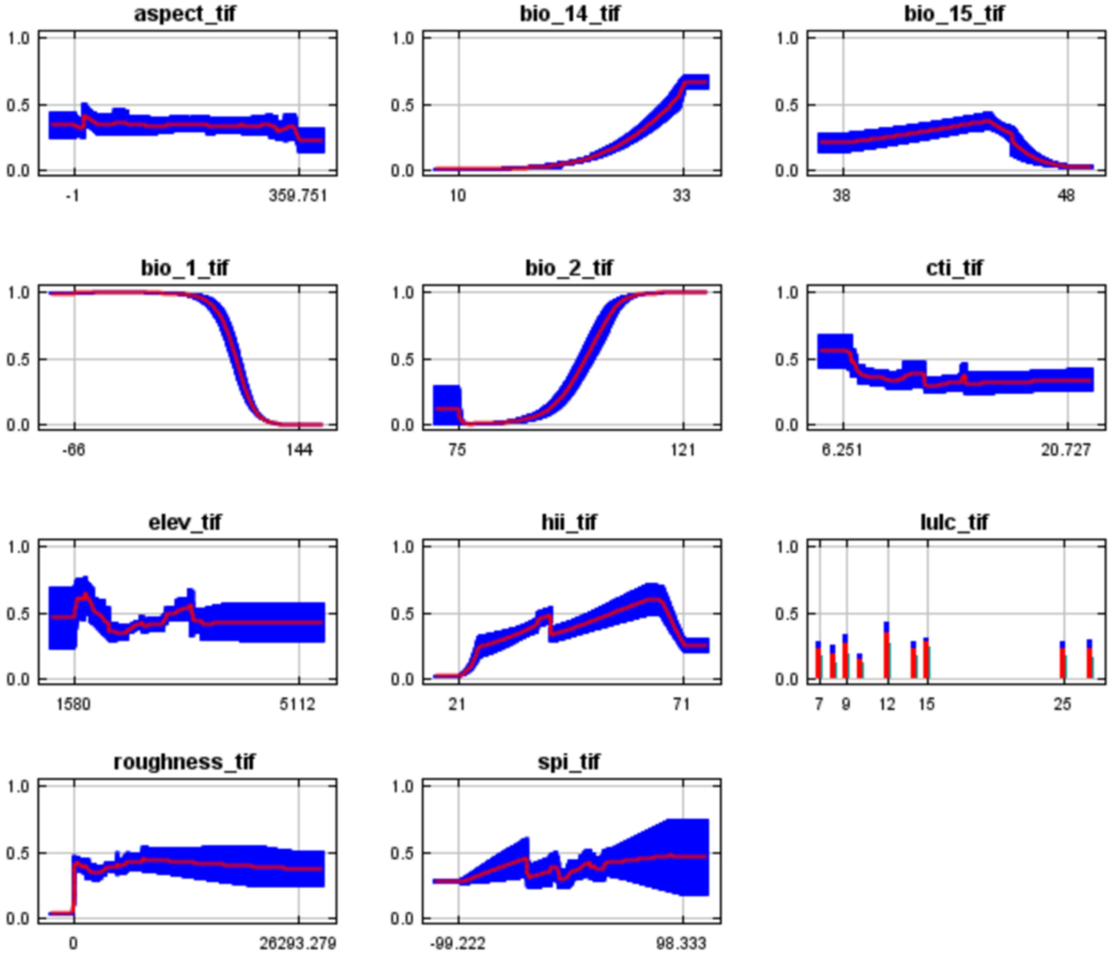


Figure 5.2 Response curves depicting relationship between environmental variables and the probability of leopard in Dachigam landscape

