Prey abundance and leopard diet in a plantation and rainforest landscape, Anamalai Hills, Western Ghats

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Leopards use a wide range of habitats from natural forests to plantations in human-dominated landscapes. Within interface areas, understanding leopard ecology and diet can help in conservation management and conflict avoidance. In a fragmented rainforest and plantation landscape in southern India, we examined diet of large carnivores (with a focus on leopards) using scat analysis with DNA-based identification of predator species, and estimated relative abundance of prey species in different land uses through transect surveys. Large carnivores predominantly consumed wild prey species (98.1%) and domestic prey species contributed <2% to overall prey biomass. For leopards, four wild prey species (Indian muntjac, Indian spotted chevrotain, sambar and Indian porcupine) contributed 95.1% of prey biomass, with the rest being minor wild prey species (no livestock in identified scats). Wild prey species occurred across the landscape but varied in relative abundance by land-use type, with forest fragments supporting higher abundance of many species relative to tea and coffee plantations. As large carnivores mainly depend on wild prey and rainforest fragments act as refuges for these mammals within the tea and coffee plantations, it is important to continue to retain or restore these forest fragments.

Keywords: Diet, leopards, prey abundance, plantation, tropical rainforest.

THE expansion of agriculture along with the loss, alteration or fragmentation of natural ecosystems has increased the interface between people and wild animals. This is particularly significant for large-bodied animals that range widely to meet their energy requirements, especially when resources are more patchily distributed in space as a result of habitat fragmentation[1,2]. Such species, exemplified by mammals such as large carnivores and ungulates, are then likely to encounter people more often, resulting in incidence of crop damage, livestock depredation or attacks on people[2–5]. This may also spark retaliatory killings of wild animals, particularly when animal husbandry or subsistence-level agriculture is the main source of livelihood[2,4,6].

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Within India, interface areas between people and wild animals occur in and around most protected areas, and conflicts often involve species that are adapted to also use human-modified areas in the landscape. The common leopard (*Panthera pardus*) is one such species implicated in human–wildlife interactions across a wide range of forest–cultivation interface landscapes in India, such as in Gir National Park in the west, Uttarakhand and Himachal Pradesh in the north, tea plantations in West Bengal and Assam in the east, to many parts of central and southern India[2,7,8]. Leopards and other carnivores may persist in human-use landscapes, including agricultural fields outside wildlife protected areas, where they may subsist on wild prey and livestock[9]. In landscapes shared with people, leopards ranging in search of prey animals may pass in close proximity to housing and settlements, leading to interactions such as leopard sightings, predation on domestic animals, and in rarer cases, attacks on people. Studying the diet of leopards and their degree of dependence on livestock is necessary to understand their ecology in such landscapes and their interactions with people. As leopards almost inevitably co-occur with people in many human-dominated landscapes[10], such studies help assess the potential for human–leopard coexistence and plan measures to prevent or mitigate the incidence of conflict.

Here, we explore aspects of leopard feeding ecology to derive insights for human–leopard coexistence in a fragmented rainforest and plantation landscape in southern India. Our study area, the Valparai plateau in the Anamalai region of the Western Ghats, has witnessed conflict incidents involving both loss of livestock and human life, that has caused rising concern among government authorities and local communities[11,12]. Our study examines the following questions: (i) What is the relative contribution of domestic and wild prey species in leopard diet in the landscape? (ii) What is the relative abundance and community composition of wild prey species in different land-use types (tea, coffee, forest fragments and continuous forests) in the landscape?

The results are examined in relation to conservation of leopard and prey species and potential for coexistence with people in a landscape that is being intensively used for cultivation of cash-crops.

