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Leopard (*Panthera pardus*) Food Habits in Shared Landscapes: A Case Study of Dabka and Khulgarh Watersheds

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ABSTRACT

Leopard (*Panthera pardus*) food habits was investigated in the human-used landscape of Dabka and Khulgarh Watershed areas of Kumoan Himalayan, Uttarakhan, India between September 2007 and June 2009. In total, 91 and 118 leopard scats were collected from Dabka and Khulgarh, respectively. Prey items were identified using non-digested material isolated from scats, as well as a reference collection of hairs and bones from potential prey. Faecal analysis revealed that leopards preyed on 11 and 12 species in Dabka and Khulgarh, respectively. Total diet diversity of leopard was 2.98 in Dabka and 3.00 in Khulgarh. Sambar (53.41%) in Dabka and domestic dog (36.23%) in Khulgarh constituted the bulk of leopards diet both in terms relative prey biomass consumed. Comparison of the observed and expected frequency of occurrence of prey species in leopard diet rejected the hypothesis of non-selective predation in both the study sites. This study showed the survival strategies of leopard by switching diet according to the prey composition of the study area indicating that leopard can survive anywhere. The study highlights the wide dietary width of leopards identified in other research but rarely investigated in shared spaces. Such studies are crucial to the successfull management of “potentially harmful” wildlife in human-use areas. In particular, our result suggest that there is no single key for the existence of the leopard, which should rather depend upon on ecological features of the study area for example, abundance, prey composition, habitat condition and human settlement.

Key words: Biomass, Kumoan Himalayas, *Panthera pardus*, Prey selectivity, Scat analysis

INTRODUCTION

Although the number of large carnivores exploiting human-use areas is growing, our knowledge of their ecology in these habitats is limited (Bhattacharjee and Parthasarathy 2013, Athreya et al. 2013, 2014, Kshettry 2017, Kshettry et al. 2018) Furthermore, a lack of comprehensive knowledge about large carnivore feeding and habitat ecology in densely populated areas sometimes obstructs scientific conservation and management of these populations (Odden et al. 2014). True in a country like India, where people density is high (Kshettry et al. 2018), livestock numbers are among the highest in the world 536.76 million (Anonymous 2019) and a variety of wild carnivores coexist with humans (Athreya et al. 2013).

Leopards (*Panthera pardus fusca*) are one of the most extensively dispersed large carnivores in India, with most of their range overlapping with that of people (Athreya et al. 2013, Kshettry et al. 2018). Leopard is an important component of India’s megafauna. The rate at which leopard loses its range is a sure indication of the extinction of this species. The gradual loss of this species will also put extra pressure on other species it interacts (Ceballos et al. 2020).

Due to their highly flexible hunting and eating behavior, leopards can dwell in a multitude of environments, from rainforest to desert, and from the outskirts of cities to distant mountain ranges (Nowell and Jackson 1996), demonstrating that they may exist wherever there is sufficient shelter and appropriately sized animals (Bertram 1999, Ahmed and Khan 2008, Ahmed 2010, Zehra et al. 2019). Large carnivore prey needs in human-use contexts are rarely studied in India (Bhattacharjee and Parthasarathy 2013, Athreya et al. 2013, Athreya et al. 2014, Kshettry 2017, Kshettry et al. 2018).

The majority of studies on leopards are restricted to protected regions (Karanth and Sunquist 1995, Ramakrishnan et al.1999, Jathanna et al. 2003, Ahmed and Khan 2008, Ahmed 2010, Kshettry et al. 2018). Understanding the complicated interaction between predator and prey requires knowledge of a wide range of diets and eating habits. Therefore, a study of large carnivores' diets, such as leopards, is crucial for advancing basic ecological knowledge and providing extra support for their conservation (Sharbafi et al. 2016). Understanding these predators' feeding ecology is essential for formulating better management strategies for managing and conserving big cats within their particularly in human used landscape. Therefore, in the present study, leopard feeding behaviors were investigated in a setting that had small pockets of forest interspersed among human settlements. By studying prey remains from scat, researchers were able to learn more about leopards' feeding habits. This study adds to our understanding of leopard dietary ecology in areas where humans and leopards coexist.

