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Notes on the diet and habitat selection of the Sri Lankan Leopard *Panthera pardus kotiya* (Mammalia: Felidae) in the central highlands of Sri Lanka

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Abstract: The endangered Sri Lankan Leopard *Panthera pardus kotiya* occupies the island's highly fragmented central hills where data on its feeding ecology and habitat use is largely absent. This study's objective was to investigate diet and resource selection of leopards here with a focus on the extent of potential interactions with humans in this heavily populated, largely unprotected landscape. Fecal sample analysis was undertaken to investigate diet and sign index counts and selectivity index analysis to determine habitat and landscape features important to fine scale leopard utilization. Results indicated that leopards in the central hills hunt a wide range of prey (at least 10 genera), including larger species where available (e.g., Sambar *Rusa unicolor*) and smaller, more specialized prey (e.g., Porcupine *Hystrix indica*) where necessary. No domestic species were recorded in scat analysis (N=35) despite the availability of dogs *Canis familiaris*, suggesting such predation may be atypical in Sri Lanka. Leopards use a range of landscapes within the region including established and regenerating forests, plantation lands (e.g., pine, eucalyptus, tea), and areas in close proximity to human settlement. At a fine scale, areas of dense undergrowth including tall grasslands were preferred to more open forest, as well as to Pine *Pinus caribaea* monocultures. Avoidance of humans may be influencing these patterns. This study has important implications as researchers and managers necessarily expand beyond focusing on protected areas toward integrated, landscape-level conservation strategies.

Keywords: Anthropogenic disturbance, diet, habitat use, *Panthera pardus kotiya*, unprotected areas.

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INTRODUCTION

The Sri Lankan Leopard *Panthera pardus kotiya* is an Endangered (Kittle & Watson 2008) endemic sub-species and the island's apex predator (Miththapala et al. 1996; Uphyrkina et al. 2001). It has evolved without intra-guild competition at least since Sri Lanka split off from the Indian subcontinent ~5,000–10,000 ybp (Deraniyagala 1992; Yokoyama et al. 2000), a unique scenario which may mean that this top carnivore is of keystone importance to the system (Paine 1966).

Data on the island-wide distribution and relative abundance of leopards is becoming increasingly refined (Kittle & Watson 2008; Kittle et al. 2012) and it is now acknowledged that these versatile predators occupy unprotected as well as protected areas (Watson & Kittle 2004). Between these extremes are semi-protected areas, small forest reserves and sanctuaries demarcated on paper but not actively patrolled and routinely utilized by people. Wildlife populations in unprotected and semi-protected areas are particularly susceptible to heightened levels of human-wildlife conflict.

Sri Lanka is a small (65,610km²) mostly rural (74–78 %) nation with substantial spatial overlap between humans and wildlife (Dept of Census and Statistics 2012). In the central hills, high human population density (301–450 /km², Dept of Census and Statistics 2012), heterogeneous land cover and a lack of protected areas makes understanding leopard diet and resource selection vital. Minimal diet analysis has been conducted here (Ranawana et al. 1998) and leopard diet outside protected areas remains unknown. Furthermore, how leopards use this heavily fragmented habitat mosaic has not been investigated. This data deficiency has been recognized as a barrier to designing conservation and management action plans to ensure the leopard's continued survival in the wild (Samarakoon 1999). A minimum of 66 leopards were killed island-wide from 2002–2012, mostly caught in snares set for other species (Kittle & Watson, unpublished data). True mortality figures are unknown but if leopards are preying on domestic species outside protected areas, human-leopard conflict is likely to increase.

Our research objective was to investigate leopard diet and habitat use at two semi- to un-protected study sites in the central hills where leopards have been previously documented (Kittle et al. 2012).

Study Areas

The central highlands occupy a ~2400km² section of Sri Lanka's south-central interior (Fig. 1), encompassing a vast expanse of often-rugged terrain, which varies greatly in elevation, topography and climate.