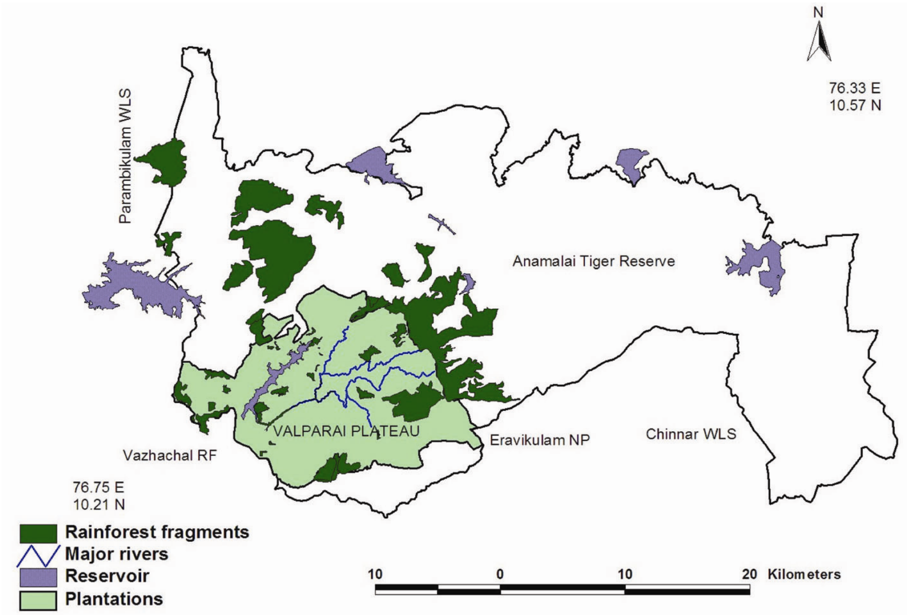

Figure 1. Map of Valparai plateau (light green) and surrounding Anamalai Tiger Reserve. Rainforest fragments are shown in dark green and water bodies in blue.

Study area

We carried out the study in the Valparai plateau (220 sq. km) and surrounding Anamalai Tiger Reserve (958 sq. km, 10°12′–10°35′N and 76°49′–77°24′E; Figure 1), which lie in the Anamalai Hills of the Western Ghats, a global biodiversity hotspot[13]. It adjoins several protected areas within Tamil Nadu and Kerala in the southern Western Ghats. The Valparai region is an undulating plateau that underwent land-use changes in the late 19th and early 20th century from mid-elevation tropical wet evergreen forest into plantations of commercial importance such as tea, coffee, cardamom and *Eucalyptus*[14]. At present, around 75% of the cultivated area on the Valparai plateau is dominated by tea plantations, with the remaining comprising other forms of land uses, including remnant forest fragments on private land[14]. The plateau, with an altitudinal range between 800 m and 1100 m above mean sea level, receives a mean annual rainfall of 3500 mm, most of which falls during the southwest monsoon between June and September. The main natural vegetation type in this region is classified as mid-elevation tropical wet evergreen forest of *Cullenia exarillata–Mesua ferrea–Palaquium ellipticum*-type[15].

Carnivores present in Valparai and the surrounding protected area include leopard, tiger *Panthera tigris*, dhole *Cuon alpinus*, and sloth bear *Melursus ursinus.* Small carnivore species that occur are brown mongoose *Herpestes fuscus*, stripe-necked mongoose *H. vitticollis*, brown palm civet *Paradoxurus jerdoni*, leopard cat *Prionailurus bengalensis*, Nilgiri marten *Martes gwatkinsi* and small Indian civet *Viverricula indica*. Some other mammal species in the study area are Asian elephant *Elephas maximus*, bonnet macaque *Macaca radiata*, black-naped hare *Lepus nigricollis*, dusky-striped squirrel *Funambulus sublineatus*, jungle striped squirrel *F. tristriatus*, gaur *Bos gaurus*, Indian giant squirrel *Ratufa indica*, Indian muntjac *Muntiacus muntjak*, Indian porcupine *Hystrix indica*, Indian spotted chevrotain *Moschiola indica*, lion-tailed macaque *Macaca silenus*, Nilgiri langur *Semnopithecus johnii*, sambar *Rusa unicolor* and wild pig *Sus scrofa*.