MATERIAL AND METHODS

Study Area

The Khulgarh Watershed Area (henceforth KWA) lies between latitudes 29^0 34" 31' to 29^0 41" N and latitudes 79^0 32" 15' and 79^0 37" E in the Kumaon Himalaya district of Almora, Uttarakhand (Fig. 1). The area spreads over 32 km^2 and represents the Shiwaliks midway through. It is located 15 km west of the town of Almora and has 34 inhabited villages. Summer, winter and monsoon are three distinct seasons (Ahmed and Khan 2021). The average yearly temperature is 20^0C, which varies from 25.2 to 13.6^0C. General elevation of the area is 1100 to 2200 meters above sea level (msl). Kumaon Himalayan vegetation has been divided into four different zones (Champion and Seth 1968). *Pinus roxburghii* was the most dominant tree species in the study area.

Dabka Watershed Area (henceforth DWA) has an area of approximately 69 km^2 and is situated between 29^0 30' 19" N and 29^0 24' 09" N latitudes 79^0 17' 53" E and 79^0 25' 38" E longitude, in the region of the Lesser Himalayas in the state of Uttarakhand. The area's climate is temperate to cold with the temperate vegetation. This area falls within 700-2600 meters of altitudinal ranges. The mean annual temperature

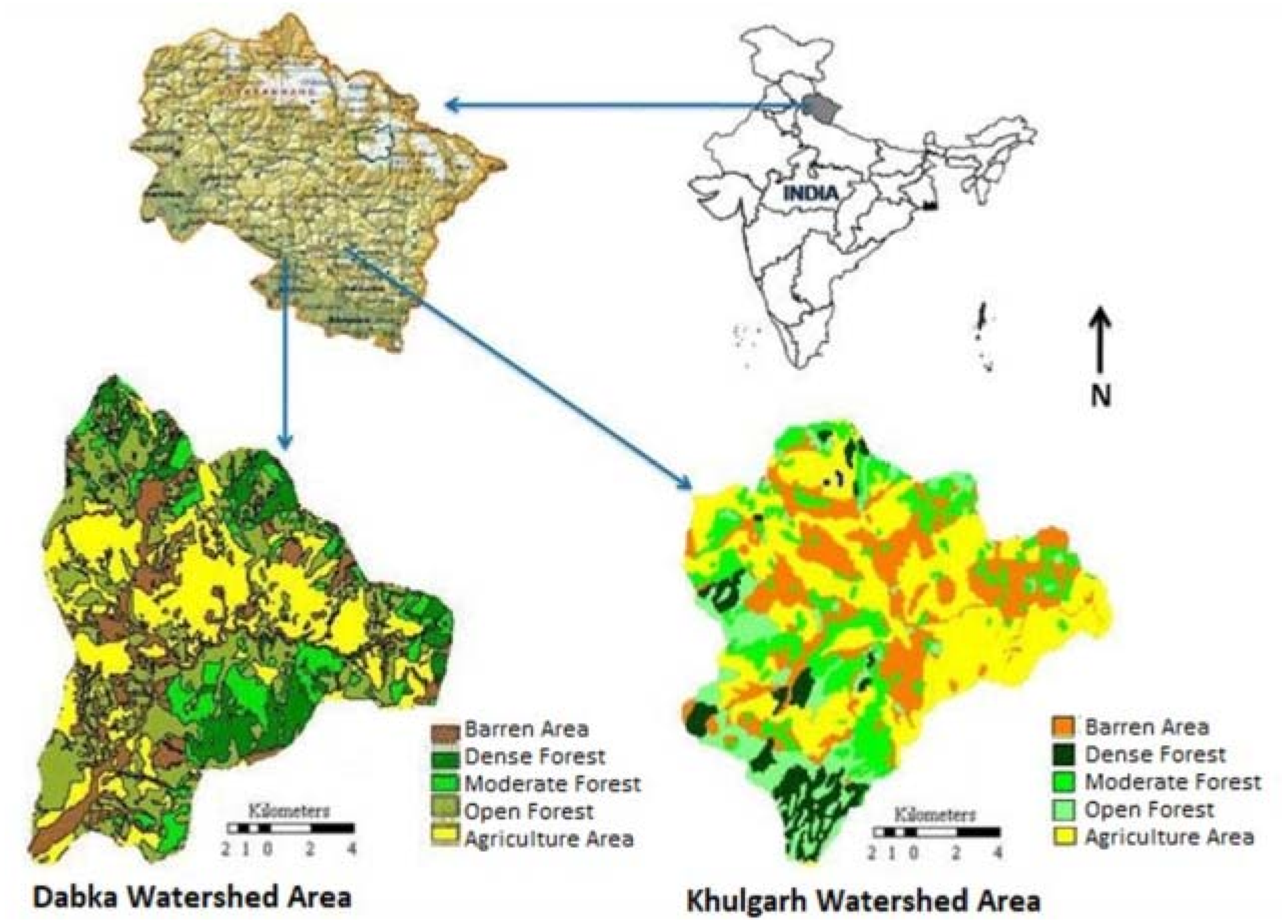

Figure 1. Map of study sites showing the location of both the watersheds, Uttarakhand, India

varies at different altitudinal ranges (600-900, 18.9 to 21.1^{0}C), (900-1800, 13.9 to 18.9^{0}C), (1800-2500, 10.3 to 13.9^{0}C) (Sultana 2002). The study area, though a reserve forest, includes 33 villages within the revenue villages category. DWA is a reserve forest divided into the Vinayak and Naina woodlands. Most of the study area lies within the Kumaon division's of Vinayak forest range with dominant *Quercus leucotricophora* and a few patches of *Pinus roxburgii*, *Taxus baccata*, and *Cedrus deodara* (Ahmed and Khan 2021).

Data Collection

Scat analysis is an indirect, non-destructive, and cost-effective tool for monitoring the frequency of occurrence of prey in a carnivore diet (Sunquist 1981). The leopard scats were collected in both the study sites, from September 2007 to June 2009. Large carnivores known to use the forest roads and trails for scat deposition (Karanth and Sunquist 1995, Ahmed 2007, Ahmed and Khan 2008, Ahmed 2010) were searched. These scats have been identified from other predators based on the associated signs, tracks, size, and scat appearance. Scats were collected after