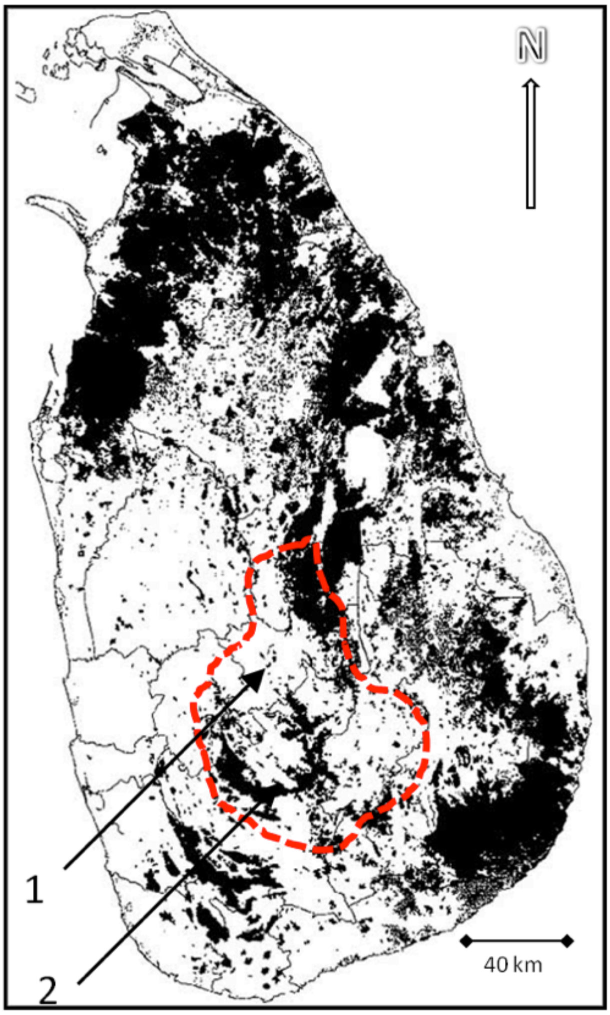

Figure 1. Map of Sri Lanka showing remaining forest cover (black). Approximate extent of central highlands is outlined in dashed red with hill country study sites indicated by arrows. 1 = Dunumadalawa forest reserve, 2 = Agrapatana study area.

The Dunumadalawa Forest Reserve is a secondary growth mid-country wet zone forest situated at the northern end of Sri Lanka's Central massif (Figs. 1, 2a). This was an active estate until the early 1900s when it was released from plantation use (tea, coffee and cocoa) and allowed to naturally re-generate, with some active reforestation of native plant species since 2000. It now protects the watershed of two reservoirs providing water for Kandy, a town of ~100 000 within the limits of which the reserve is located. Dunumadalawa is characterized by high canopy mixed forest which includes *Albizia sp.* and jak *Artocarpus heterophyllus* remaining from the estate days. Large-leaf Mahogany *Sweitinia macrophylla*, Ceylon Almond *Canarium zeylanicum* and various