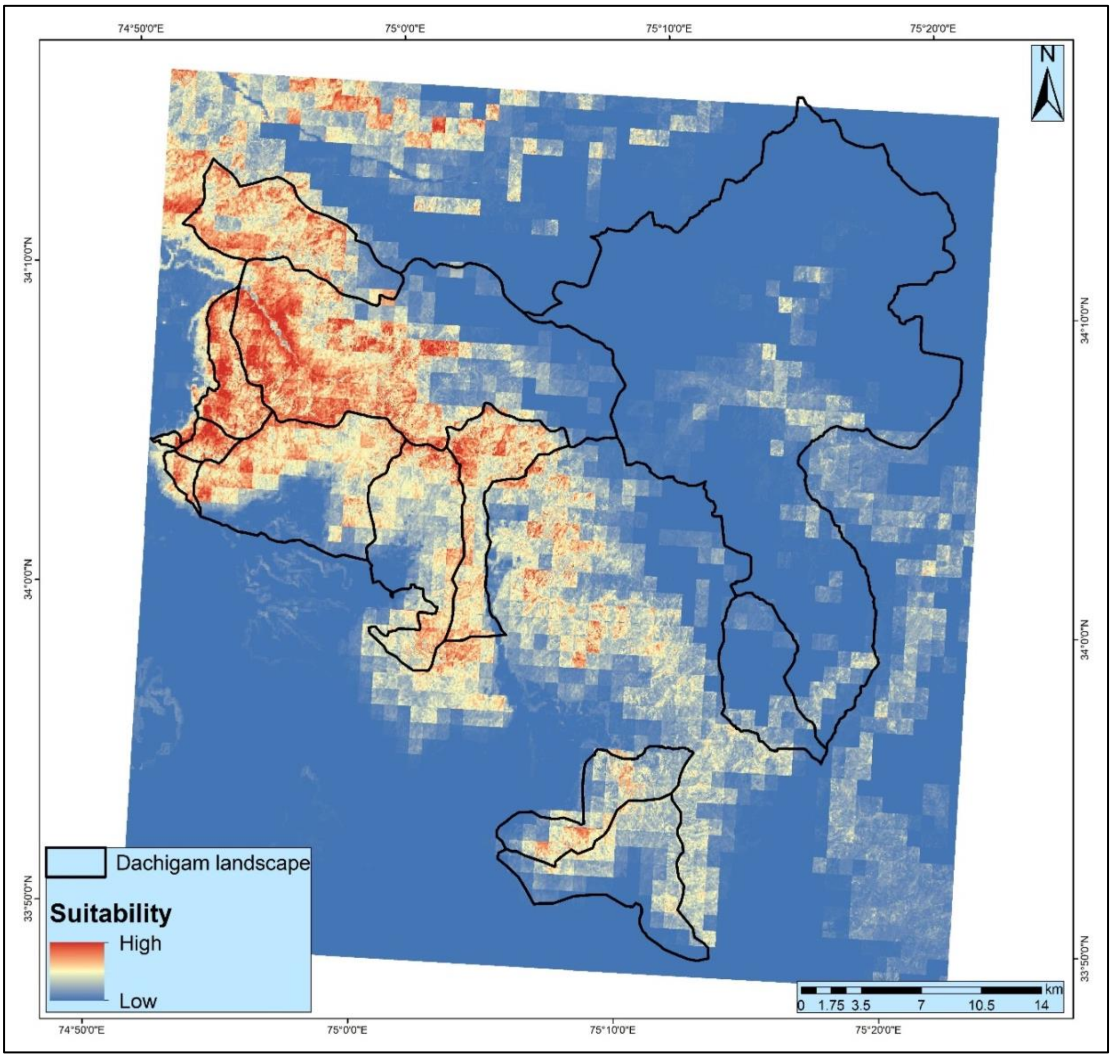


Figure 5.3 Predicted maximal entropy-based occurrences of leopard. The gradient of colors from blue to red illustrates the gradient of more appropriate environmental conditions (red = favorable; blue = adverse)

5.4 Discussion

This suitability modelling predicted the potential distribution of leopards in Dachigam landscape which lies in the western Himalaya of India based on presence only records. This is a first study involving suitability predictive modelling for leopard in Dachigam landscape. Therefore, the results of this study can assist in developing conservation and management strategies. In Dachigam landscape, leopard shares its habitat with the critically endangered Bactrian Red Deer subspecies – Hangul (*Cervus hanglu* ssp *hanglu*), thus management implications from this study will be of major importance.