Methods

Mammal abundance survey

Mammals were surveyed using transects placed inside randomly chosen 2 km × 2 km grids overlaid on a map of the study region. Inside Valparai plateau, our minimum sampling effort was guided by the availability of forest fragments that could be sampled, but was increased to represent available land uses. We surveyed 42 line transects each of 2 km length. These transects were located in different land-use types: tea plantations (15 transects), coffee plantations (13) and forest fragments (8). We also sampled six transects within the adjoining Anamalai Tiger Reserve (Figure 2). The transects within the Tiger Reserve were located in mature rainforest habitat and at comparable altitude and abiotic conditions as those sampled within the plateau. One transect in a cardamom plantation was grouped with coffee plantation transects as these plantations are grown under a canopy of mixed native and alien shade tree species. Tea plantations, in

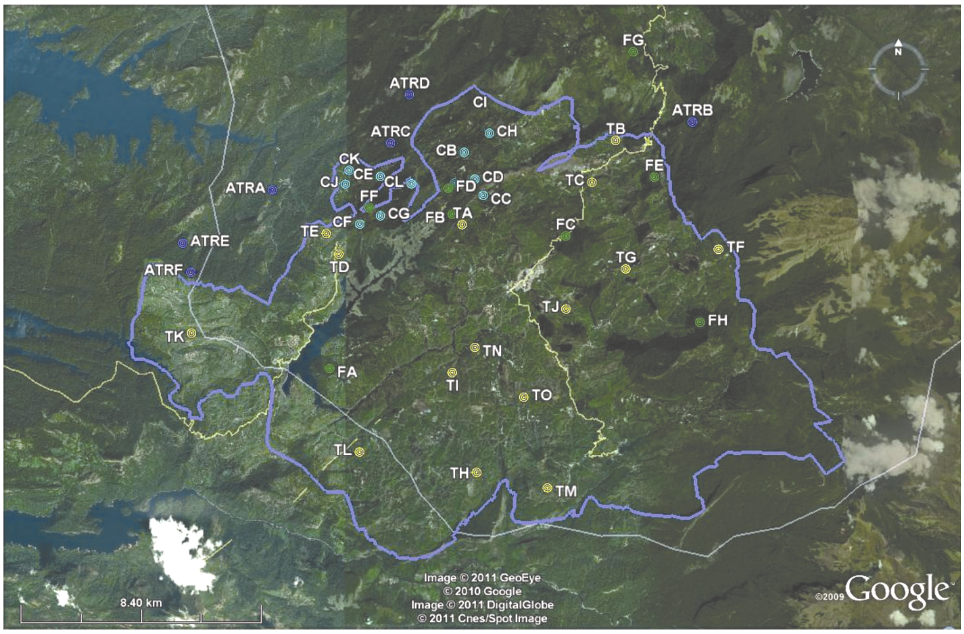

Figure 2. Transect sampling points in Valparai plateau (boundary in dark blue). Transect locations are indicated by different label prefixes (T, Tea plantation; C, Coffee plantation; F, Forest fragment; ATR, Anamalai Tiger Reserve) and differently coloured markers according to land use. Tea plantation transects are in yellow, coffee plantations in light blue, forest fragments in green and protected area in dark blue.

contrast, were open monocultures with a sparse canopy of the alien silver oak (*Grevillea robusta*) trees planted in well-separated rows.

Our transects within commercial plantations were placed on existing paths or trails, although we restricted our sampling to days when sampled trails were not being used by plantation workers to minimize disturbance in our sampling. While all direct sightings of potential prey species were recorded on transects, relative abundance data were based on counts of indirect signs of mammals such as pellets (porcupine), track marks (sambar, Indian muntjac, Indian spotted chevrotain, gaur), scats (civets and large carnivores), dung piles (Asian elephants) and feeding signs (stripe-necked mongoose) occurring within 1 m on either side of the transect line. The narrow width was chosen to minimize biases associated with detectability of signs. As it is possible that sign detection was higher in more open trails through tea plantations, intermediate in coffee, and least in forests, the relative abundance results may be taken as a conservative estimate of the effects of habitat modification from forest to plantations.

All transects were surveyed twice between November 2009 and June 2010, during the relatively drier months preceding the 2010 southwest monsoon. Transects were surveyed in the morning between 0600 and 1030 h with average sampling duration of each transect being around 1½ h. Two observers carried out the surveys, one recording direct sightings and the other indirect signs. Transects in tea, coffee and forest fragments were surveyed over the same comparable temporal period, while transects in the Tiger Reserve were sampled in the latter part of the dry season (prior to monsoon onset) due to logistical delays with permits.