confirming leopard signs (pugmark and scrapes) within the proximity (around 15–20 m). Only such signs that could be identified unambiguously were recorded to avoid problems of false-positive detections (Miller et al. 2011). Feacal samples were processed using the methods defined in Mukherjee et al. (1994), Karanth and Sunquist (1995), Athreya et al. (2014), prey species were identified on the basis of medullary and cuticular patterns by comparing with reference hair samples of mammalian species prepared at the Department of Wildlife Sciences, Aligarh Muslim University, Aligarh.

For all prey species, we first calculated the frequency of occurrence in scats. We then applied the non-linear correction factor described in (Chakrabarti et al. 2016) to calculate relative prey biomass consumed and the relative number of prey individuals consumed by leopards.We followed (Mukherjee et al. 1994), for sample size estimation. The live weights of wild prey species were taken from Karanth and Sunquist (1995), Khan et al. (1996), Henschel et al. (2005), and those of domestic livestock from Schaller (1967). We used corrected frequency of occurence obtained by counting each prey item as 1/2, if two prey items occurred in one scat and 1/3, if three species occurred, etc (Karanth and Sunquist 1995). We could not perform molecular identification of leopard based on fecal DNA as it was beyond the scope when scats were collected and the resources available were limited. Moreover, an indirect sign survey is a well-established, widely accepted and implemented methodology, particularly when large areas need to be covered with limited financial resources with skilled field workforce.

Analysis of Prey Selection

Selectivity for main prey species tested on the basis of the null hypothesis of random or non-selective prey killing by predators using a goodness-of - fit test (Zar 1999). SCATMAN program (Link and Karanth 1994) used to calculate the proportion of prey species expected in scats.

RESULTS

Sample Size Estimation

In DWA, hair needed to be scanned per scat to detect 100 per cent of the mammalian prey species in one scat with 95% certainty were11-12 hair, while 95% of mammalian prey species with 95% confidence limits were detected by analyzing nine hairs per scat (Fig. 2). Maximum scats were found with only one prey species (45%), whereas very few scats contained hair remains of two (32%), three (15.38%) and four prey species (87%).

