

Dependence of the leopard *Panthera pardus fusca* in Jaipur, India, on domestic animals

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Abstract The ecology and predator–prey dynamics of large felids in the tropics have largely been studied in natural systems where wild ungulates constitute the majority of the prey base. However, in tropical countries where communities are primarily agrarian, the high density of domestic animals in human-dominated landscapes can be a potential prey source for large carnivores. We demonstrate almost complete dependence of the Vulnerable leopard *Panthera pardus fusca* in the Jhalana Reserve Forest in Jaipur, north-west India on domestic animals as prey. We analysed 132 leopard scats collected during the dry season of November 2017–April 2018. Domestic animals comprised the majority of the leopards' prey (89.5% frequency of occurrence): dogs *Canis lupus familiaris* (44%), cats *Felis catus* (13%), goats *Capra aegagrus hircus* (16%) and cattle *Bos taurus* (15%). Wild species, which occurred in the leopards' diet at a relatively low frequency, were rodents, the hare *Lepus nigricollis*, small Indian civet *Viverricula indica*, rhesus macaque *Macaca mulatta*, northern plains grey langur *Semnopithecus entellus* and mongoose *Herpestes edwardsii*. Diet is also a function of availability of potential prey, but no data are available on the density of the leopard's wild prey species in Jhalana Reserve Forest. Nevertheless, our results suggest that abundance of domestic prey around Jhalana Reserve Forest sustains the c. 25 known leopards. We conclude that these leopards, by preying on feral dogs in an urban environment, could be considered as suppliers of a service to the human population amongst whom they thrive, although this potentially exposes the leopards to the canine distemper virus.

Keywords Diet, environmental service, human-dominated landscape, India, Jhalana, leopard, *Panthera pardus fusca*

Introduction

Knowledge of prey selection and diet is important for understanding the life history strategies of carnivores and for planning the conservation of an apex predator (Miquelle et al., 1996). The density of carnivores is related to habitat quality, in particular to the availability of prey (Fuller & Sievert, 2001; Carbone & Gittleman, 2002; Andheria et al., 2007; Karanth & Nichols, 2010). To enhance the cost–benefit ratio of energetic intake, large carnivores may visit areas close to, or even inside, human settlements (Gehrt et al., 2010; Yirga et al., 2012; Athreya et al., 2013). Fear of carnivores, especially in the context of livestock depredation, can negatively affect people's well-being (Inskip & Zimmermann, 2009). It has been shown that the abundance and availability of wild and domestic prey is the predominant factor that determines the potential carrying capacity of human-dominated landscapes for large carnivores (Boitani & Powell, 2012). In human-dominated landscapes in Brazil, Nepal and Kenya (Schaller, 1983; Seidensticker et al., 1990; Mizutani, 1999) the biomass of potential domestic prey of carnivores was higher than that of wild prey species. Discarded food waste and pet food may also contribute to the food resources of carnivores (Gehrt et al., 2010). This reduces carnivores' fear of humans and, in consequence, the density of carnivores in urban or semi-urban areas can be higher than in the wild (Butler et al., 2014).

In India, the intrusion of large predators into urban areas is well documented. Wolves *Canis lupus* (Jhala & Giles, 1991), Asiatic lions *Panthera leo persica* (Meena et al., 2011), striped hyaenas *Hyaena hyaena* (Singh et al., 2010) and tigers *Panthera tigris* (Karanth & Gopal, 2005) are known to attack livestock and persist in human-dominated landscapes. The leopard *Panthera pardus fusca* also lives successfully in the proximity of people (Athreya et al., 2004). Its broad diet includes amphibians, arthropods and carrion, reducing dependence on water sources, which is obtained from the prey (Daniel, 2009; Kshetry et al., 2018). Compared to larger felids, the small body size of the leopard reduces the territory required to sustain a population and allows it to survive and thrive in proximity to people (Daniel, 2009; Kshetry et al., 2018).