Scat analysis

During transect surveys and supplementary visits to same or different locations, 147 scats belonging to large carnivores (leopard, tiger or canid) were collected. While leopards also used plantations and the vicinity of Valparai town and estate colonies[10], tigers have reportedly been sighted in plantations only in locations close to the protected area boundary. It is therefore possible that some scats collected from plantations closer to the protected area may have belonged to tigers. Although canid scats are not separated by species in this study, scat samples collected were most likely those of dholes, as they were collected farther away from human colonies in locations where domestic dogs rarely occurred. During scat collection, 40% by volume of each scat was left behind in the field as scats may have been used for marking territory. All scats collected for diet analysis were washed in water over a sieve and sun-dried. These were then analysed for predator diet using indigestible remains of prey species, particularly hairs, bones, quills and feathers. From each scat, 20 items were chosen at random following Mukherjee *et al.*[16] and hairs were identified based on external morphology, cuticular and medullary patterns, and ratio of medulla to cortex in cross-section, with the help of a microscope and comparing with photographs of reference slides.

Predator identification

A small portion from the field-collected scat was stored in ethanol (Merck, India) for DNA-based identification of predator species (leopard, tiger and canid) which was carried out at the National Centre of Biological Sciences, Bengaluru. A total of 102 scats were analysed for predator identity (remaining scats had disintegrating boluses and were unsuitable for DNA analysis). This was done to examine potential dietary preferences of leopards compared to other large carnivores. The scat samples were stored at room temperature until DNA extraction. Identification of leopard and tiger was based on a primer that distinguishes between the two species. DNA was extracted using QIAGEN stool kit (QIAGEN, Inc.). DNA extractions were carried out in a separate pre-PCR room under sterile conditions to avoid contamination. Negative controls were included to check for contamination. DNA was extracted from the outer layer of the scat, which is known to contain epithelial cells or mucous. The primer that amplified NADH4 region of the mitochondrial DNA was used during PCR. A 10 μl reaction mix containing 5 μl of QIAGEN mutliplex PCR buffer mix (QIAGEN, Inc.), 1 μl (4 mg/ml) of bovine serum albumin, 1 μl (2.5 μM) of primer (Applied Biosystems, India) and 3 μl of DNA extract was used for amplification. PCR was carried out under the following conditions: an initial denaturation (95°C for 15 min), 65 cycles of degradation (94°C for 30 sec), annealing (50°C for 30 sec) and extension (72°C for 35 sec), followed by a final extension (72°C for 10 min) in an Eppendorf thermocycler. One reaction mix without sample DNA was used as PCR negative in each reaction cycle to monitor contamination. The PCR products were visualized under UV light after gel electrophoresis in 2% agarose gel. Samples that show positive amplification for leopard produce bands at 130 base pair (bp) and 200 bp under UV light on agarose gel, whereas tiger shows 88 and 110 bp bands. Scats that did not yield a positive result for leopard or tiger were tested to see if they belonged to the canid family using canid-specific primer. However, we did not distinguish between canid species (dholes and domestic dogs).

Data analysis

As the number of detections was too few for distance sampling density estimation, we estimated encounter rates of species per transect from direct sightings. A detection was defined as an individual or cluster of individuals of a species seen during a transect survey. We also used indirect sign density – as number of signs per 0.4 ha, the area on any sampled belt transect – to assess use of different habitats. Statistical significance of differences among the four major land uses in abundance indices was assessed using one-way ANOVA followed by Tukey's HSD test.

Frequency of occurrence (percentage of scats containing remains of a given prey species) was estimated from the number of times a prey item (defined as remains of any prey species) was found in predator scats. As frequency of occurrence tends to overestimate the importance of smaller prey species due to their larger surface area to volume ratio when compared to larger prey species, we applied a correction using Ackerman's formula[17,18]. This formula relates the mass (Y) of consumed prey represented by one field-collectible scat to the average body mass (X) of the prey species. We applied the correction formula developed for cougars ($Y = 1.980 + 0.035X$) for scats of leopards and large carnivores (as we expect most scats to belong to leopards), and the formula developed for wolves ($Y = 0.035 + 0.020X$) was used for dholes. After applying the correction, we also obtained relative biomass and number of each consumed prey species with average body mass >2 kg. Statistical analyses were performed using the R statistical and programming environment[19] (version 2.10.1).