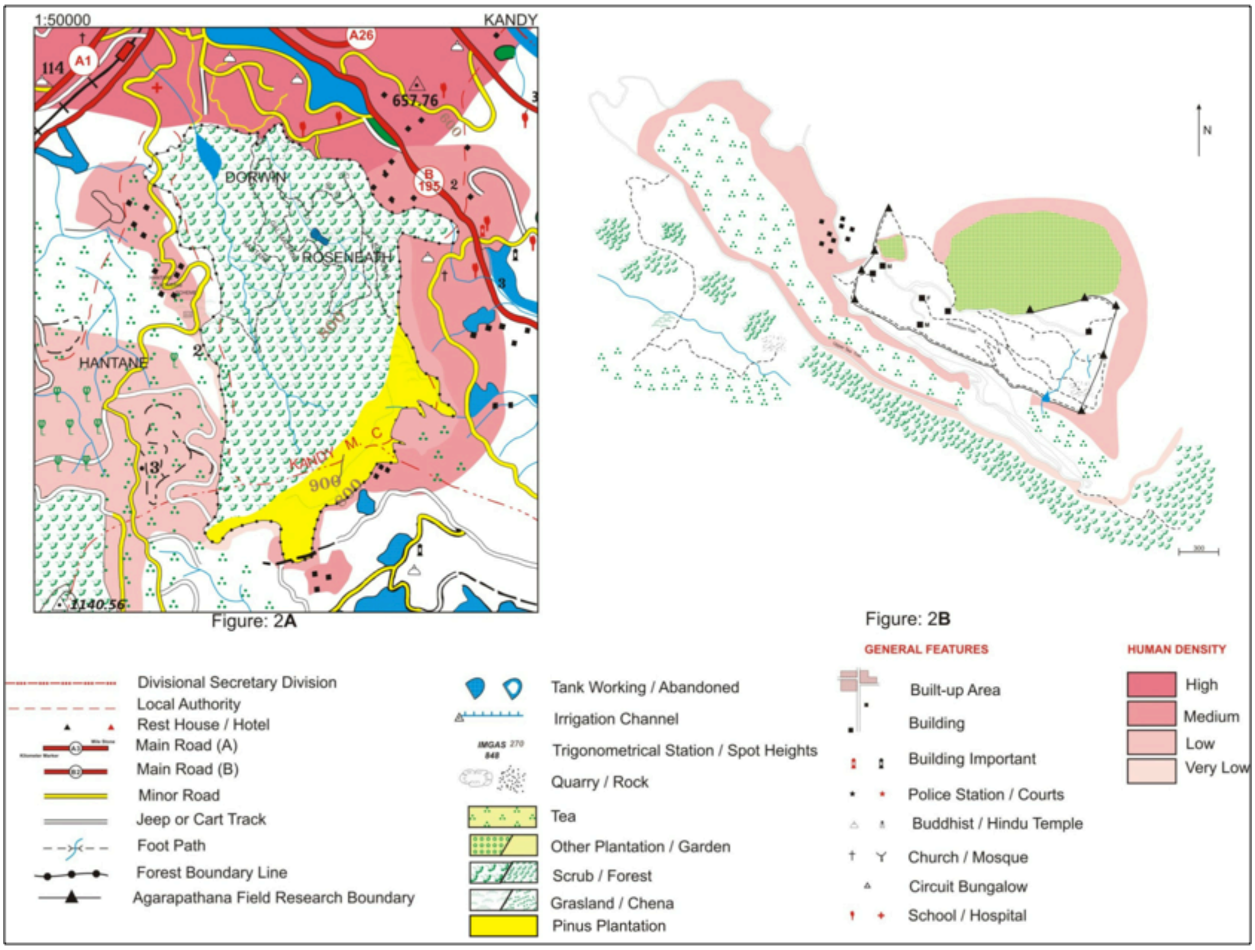

Figure 2 (a-b). Map of (a) Dunumadalawa forest reserve and (b) Agrapatana study area in context of surrounding landscape. Areas of high, medium and low human population pressure are indicated. Trails/roads used for prey index and habitat selection inside Dunumadalawa are shown but details of those interior trails/roads are not represented.

Ficus species are also conspicuous. The understory is dominated by unattended tea, coffee and cocoa plants grown wild in sections and the ironwood tree *Mesua ferrea* in others. Patches of grassland, composed mostly of *Imperata cylindrica* are scattered throughout the reserve. This grass can grow up to 3m tall and form dense monocultures. The abundant jak appears to provide an important continuous food source for potential leopard prey species including Toque Macaques *Macaca sinica aurifrons*, Barking Deer *Muntiakus muntjak*, Wild Boar *Sus scrofa* and Porcupines *Hystrix indica*. The reserve includes a small (<40ha) Caribbean Pine *Pinus caribaea* plantation at its highest point in the southeast. Anthropogenic disturbance is acute in the surrounding area which is characterized by a mosaic of land-use types including sub-montane forest, tea estates, pine and eucalyptus plantations, open scrub, home gardens and villages. The reserve falls under the purview of the Kandy Municipal Council and is extensively utilized by a number of surrounding villages for firewood and fruit collection.

The Agrapatana Arboreatum is in the heart of the tea industry's vast plantation lands near the southern extent of the central hills (Figs. 1, 2b; Image 1). A regenerating forest, this was part of a much larger tea estate until the 1990s. It adjoins the Agra-Bopats Forest Reserve, a thickly vegetated 9,800ha sub-montane, montane and cloud forest bordered by tea estates on three sides and connected to Horton Plains National Park (3160ha) to the southeast. Sambar Deer *Rusa unicolor*, Wild Boar *Sus Scrofa*, Toque Macaque *Macaca sinica,* Purple-faced Langur *Trachypithecus vetulus* and Porcupine all reside within this forest reserve. The two study areas differ in a number of important aspects (Table 1).