To examine resource utilization by leopards in a rural, semi-urban human-dominated landscape, we analysed the diet of leopards of the Jhalana Reserve Forest. Because the Reserve is in close proximity to and surrounded by human habitations, leopards have little fear of people and

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FIG. 1 Jhalana Reserve Forest in north-west India, and the surrounding city of Jaipur, with the locations of the leopard *Panthera pardus fusca* scats collected.

often feed opportunistically on easily accessible domestic prey (Athreya et al., 2013, 2014). We thus hypothesized that the leopards' diet comprises principally of domestic animals. Our objectives were to identify the leopards' key prey species and examine their importance for human-leopard coexistence and acceptance of the presence of leopards in the urban landscape (Kumbhojkar et al., 2019).

Study area

The 29 km² Jhalana Reserve Forest lies on the south-east border of the city of Jaipur in north-west India (Fig. 1). It was designated on 21 November 1961 in accordance with the provisions of Rajasthan Forest Act 1953. The Reserve has a mean altitude of 516 m, with higher elevations in the north in the form of low, flat-topped hills, and is characterized by tropical dry deciduous forest. During the 1980s the main valley was planted with the native species *Acacia tortilis* and *Acacia senegal*.

Methods

The population of leopards in the Reserve has been estimated, using camera traps and recognition of individuals, to comprise 25 individuals (authors, unpubl. data). In a 2017 survey of the Reserve we found that leopards used trails and tourist routes for defecation. We monitored the trails, collecting 138 scat samples in the dry season of November 2017–April 2018 (Kumbhojkar et al., 2019; Fig. 1).

The identity of leopard scats was confirmed using their occurrence in scrapes characteristic of those made by large

felids (the leopard is the only large felid present in the Reserve). Trained volunteers wearing gloves used forceps to collect the scats. A small portion of each scat was left, so as to not disrupt the natural markings of the leopards (Schwarz & Fischer, 2006). The location of each scat was noted, with a GPS, at the time of collection. Scats were stored in numbered polythene, zip-lock bags. Preliminary observations such as the presence of bones, claws, skin and other biological remains were noted if appropriate.

Highly degraded scats ($n = 6$; 4.3%) were excluded from the analysis and only well-preserved scats ($n = 132$) were analysed. They were washed under running water and sundried. The cuticular and medullar patterns of any hair remains were observed and photographed under a compound microscope. Scat analysis was based on Mukherjee et al. (1994), Mukherjee & Mishra (2001), diet-related studies (Karanth & Sunquist, 1995; Biswas & Sankar, 2002; Sankar & Johnsingh, 2002; Andheria et al., 2007; Khorozyan et al., 2008; Odden & Wegge, 2009), and our own collections of prey remains. All hair, hooves, claws, teeth, nails and bones were separated for further analysis. Prey species were identified based on comparison with reference slides of hair samples from domestic animals in the study area and from reference slides of hair samples from wild prey and from previous studies (Oli, 1993; Tiwari, 2008).

To assess if the sample size was sufficient for accurate diet analysis (Edgaonkar & Chellam, 1998; Kshetry et al., 2018) we applied the rarefaction method, implemented in *EstimateS 9.1* (Colwell, 2005). This method estimates the expected cumulative number of species, with 95% confidence intervals (the Mao Tau estimator; Colwell, 2005).

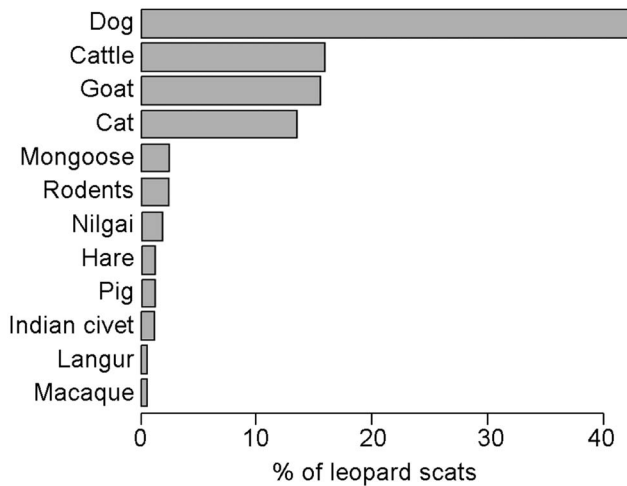


FIG. 2 Per cent of 132 leopard scats collected in Jhalana Reserve Forest (Fig. 1) that contained various prey species/taxa (Table 1).