Results

DNA analysis

Of 102 large carnivore scats analysed, DNA-based identification of predator species was achieved in 57 scats indicating these were either leopard or canid (dhole and domestic dogs). The low success rate in identifying scats using DNA-based analyses was mainly because several scats were extremely old and had disintegrated boluses. Scat samples that had at least some portion of bolus intact yielded better results.

Eleven scats could not be identified in the field, but of the remaining 46 scats that had field as well as DNA-based identification, 36 (78.3%) showed matching identification (i.e. field identification of predator species corroborated by DNA analysis). Of the 10 scats incorrectly identified in the field, 7 were canid scats inaccurately identified as leopard, while 3 were leopard scats inaccurately attributed to canids. Although based on a small sample size, this suggests a higher probability of misidentifying a canid scat as belonging to the leopard.

Diet analysis

In 147 scats analysed for large carnivore diet, 206 different prey items were found, with 31% of scats containing remains of two prey species and 5% containing remains of three prey species. Muntjac and Indian spotted chevrotain had the highest frequency of occurrence followed by unidentified rodents (Table 1). Muntjac, sambar and Indian spotted chevrotain were the three most important prey species in terms of relative numbers (82.5%) and relative biomass (83.95%) consumed by large carnivores

Table 1. Diet of carnivores in Valparai landscape in terms of frequency of occurrence (percentage of scats containing remains of a given prey species), relative number of individuals and relative biomass of a given prey species consumed. *N* is the number of scats in which remains of a given prey species were found. Ackerman's *Y* is a correction factor used in the analyses

Carnivore and prey species	*N*	Frequency of occurrence (%)	Average body mass (kg)	Ackerman's *Y*	Scats produced/ kill	Relative numbers consumed (%)	Relative biomass consumed (%)
All large carnivores (*N* = 147 scats)							
Indian muntjac	67	45.58	21	2.72	7.73	21.71	36.71
Sambar	26	17.69	125	6.36	19.67	3.31	33.35
Indian spotted chevrotain	33	22.45	3	2.09	1.44	57.48	13.89
Nilgiri langur	6	4.08	12.5	2.42	5.17	2.91	2.93
Wild pig	1	0.68	37	3.28	11.3	0.22	0.66
Indian porcupine	10	6.8	14.5	2.49	5.83	4.3	5.02
Mongoose*	2	1.36	2.55	2.07	1.23	4.07	0.84
Bonnet macaque	2	1.36	6.5	2.21	2.94	1.7	0.89
Black-naped hare	1	0.68	2.2	2.06	1.07	2.34	0.42
Cattle	2	1.36	125	6.36	19.67	0.25	2.57
Goat	3	2.04	25	2.86	8.76	0.86	1.73
Dog	2	1.36	15	2.51	5.99	0.84	1.01
Unidentified rodent	31	21.09	–	–	–	–	–
Unidentified bird	4	2.72	–	–	–	–	–
Unidentified	16	10.88	–	–	–	–	–
Leopard (*N* = 34 scats)							
Indian muntjac	14	41.18	21	2.72	7.73	18.95	40.27
Indian spotted chevrotain	8	23.53	3	2.09	1.44	58.24	17.68
Sambar	2	5.88	125	6.36	19.67	1.06	13.45
Indian porcupine	9	26.47	14.5	2.49	5.83	16.15	23.7
Nilgiri langur	1	2.94	12.5	2.42	5.17	2.02	2.56
Bonnet macaque	1	2.94	6.5	2.21	2.94	3.55	2.34
Unidentified rodent	7	20.59	–	–	–	–	–
Unidentified bird	3	8.82	–	–	–	–	–
Unidentified mammal	2	5.88	–	–	–	–	–
Canids (*N* = 23 scats)							
Indian muntjac	13	56.52	21	0.46	45.65	53.58	49.17
Indian spotted chevrotain	5	21.74	3	0.09	33.33	30.12	3.95
Sambar	2	8.7	125	2.54	49.21	7.72	42.15
Nilgiri langur	2	8.7	12.5	0.29	43.10	8.67	4.74
Unidentified rodent	6	26.09	–	–	–	–	–
Unidentified bird	1	4.34	–	–	–	–	–
Unidentified mammal	2	8.7	–	–	–	–	–

**Herpestes* sp.

(Table 1). The percentage of domestic species in large carnivore diet was low both in terms of relative numbers (1.95%) as well as relative biomass (5.30%) consumed. The domestic prey included cattle, domestic goat and domestic dog (Table 1).