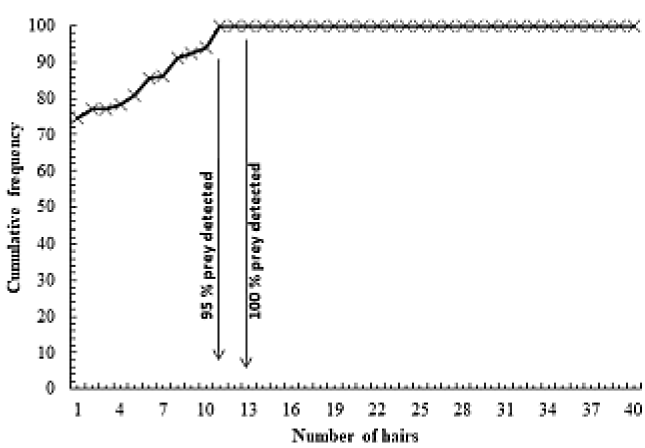

Figure 2. Standardization of minimum number of hairs required per scat to know the food habit of leopard in DWA

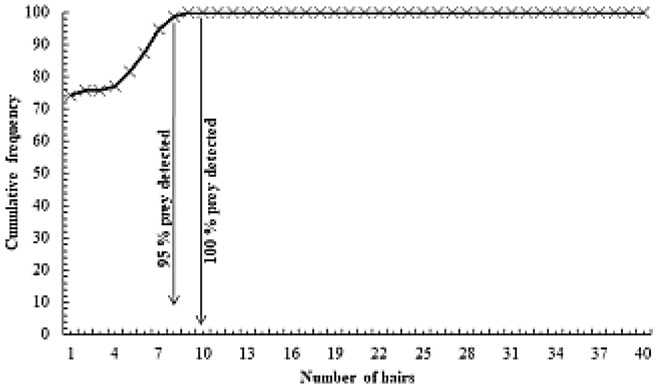

Figure 3. Standardization of minimum number of hairs required per scat to know the food habit of leopard in KWA

In KWA, the number of hairs to be scanned per scat were between 9-10 hairs to detect 100 per cent of mammalian prey species consumed by leopards with 95% certainty, whereas 95% of mammalian prey species were detected by analyzing eight hairs per scat (Fig. 3). Maximum scats contained prey remains of only one prey species (62%), whereas two prey species were detected in 25.42% scats, and three prey species in 13% scats.

Diet Diversity

In DWA, 11 food items (n = 91) were found in the scats of leopard with total diet diversity (Shannon-Wiener Index H') of 2.982. In all, sambar (*Rusa unicolor*) constituted the diet of leopard in bulk in terms of frequency of occurrence (27.47%) and

Table 1. Diet profile of leopards in DWA (n = 91) and KWA (n = 118), September 2007-June 2009. Average prey weight (A), frequency of prey occurrence (F), prey biomass consumed (Y; derived using correction factor described in Chakrabarti et al. 2016), relative biomass consumed by leopards (D) and relative number of individuals consumed (E)

Species		**DWA**				**KWA**			
	A (kg)	**F (%)**	**Y (kg/scat)**	**D (%)**	**E**	**F (%)**	**Y (kg/scat)**	**D (%)**	**E**
Sambar (*Rusa unicolor*)	166	27.47	2.17	53.41	0.37	1.32	2.17	2.56	0.02
Rodent species	0.113	8.79	0.51	4.02	41.23	17.54	0.51	8.02	82.28
Indian Wild pig (*Sus scrofa*)	32	7.14	1.89	12.11	0.44	2.19	1.89	3.72	0.13
Muntjac (*Muntiacus muntjac*)	20	6.59	1.63	9.60	0.56	10.96	1.63	15.96	0.93
Himalayan langur (*Semnopithecus schistaceus*)	8	4.40	1.10	4.34	0.63	13.16	1.10	13	1.88
Bird Species	0.251	4.40	0.52	2.06	9.51	3.51	0.52	1.64	7.59
Himalayan serow *(Capricornis thar)*	90	1.65	2.16	3.19	0.04				
Porcupine (*Hystrix indica*)	8	1.65	1.10	1.63	0.24	2.19	1.10	2.17	0.31
Rhesus macaque (*Macaca mullata*)	4	-	-	-	-	8.77	0.84	6.56	1.90
Golden jackal (*Canis aureus*)	7	-	-	-	-	1.32	1.04	1.23	0.20
Domestic dog (*Canis familiaris*)	12	21.98	1.32	25.93	2.51	30.70	1.32	36.23	3.50
Goat (*Capra* spp.)*	22	7.14	1.68	10.77	0.57	3.07	1.68	4.63	0.24
Unknown	5	8.79	0.91	7.15	1.66	5.26	0.91	4.28	0.99