We calculated the relative biomass of prey species consumed using the regression equation $Y = 0.35X + 1.98Y$, where Y is the mass of prey consumed per scat and X is the mean mass of the prey (cf. Ramesh et al., 2009). The regression equation is derived based on feeding trials with captive mountain lions *Puma concolor* (Ackerman et al., 1984) to calculate relative biomass based on their relative proportions in scats. As mountain lions and leopards are similar in size, this method has been used previously for leopards (Karanth & Sunquist, 1995; Andheria et al., 2007; Khorozyan et al., 2008; Odden & Wegge, 2009; Wegge et al., 2009; Athreya et al., 2014).

The frequencies of occurrence of prey species (the per cent of the total number of scats that contained a specific prey item) were calculated but, as smaller prey species may contribute more to scats than larger species (Karanth & Sunquist, 1995; Klare et al., 2011), this variable may potentially be misleading. The relative biomass (D) was therefore calculated using:

$$D = \frac{AY}{\sum AY} \times 100$$

where A is the frequency of occurrence of the prey species. The relative per cent of each prey species consumed (E) was obtained using:

$$E = \frac{\frac{D}{\bar{X}}}{\sum \frac{D}{\bar{X}}} \times 100$$

Because we found that the correlations between Y , D , and E (R^2 0.28–0.99) were all significant at $P < 0.01$, we only tested differences in biomass (D) between domestic and wild prey species by t test with Cochran–Cox adjustment

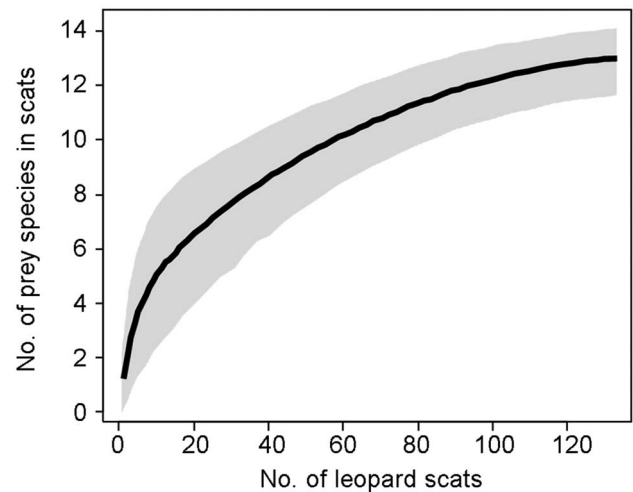


FIG. 3 Cumulative number of prey species in leopard scats (solid line), with 95% confidence interval (shaded area).

(Zar, 1996). All calculations were conducted in *R* 3.6.0 (R Core Team, 2013).

Results

The 132 scats had a mean of $9.8 \pm \text{SE } 0.24$ (9.3–10.3 95% CI) prey species. Most of the scats (108; 82%) were found alongside trails or jeep tracks. Of the 2,640 hairs selected from scats, 158 (6%) were unidentified. The scats contained a total of 12 prey taxa: 11 individual species and rodents, which were not identified to species level (Fig. 2). Seventy-nine per cent (105) of the scats contained only one prey species; 21% contained two or more species. The individual-based rarefaction curve shows that the increase in the cumulative number of species in scats was rapid for the first c. 80 scats but began to level off thereafter (Fig. 3). In the 132 leopard scats the majority (89.5%) of prey frequency of occurrence comprised domestic animals (domestic dogs *Canis lupus familiaris*, 44%; domestic cats *Felis catus*, 13%; goats *Capra aegagrus hircus*, 16%; cattle *Bos taurus*, 15%) and wild prey comprised 11% of prey frequency of occurrence; the difference was significant (G test; $G = 4.16$, $P < 0.001$). The mean biomass of domestic animal species detected in the scats was 1.29 and that of wild prey was 0.02 kg; the difference was significant ($t = 2.78$, $P = 0.038$; Table 1).