Analysis of scats confirmed to be of leopards or canids through DNA analysis (34 leopard scats and 23 canid scats), showed differences in their diet (Table 1). Indian muntjac was the important prey species for leopards (40.27%) and canids (49.17%). In addition to Indian muntjac, leopards consumed Indian porcupine, Indian spotted chevrotain and sambar (54.83% in terms of relative biomass). For canids, sambar alone contributed 42.74% in terms of relative biomass consumed, while porcupines were not recorded in their diet. The preferred prey size for leopards was just above 30 kg, with most prey biomass being obtained from prey species within a weight range 3 to 125 kg.

Mammal surveys

Comparison of encounter rates of mammals from direct sightings revealed patterns of variation across land-use types (Table 2). Encounter rates of Indian giant squirrel and Nilgiri langur, the latter a leopard prey species recorded also in scats (Table 1), were highest inside the protected area. Sambar encounter rate was highest in protected area and forest fragments. All direct sightings of Indian spotted chevrotain were within forest fragments, while Indian muntjac encounter rate was highest inside coffee plantations.

Based on indices of indirect signs, relative abundances were found to vary significantly with land use for several species (Table 3). For Indian spotted chevrotain, an important prey species for large carnivores in Valparai region, use of protected forest was found to be higher than tea and coffee plantations. Similarly, sambar,

Table 2. Detections and encounter rates (detections/2 km) of various mammal species in the four major land-use types surveyed in the Anamalai hills

	Tea plantation		Coffee plantation		Forest fragment		Protected area	
Species	*Nd* (*Ni*)	Er (SE)	*Nd* (*Ni*)	Er (SE)	*Nd* (*Ni*)	Er (SE)	*Nd* (*Ni*)	Er (SE)
Asian elephant	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0.08 (0.08)
Bonnet macaque	0	0 (0)	8	0.29 (0.11)	1	0.06 (0.06)	1	0.08 (0.08)
Brown mongoose	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0.06 (0.06)	0 (0)	0 (0)
Dhole	0 (0)	0 (0)	1 (2)	0.04 (0.04)	0 (0)	0 (0)	0 (0)	0 (0)
Dusky-striped squirrel	0 (0)	0 (0)	1 (1)	0 (0)	2 (2)	0.13 (0.13)	0 (0)	0 (0)
Gaur	1 (2)	0.03 (0.03)	6 (28)	0.25 (0.15)	0 (0)	0.31 (0.19)	1 (19)	0.08 (0.08)
Indian giant squirrel	0 (0)	0 (0)	51 (55)	1.79 (0.31)	57 (59)	3.5 (0.6)	55 (56)	4.58 (0.61)
Indian spotted chevrotain	0 (0)	0 (0)	0 (0)	0 (0)	3 (3)	0.13 (0.09)	0 (0)	0 (0)
Jungle-striped squirrel	17 (19)	0.57 (0.13)	12 (13)	0.21 (0.10)	1 (1)	0.06 (0.06)	2 (3)	0.17 (0.11)
Lion-tailed macaque	0 (0)	0 (0)	0 (0)	0 (0)	6	0.38 (0.13)	1	0.08 (0.08)
Indian muntjac	5 (7)	0.17 (0.08)	20 (24)	0.63 (0.14)	6 (7)	0.31 (0.12)	1 (1)	0.08 (0.08)
Nilgiri langur	0 (0)	0 (0)	53	1.96 (0.14)	17	1.06 (0.19)	32	2.67 (0.28)
Sambar	0 (0)	0 (0)	2 (2)	0.04 (0.04)	4 (5)	0.25 (0.15)	4 (4)	0.25 (0.13)
Stripe-necked mongoose	4 (4)	0.13 (0.08)	1 (1)	0.04 (0.04)	1 (1)	0.06 (0.06)	0 (0)	0 (0)
Wild pig	2 (2)	0.07 (0.05)	2 (2)	0.08 (0.02)	0 (0)	0 (0)	0 (0)	0 (0)

Nd, Number of detections; *Ni*, Number of individuals; Er, Encounter rate and SE, Standard error of encounter rate.