Leopard is a generalist big cat and is reported to have a close association with human habitations (Odden *et al*. 2014) apart from other environmental and topographic factors such as elevation, aspect, ruggedness and vegetation types (Carroll and Miquelle 2006; Linkie *et al*. 2006). In this study, the leopard distribution is positively related to areas of human influence, elevation and vegetation types. Amongst the vegetation categories, highest influence on leopard distribution is of broadleaved vegetation followed by temperate grasslands and scrubs. Preference is shown for broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain. It is expected that the vegetation at the valley floor provides good cover and stealth for ambush or stalking prey to leopard benefitting it in obtaining prey (Gittleman and Harvey 1982; Karanth and Sunquist 1995; 2000) as it inhabits mainly in forested habitats (Karanth 2013). The results from this suitability analysis and habitat use analysis (Chapter 4) suggest the same findings.

Leopard dis not use higher elevations of Dachigam landscape and never go beyond 3700 m a.s.l. though it has been recorded to go up to 5200 m a.s.l. (Stein *et al*. 2016). North to north-eastern aspects are predicted by the suitability model even though it used almost all aspects uniformly as suggested by the response curves obtained from the predictive model.

CHAPTER 6

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

The state of Jammu and Kashmir, India, in the western Himalayan region has been going through armed insurgency and political instability for the past three decades (Akbar 2002) which is a major threat to local biodiversity (Hanson *et al*. 2009). All this impacts negatively on the biodiversity and results in increased hunting and natural resource extraction, lack of investment of funds in biodiversity conservation, and displacement of people (Hart *et al*. 1997; McNeely 2003; Loucks *et al*. 2008) thus, causing large declines in the wildlife populations and their distribution.

6.1 Significance and contribution of the study

Chapter 3 provides first ever information pertaining leopard density in Dachigam National Park, however with sample size limitations constrained mainly because of security concerns. Therefore, interpretation of results should be made with caution. This study also provides basic information about co-occurrence of mammalian species in the community of the moist temperate forest of the Kashmir Himalaya, India. The leopard density estimate was found to be lowest (SECR estimate – 0.74 per 100 km^2) among the areas consisting leopard populations across India (see Table 3.6). Densities of large cats in particular have been found to get depressed due to both direct mortality from hunting and the collapse of prey populations (Gray and Prum 2012). Owing to the present scenario it cannot be ruled out that the forests of the Kashmir Himalaya including Dachigam are susceptible to or suffering through “empty forest” syndrome (Karanth *et al*. 2004; Datta *et al*. 2008). Recently, similar results have been presented by Shehzad *et al*. (2014) in similar ecosystem of western Himalaya in Pakistan. Overall, large mammalian prey availability in Dachigam NP appears to be very low as photo-captures of potential large wild prey species such as Hangul, wild pig were very low. As the sampling was not meant for the arboreal Kashmir gray langur so detection through camera traps cannot be meaningful. The status of other ungulate species reported from the area such as Kashmir musk deer, Himalayan serow and wild pig is not known. The detection of wild pig was after a gap of three decades (Ahmad *et al*. 2013).

This study also sheds some light on leopard activity pattern in the Dachigam NP and has revealed that this area has very poor prey base which costs leopard very high searching efforts with very less benefits (Habib *et al*. 2014). This prey scarcity ultimately forces the leopard to spend great amount of energy in search efforts across time and space thus, resulting cathemeral activity pattern i.e. it is active throughout the day although it is regarded as a nocturnal and crepuscular species (Sunquist and Sunquist 2002). This diurnal and crepuscular activity pattern of leopard has also been reported from forested ecosystems earlier (e.g. Karanth and sunquist 1995; Jenny and Zuberbuhler 2005).

Chapter 4 provides crucial information on leopard's ranging pattern which is a first in the western Himalayan region from India. The home ranges of both male and female were found to be largest in comparison to reported ranges from elsewhere in India (Table 4.1). The large home range estimates suggest the low availability of food resources in the study area as abundance and distribution of food resources govern the home ranges of adult females (Bailey 1993; Sunquist and Sunquist 1989). This is part of the cycle where low availability would cause low abundance of females. In absence of more numbers of reproducing females male home ranges are bound to get larger as male leopard's home ranges depend mostly on available females to mate (Bailey 1993; Sunquist and Sunquist 1989). Large home ranges of males are also an artefact of more energy requirements of males due to their large body sizes in comparison to females (Carbone and Gittleman 2002; Smith *et al*. 2017) and also for territorial patrolling. Hence, less abundance of food resources contributes to large home ranges of males as well.