Discussion

In urban landscapes the relationship between large felids and humans is complex, influenced by people's fear and awe (Boomgaard, 2001; Loveridge et al., 2010). Aversion occurs when the presence of a large felid results in damage to property or loss of human life (Treves et al., 2006), with retaliatory killings resulting in significant felid mortality

TABLE 1 Mean weight, per cent frequency, mass consumed per scat, relative biomass consumed and relative per cent of prey, in decreasing order of frequency, for each of the 12 prey taxa recorded in the 132 scat samples of the leopard *Panthera pardus fusca*.

Taxon	Weight ¹ (kg)	Frequency (%)	Y ² (kg)	D ² (kg)	E ² (%)
Domestic dog <i>Canis lupus familiaris</i>	18.00	44.0	8.28	2.96	37.16
Domestic goat <i>Capra aegagrus hircus</i>	25.00	16.0	10.73	1.50	18.82
Domestic cattle (calf) <i>Bos taurus</i>	40.00	15.0	15.98	2.14	26.93
Domestic cat <i>Felis catus</i>	2.00	13.0	2.68	0.30	3.84
Indian grey mongoose <i>Herpestes edwardsii</i>	2.00	3.0	2.68	0.05	0.69
Rodents (Rodentia)	0.10	3.0	2.01	0.05	0.63
Nilgai <i>Boselaphus tragocamelus</i>	140.00	2.2	50.98	0.76	9.64
Hare <i>Lepus nigricollis</i>	2.10	1.5	2.71	0.02	0.35
Domestic pig <i>Sus scrofa domesticus</i>	21.00	1.5	9.33	0.09	1.20
Indian civet <i>Viverricula indica</i>	0.08	1.5	2.01	0.02	0.25
Langur <i>Semnopithecus entellus</i>	8.00	0.7	4.78	0.02	0.28
Rhesus macaque <i>Macaca mulatta</i>	7.00	0.7	4.43	0.02	0.25

¹From Karanth & Sunquist (1995), Biswas & Sankar (2002), Sankar & Johnsingh (2002) and Andheria et al. (2007).

²Y, mass of prey consumed per scat; D, relative biomass; E, relative per cent of each prey species consumed (see text for further details).



PLATE 1 Leopard *Panthera pardus fusca* preying on a domestic dog that strayed into the boundaries of Jhalana Reserve Forest. Photo: Devam Shah.

(Inskip & Zimmermann, 2009). Studies have therefore focused on so-called human–felid conflict (Inskip & Zimmermann, 2009). Dependence of felids on domestic livestock has rarely been observed, however; domestic livestock usually contribute only a small proportion of the biomass consumed by felids (Athreya et al., 2014). In urban landscapes the biomass of domestic animals is usually high and usually exceeds that of wild prey in the neighbouring forests (Schaller, 1983). So, if domestic animals lack anti-predatory behaviour, they are more susceptible to attacks (Diamond, 2002). Jhalana Reserve Forest is surrounded by urban and rural areas with c. 4 million inhabitants (World Population Review, 2020). People living in the surrounding neighbourhoods and villages practice traditional livelihood professions such as livestock farming. Goats and the calves of cattle are available as leopard prey along with domestic dogs, cats and pigs. An estimated population of 36,580 domestic dogs was documented in a 2011 survey in Jaipur (Hiby et al., 2011). This is a sizeable source of potential prey for

the leopards. Hence, it is unsurprising that leopards move between the protected area and human habitat, despite the 5 m high barrier built around Jhalana to separate it from the city of Jaipur (Fig. 1). There are no data available on the densities or numbers of the leopards' wild prey species in Jhalana Reserve Forest. There are, however, data on the vaccination and sterilization of feral domestic dogs undertaken for the past 2 decades by the Help in Suffering Foundation, Jaipur (J. Reece, pers comm., 2019): a mean of c. 7,500 rabies inoculations were conducted annually over the past 21 years, to protect residents in the case of bites from feral dogs. Previous studies have shown that the availability of a large number of domestic animals in rural and urban areas facilitates the survival of leopards near human habitats (Athreya et al., 2004; Kshetry et al., 2018). Persistence of leopard populations in human-dominated habitats beyond protected areas is dependent on a stable and abundant domestic prey base (Athreya et al., 2013).