Table 3. Abundance indices of mammal species derived from indirect evidence inside different land uses in the Valparai plateau. Tabled values are mean number of signs (per 0.4 ha) with standard errors in parantheses. Values superscripted with different alphabets were significantly different from each other by Tukey's HSD test ($P < 0.05$)

Species	Tea plantation	Coffee plantation	Forest fragment	Protected forest	$F_{3,37}$	P
Indian muntjac	2.00^{a} (0.46)	5.20^{b} (1.51)	$3.19^{a,b}$ (0.85)	$3.83^{a,b}$ (0.62)	3.422	0.030
Indian spotted chevrotain	0.37^{a} (0.14)	0.46^{a} (0.29)	$0.94^{a,b}$ (0.18)	1.75^{b} (0.52)	3.746	0.020
Sambar	0.50^{a} (0.26)	4.63^{b} (1.06)	6.56^{b} (1.45)	6.00^{b} (1.01)	11.471	<0.001
Indian porcupine	1.53^{a} (0.35)	1.00^{b} (0.37)	0.06^{b} (0.07)	0.25^{b} (0.08)	5.714	0.002
Wild pig	0.17 (0.12)	0.13 (0.12)	0	0	0.911	0.445
Black-naped hare	2.17^{a} (0.49)	0^{b}	0^{b}	0^{b}	13.488	<0.001
Gaur	0.17 (0.09)	0.42 (0.37)	0.69 (0.46)	1.25 (0.41)	1.847	0.156
Mongoose*	1.67^{a} (0.49)	0.42^{b} (0.04)	0.06^{b} (0.07)	0.17^{b} (0.08)	6.895	0.001
Civet^{+}	0.10^{a} (0.09)	$0.88^{a,b}$ (0.49)	2.06^{b} (0.99)	$1.00^{a,b}$ (0.16)	3.284	0.030
Asian elephant	0.77^{a} (0.35)	1.25^{a} (0.55)	$4.12^{a,b}$ (1.77)	6.42^{b} (1.34)	6.020	0.002
Sloth bear	0.03 (0.03)	0.33 (0.35)	0	0	1.257	0.303

*Herpestes sp.; $^{+}$*Viverricula indica* and *Paradoxurus jerdoni*.

another important prey species, used tea plantations less compared to coffee plantations, forest fragments and protected forests. For Indian muntjac, use of coffee plantations was higher than tea plantation, whereas Indian porcupine, an important prey for leopards, used tea plantations more than other land-use types. Black-naped hare was found using only tea plantations and not detected in coffee plantations, forest fragments and protected forests. Comparisons of the number of large carnivore scats per hectare (mean ± SE) revealed no statistically significant difference between land-use types: forest fragment, 0.50 (± 0.28); coffee, 0.92 (± 0.26); tea, 0.83 (± 0.17) and protected forest, 0; (ANOVA $F_{3,78} = 2.571$, $P = 0.06$).

Discussion

Nature conservation outside the boundaries of traditional protected areas, particularly in agricultural and human-use landscapes, is the focus of much contemporary research in wildlife and human ecology[20]. In this context, the study of large carnivore diet and prey availability in the Valparai plateau helps understand the prospects for human and leopard coexistence in a fragmented rainforest–plantation landscape.