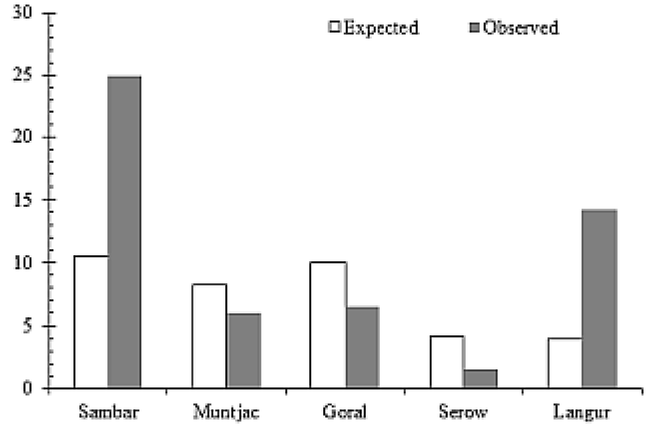

Figure 4. Comparison of observed and expected proportions of prey consumed by leopard DWA

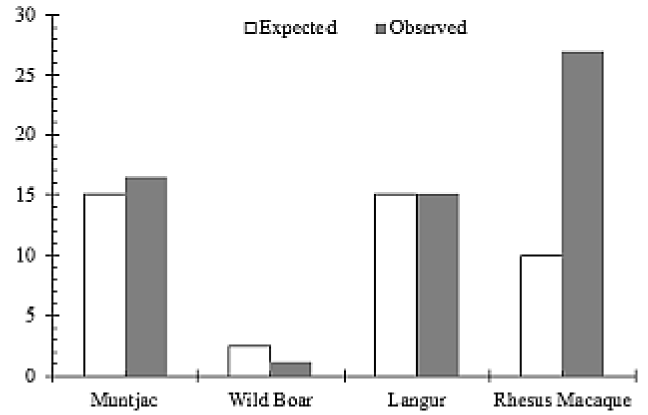

Figure 5. Comparison of observed and expected proportions of prey consumed by leopard KWA

relative biomass consumed (53.41%) (Table 1). In KWA, a total of 12 prey species (n=118) were identified with diet diversity (Shannon-Wiener Index H') of 3.003. Dog constituted the bulk of the leopard diet (30.70%). In terms of relative biomass consumed, dogs contributed a significant portion of leopards diet (36.23%) (Table 1).

Prey Selectivity

We investiagted prey selectivity by estimating densities of wild prey. Comparison of the observed and expected frequency of occurrence of prey species in leopard scats indicated a significant difference in leopard use of prey species and rejected the hypothesis of non-selective predation in DWA (χ^2 = 67.37, df = 10, P < 0.01) as well as KWA (χ^2 = 113, df = 11, P < 0.01). In DWA, sambar and Himalayan langur (*Semnopithecus schistaceus*) found to be consumed more than their availability by leopards, while muntjak (*Muntiacus muntjak)*, Himalayan brown goral (*Nemorhaedus goral)*, and serow (*Capricornis sumatraensis)* were found to be consumed less than their availability (Fig. 4). In KWA, rhesus macaque (*Macaca mulatta)* and muntjak were found to be consumed more than their availability while langur was found to be consumed by leopards in proportion to its availability and wild pig (*Sus scrofa)* was consumed less than its availability (Fig. 5).

DISCUSSION

The leopard is one of those large carnivores capable of persisting in human-use areas throughout its range, especially in India (Athreya et al. 2013, Navya et al. 2014, Kshettry et al. 2018). The versatility of leopards, the availability of suitable habitat, the dense population of potential prey species in the form of domestic animals, the favourable legal environments, and some other social and cultural factors may promote leopards' survival in human-use areas (Ghosal et al. 2013, Odden et al. 2014). This study highlights the ability of leopards to adapt to a human-use landscape with varied diets from rodents to sambar. There was no absolute selectivity in the leopard diet, suggesting the generalized nature in relation to its diet, which was also seen in other studies (Hayward et al. 2006, Ahmed and Khan 2008, Ramesh et al. 2009, Mondal et al. 2012). In DWA, sambar and dog and in KWA, dog and rodents were the most important prey species of leopards in frequency and biomass. Livestock, along with dogs, has also been found to form a significant portion of the leopard diet in other studies (Athreya et al. 2014, Shehzad et al. 2015). The DWA and KWA, each inhabited with 33 and 25 villages respectively, contain a sizeable dog population, and thus provide easy leopard targets. A similar study in human-used areas in West Bengal, northeast India found livestock comprising a large portion of the leopard diet (Kshettry et al. 2018). In Bandipur, south India, Johnsingh (1983) although identified chital, sambar, langur, cattle, and hare as leopard prey items from scats, also reported killing of village dogs.