There is seasonal variation in selecting different habitats by female leopard for which complete one year's telemetry data in the study area is available. Overall, leopard prefers broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain. It is expected that the vegetation at the valley floor provides good cover and stealth for ambush or stalking prey to leopard benefitting it in obtaining prey (Gittleman and Harvey 1982; Karanth and Sunquist 1995; 2000) as it inhabits mainly in forested habitats (Karanth 2013). In the study area leopards appear to cope with temporal and spatial variation in resources as its diet fluctuates with season (Mir 2016).

Chapter 5 describes the habitat suitability modelling in Dachigam landscape. This is a first study involving suitability predictive modelling for leopard in Dachigam landscape. Therefore, the results of this study can assist in developing conservation and management strategies. In Dachigam landscape, leopard shares its habitat with the critically endangered Bactrian Red Deer subspecies – Hangul (*Cervus hanglu* ssp *hanglu*), thus management implications from this study will be of major importance. In this study, the leopard distribution is positively related to areas of human influence, elevation and vegetation types. Amongst the vegetation categories, highest influence on leopard distribution is of broadleaved vegetation followed by temperate grasslands and scrubs. Preference is shown for broadleaved forests which include the habitats with high diversity and density present at the bottom of the Dachigam valley on almost flat and less undulating terrain. The results from this suitability analysis and habitat use analysis (Chapter 4) suggest the same findings.

6.2 Recommendations

In context of the present study and findings a few recommendations can be made in order to improve the status of wildlife as whole and leopard in particular.

- ✓ Steps should be taken to improve quality of habitat and strengthen the protection levels so that lower prey base gets improved as the natural prey base is very in Dachigam and the abundance of large prey like hangul is very low furthermore, status of recently rediscovered wild pig and of Himalayan Serow are not known. It is anticipated that if the natural prey base is increased due to measures undertaken to improve habitat there will be an increase in leopard abundance and thus leopard home range might get smaller if food resources are abundant. In similar conditions and landscape in Pakistan, a bottom-up conservation approach has been suggested (Khan *et al*. 2018).

- ✓ There are several government departments operating from inside the study area. Though direct impact of this was not assessed in this study but yes disturbance due to presence of these cannot be ruled out. Therefore, political will is needed from the government body to shift these establishments elsewhere from the study area.

- ✓ Tourism is also an important factor which should be sustainable and regulated to reduce disturbance pressure on wildlife. Tourism is mainly for the hangul species which people want to see and enjoy but this should not be at the cost of peace of this shy species.

- ✓ Integrated approaches involving ecological and socio-economic aspects should be planned to develop effective strategies for conservation and management of leopards in the Dachigam Landscape in particular and in the valley in general. Active participation of local communities should be ensured to achieve long term conservation goals.

6.3 Challenges and limitations

As mentioned earlier the instability in the Kashmir region drives all the security concerns in the region. Therefore, it is imperative for the managers to have strong and well equipped field personnel in order to tackle conflicting situations. Research teams should feel secure while doing research works to generate reliable information and outputs.

6.4 Future research

This study provides valuable insights into basic ecological aspects of leopard such as abundance, activity, habitat use and ranging pattern in Dachigam National Park. The estimates obtained during this study are based on limited sample sizes and period. Therefore, it is recommended that the same aspects be replicated in future also in order to obtain robust estimates for future management planning. The future studies should also target the adjoining conservation reserves. The north, central and south divisions should be covered in order to produce information on all aspects of leopard ecology and its interaction with other wildlife. Leopard also shares its habitat with critically endangered Hangul (a subspecies of Bactrian Red Deer) therefore, a long term monitoring program should be initiated in Dachigam to cover all such ecological aspects.

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PUBLICATIONS

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