The Mao Tau diversity estimator indicated that 90–100 scat samples sufficed to give a representative sample of the species included in the diet of the leopards (Fig. 3). Biswas & Sankar (2002) considered that a minimum of 60 scats needed to be analysed to examine the prey base of tigers.

Scat analysis substantiated our hypothesis that the predominant prey of leopards in Jhalana Reserve Forest are domestic animals, presumably from the neighbouring city and villages. Our results corroborate the results of Daniel (2009) and demonstrate that dogs are a major food resource for leopards in the Reserve (Plate 1). Scat analysis from the states of Maharashtra and Jammu and Kashmir have also reported the importance of dogs as prey for leopards (Edgaonkar & Chellam, 2002; Shah et al., 2009). In West Bengal, however, livestock (cattle and goats; 48%) predominated in the diet of leopards (Kshetry et al., 2018), whereas cattle and goats comprised 31% of the diet in Jhalana Reserve Forest. In Ayubia

National Park, Pakistan, the leopard similarly subsisted mainly on domestic animals, with goats predominating (64.9%) the frequency of occurrence (Shehzad et al., 2015).

The differences between our results and other studies are a consequence of the high number of dogs and cats in our study area. The total dog and cat populations in the area are estimated to be c. 32,500 and 7,500 individuals, respectively (J. Reece, pers. comm., 2019); these species are thus widely available. Cattle and goats are relatively less abundant (31%) because these animals are herded during the day and protected in enclosures at night. Similarly, in Sanjay Gandhi National Park, Mumbai, leopards have adapted to the depleted wild ungulate prey base by feeding on dogs found in the surrounding areas and by scavenging on buffalo carcasses (Edgaonkar & Chellam, 2002).

In spite of the higher frequency of goats in the leopard scats we analysed, the relative biomass of cattle was higher, a result of the greater weight of cattle. A similar finding was made in the study of leopard diet in Sri Lanka (Mukenhirn & Eisenberg, 1973). In our study the leopards were probably feeding on discarded carcasses of calves as the Rajasthan Forest Department does not have any records of claims for compensation for predation of cattle.

The fact that leopards prey on the most easily available species (the most numerous), has already been demonstrated (Schaller, 1967; Seidensticker, 1983; Kshetry et al. 2018). With a diet dominated by domestic dogs and cats rather than by domestic livestock, the potential economic impact of the leopards of Jhalana Reserve Forest is lower compared to areas where predation of livestock is high and there is a consequent lack of tolerance for such damage (cf. Margulies & Karanth, 2018). In addition a large proportion of the rural population surrounding Jhalana Reserve Forest are Jains, who practise the conservation of biodiversity, and especially of large felids (Athreya et al., 2018); this facilitates human–leopard coexistence (Kumbhojkar et al., 2019).

Domestic dogs are a public health problem in India and elsewhere (Reece & Chawla, 2006) and occasionally attack other small domestic animals (Srinivasan, 2013). For people, dog bites can result in infection, disfigurement, incapacity, post-traumatic stress, and even death, and bites from infected dogs account for > 90% of rabies cases (Seligsohn, 2014; Taylor et al., 2017). Only 2% of the total dog population in the study area are vaccinated (J. Reece, pers. comm., 2019; Reece & Chawla 2006). Dogs could also transfer infectious diseases to leopards. Canine distemper virus is the second most common cause of death in domestic dogs (Deem et al., 2000) and is also responsible for disease outbreaks amongst the African lion *Panthera leo* in the Serengeti, the Amur tiger *Panthera tigris altaica* in the Russian Far East and the Asiatic lion in India (Roelke-Parker et al., 1996; Seimon et al., 2013; ICMR, 2018). Leopards that prey substantially on domestic dogs, as do those of Jhalana Reserve Forest, could be considered as suppliers of a service

to the human population amongst whom they thrive, although this potentially exposes the leopards to the canine distemper virus.

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Author contributions Study design, fieldwork: SK, RY; data analyses, writing: all authors.

Conflicts of interest None.

Ethical standards This research do not involve handling of animals and otherwise abided by the *Oryx* guidelines on ethical standards. SK and RY worked under research permit 171 of the Rajasthan Forest Department.

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