Rodents as a whole were the second largest group in KWA in terms of frequency of occurrence and relative prey biomass consumed. The presence of rodents in scats of leopard has also been documented in several earlier studies in India (Sankar and Johnsingh 2002, Ahmed 2007, 2010, Ahmed and Khan 2008) as well as outside India (Henschel et al. 2005, Farhadinia et al. 2014, Sharbafi et al. 2016). The high percentage of rodents in leopard diet may be due to nocturnal habits of rodents, which makes them more vulnerable to predation by leopards (Grobler and Wilson 1972, Ahmed and Khan 2008). The low percentage of rodents, muntjaks, and gorals in DWA may be due to the presence of prey species having substantial body weight such as sambar and may be considered in the light of the foraging theory hypothesis (Stephens and Krebs 1986), which suggests that predators may select species that contain the most profitable prey as measured by the ratio of energy gain to handling time (Scheel 1993). Sambar contributed 27.47 percent of the leopard diet in DWA, and 53.41 percent of the total consumed biomass. Rice (1981) also reported higher predation of a leopard on sambar in Eravikulum National Park and their contribution in the diet of leopards in other studies has also been reported higher (Johnsingh 1983, Karanth and Sunquist 1995, Sankar and Johnsingh 2002, Andheria et al. 2007, Mondal et al. 2011).

Predation on langur and muntjak was almost similar in both the study sites. Leopards are known to prefer prey ranging from small to medium size within a weight range of 10-40 kg (Henschel et al. 2005) and such species are considered the leopard's most energetically profitable prey (Sunquist and Sunquist 1989). The low percentage of wild pig in the diet of leopard in both the study areas may be attributable to its inability to handle comparable weight of its aggressive prey (Karanth and Sunquist 1995). The results from both the study areas appear to support the prediction of Griffiths (1975) that "vertebrate predators would be selective "energy" maximizers in prey rich habitat, but would be non-selective where large prey was scarce." A study on diet analysis of leopards also reported that distribution patterns of wild prey (medium-sized ungulates and primates) positively affected the occurrence of leopard (Puri et al. 2020). The presence of birds, Indian crested porcupine (*Hysterix indica)* and golden jackal (*Canis aureus)* showed leopard diet flexibility at both study sites that they had enough behavioral plasticity to adapt and take advantage of a wide variety of prey species. Moreover, the present study found that leopards prefer wild prey to domestic, resorting to the latter only when wild prey populations are unavailable in contrast to a similar study conducted in human use landscape in northeast India (Kshettry et al. 2018).

The loss of human life and economic damage are the main obstacles for conserving big cats in shared landscapes. We find evidence that leopards are using both wild and domestic prey at both the sites. Domestic prey (dog and goat) are more widespread and accessible to leopards in the region that may cause conflict. Thus, proactive measures are urgently needed that should focus on future research in Uttarakhand's entire reserve forest patches where leopards share space with humans. The study adds to the rising body of literature on large wildlife thriving in peri-urban landscapes on a global scale. Such studies are crucial to the successful management of "potentially harmful" wildlife in human-use areas. The study also highlights the varied dietary extent of leopards documented in other research, which however has been rarely investigated in shared landscapes.

Moreover, the present study also provided insights into several aspects of leopard foraging ecology in both the study sites, illustrating the opportunistic nature of the leopard, which appeared to take advantage of a constantly changing environment where food resources varied temporally as well as spatially. Like other large carnivores, leopards may select larger prey at a higher proportion where it is available and smaller prey species, where larger prey may not be available. The study highlights the flexibility in the feeding ecology of leopard by switching their diet from sambar to village dogs when large prey is not available. In particular, our result suggests that there is no single key to the leopard's existence in an area, which should rather depend on ecological characteristics of the study area, such as prey abundance, prey composition, habitat condition, human settlement and competition.

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Conflict of interest: The authors declare no conflict of interest

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