Large carnivore diet

Previous studies on conflict with large carnivores emphasize the role of high livestock densities in the environment leading to relatively higher consumption of domestic prey species[5,21]. Livestock contributed 10–12% in terms of relative biomass consumed by tigers in Pench National Park and Ranthambore NP[22,23]. In Spiti, where livestock densities are between 14 animals and up to 30 animals per sq. km, 40–58% of snow leopard diet consisted of livestock species[21]. Leopards, like other large carnivores, are known to prey on domestic animals when they are available in the environment[24–27]. A recent study found that 87% of leopard diet consisted of domestic animals with domestic dogs contributing 39% to consumed prey biomass, a result of high densities of domestic animals[27]. Our study, in contrast, reveals a minor role of livestock and dominant role of wild prey species in large carnivore diet in the Valparai region, which is comparable to leopard diet within some protected areas[28]. In 2010, livestock (cattle and domestic goat) density in the Valparai landscape was less than 9 animals sq. km (Government Veterinary Hospital, Valparai, 18th livestock census conducted in 2010). Wild prey comprised 98.1% of the total prey biomass consumed by large predators. Using results on 57 scats that were identified using DNA-based methods, we found leopard and canid diet in Valparai to comprise mainly of wild prey species. Although requiring confirmation from larger samples, there appeared to be some differences among prey species being consumed by the two large carnivores with leopards mostly consuming Indian muntjac, Indian spotted chevrotain and Indian porcupine, whereas the canids mainly consuming Indian munjtac followed by sambar. Against assumption, the canids were also found to prey on Nilgiri langur, an arboreal primate, possibly by hunting or scavenging from leopard kills. Consumption of domestic prey by large carnivores is minor, in which scavenging may also have a potential role.

Leopard diet has been studied in different ecosystems in various continents and leopards are known to prey on animals of varying size[29]. Leopards are morphologically adapted to kill large prey with an optimum or preferred prey size of 23 kg (ref. 28). Choice of prey is influenced by prey availability, abundance and vulnerability[30,31]. In Africa, leopards prey mainly on medium-sized (20–80 kg) ungulates in savannah habitats[32,33], while consuming smaller prey (<5 kg) more often in rainforests, possibly due to differing abundance and profitability[34]. Studies in Nagarhole[35], India, show leopards to select medium-sized prey (31–175 kg). Leopards also take substantial small-sized prey in the 5–30 kg range[34–36]. The preferred prey size consumed by leopards in our study area (30 kg) is comparable to that reported from elsewhere in the world.

Prey community in plantation–forest fragment landscape

Sambar is known to prefer forests and hilly areas with high tree density[37,38]. Similarly, we find that relative abundance of sambar was higher in protected area, forest fragment and coffee plantations, habitats with higher tree densities compared to tea plantations. Teng *et al.*[39] reported that Indian muntjac preferred shrub grasslands and dry savanna for foraging in Hainan Island, China, while also using location with taller trees with larger canopies, taller shrubs and denser shrub canopy cover for bed sites. Similarly, we found that Indian muntjac had higher abundance of indirect signs in coffee plantations which provide a mix of tall shrubs and trees, and open patches of grasses. Indian spotted chevrotain reportedly prefers forest habitats, often close to water sources[40], preferring areas with higher understorey complexity and more refuges in rainforests[41]. The higher abundance of indirect signs of Indian spotted chevrotain inside the protected area in the present study may be due to the higher availability of suitable habitat for this species inside protected areas, compared to tea and coffee plantations. As tea, coffee and forest fragments were sampled across a comparable period, differences in abundances of indirect signs are likely to be due to habitat differences. Abundance of indirect sign in protected area transects (sampled later in the season) was similar to forest fragments and distinct from plantations, suggesting a similar effect that, however, needs to be confirmed.

Forest fragments play an important role in this tea plantation-dominated landscape as abundances of indirect signs for Indian muntjac, sambar and Indian spotted chevrotain, important prey species, were comparable to those found inside the protected area. A previous study[42] also reported that the forest fragments and protected area in our study site maintained similar mammal diversity, which may be due to the use of surrounding matrix habitat by the mammal species and low hunting pressures in this region. By supporting wild prey species populations, these rainforest fragments may decrease the dependence of large carnivores on domestic prey and possibly reduce negative encounters and interactions between leopards and humans in the landscape.

Conclusion

Our study reveals that in the commercial plantation-dominated region of Valparai plateau that is surrounded by protected areas, large carnivores predominantly feed on available wild prey. This contrasts with studies in other human-dominated areas where domestic animals contribute substantially to large carnivore diet[24–27]. The Valparai plantations, containing many embedded forest fragments, provides additional habitat for wide-ranging, large-bodied mammals and a corridor for their movements in the landscape adjoining the Anamalai Tiger Reserve. As large carnivores are predominantly dependent on available wild prey species and rainforest fragments act as refugia for these mammals within the tea and coffee plantations, the Forest Department and private landowners should both continue to protect and assist in the recovery or restoration of these forest fragments.

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