METHODS

Diet: Leopard scat was collected opportunistically and during regular sign index surveys (Rabinowitz 1997) conducted between 2003 and 2009. These were air dried and stored in re-sealable plastic bags. To differentiate leopard from Fishing Cat *Prionailurus viverrinus* scat only samples with bolus width >2.5cm were retained (Henschel & Ray 2003). Samples were washed and sieved to eliminate unwanted particles, and bones, quills, nails and hooves were manually separated and identified. Remaining hairs were mixed and oven dried at 60^{0}C for 24hr. Dried samples were placed in a shallow dish, a point grid overlaid and 50 hairs randomly sampled (Ciucci et al. 2004). Microscopic analysis followed Amerasinghe et al. (1990).

Habitat selection: We investigated fine scale leopard habitat selection at Dunumadallawa by comparing habitat variables at used and available locations (Table 2). Used locations were defined by the presence of leopard spoor (scat, pugmarks, scrapes) on reserve trails detected during regular sign index surveys between 2003 and 2009. Available locations were determined from a systematic random sample conducted in November 2009, with points taken every 100m along the same reserve trails. Four trails (1300–2000 m) that traverse the forest reserve were utilized for the use/availability analysis.

We used Jacob's selectivity index to determine habitat selection where data was categorical (Fig. 3):

$$D = (r - p) / (r + p - 2rp)$$

where r is the proportion of used locations of a given habitat/landscape class and p is the proportional availability of that habitat/landscape class (Jacobs 1974). Values of D range from -1 indicating maximum avoidance to 1 indicating maximum selection, with 0 value indicating use in proportion to availability (Jacobs

Table 1. Comparison of study areas in central hills, Sri Lanka.

	Dunumadallawa Forest	Agrapatana Arboreatum
Coordinates (Lat/Long)	7^{0}16'N & 80^{0}38'E	6^{0}50'N & 80^{0}40'E
Size (ha)	480	50
Elevation (masl)	550–980	1500–2000
Average temperature (°C)	20–25	<20
Annual precipitation (mm)	1500–3000	1500–3000
Forest classification	mid-elevation wet zone	sub-montane
Released from plantation status	early 1900s	1990s
Current protection status	Semi (Kandy Municipal Council)	None (Private)
Surrounding land use	tea estate/urban/ village/home garden/scrub	tea estate/ Eucalyptus/forest reserve
Human disturbance level	High	Low
Number of scats	13	22

Table 2. Description of variables investigated for Leopard habitat selectivity analysis.

Variable name	Data type	Description
Habitat type	Categorical	5 categories - human settlement (areas beside reserve office, bungalow or border Village), grassland (tall, 30cm–2m, *Imperata cylindrica*), pine plantation (*Pinus caribaea*), forest (typical mid-country wet zone type), and mixed (areas of more than one of the former classes, e.g., forest/grassland boundary)
Trail type	Categorical	3 categories - dirt roads (open, flat and accessible (but rarely used) to all vehicle types); jeep tracks (partially overgrown, uneven, only 4x4 vehicles); walking trails (narrow footpaths)
Understory density	Categorical, ordinal	Determined qualitatively and categorized as Dense (80-100% coverage), Moderate (50–80 %), Light (<50%) and None (no understory).
Degree of human disturbance	Categorical, ordinal	Determined qualitatively and categorized as High (frequently used by reserve staff and/or villagers), Moderate (sometimes used) and Light (almost never used). No areas were unused.
Slope	Continuous	Visually estimated for immediate location. Range from 0 (flat) to 60°.
Elevation	Continuous	Determined at each location from previously calibrated handheld GPS (Garmin e-trex summit).
Tree density	Continuous	The distance to 5 nearest trees measured and averaged.
Tree size	Continuous	The DBH of 5 nearest trees measured and averaged.
Canopy cover	Continuous, grouped	Determined using simple densiometer. Grouped into 5 categories - 0, 1-25, 26-50, 51-75, 76-100.
Distance to permanent water	Continuous, grouped	Determined from each location using previously created GPS map. Grouped into 3 categories - 0-100m, 100-500m, >500m
Distance to human settlement	Continuous, grouped	Determined from each location using previously created GPS map. Grouped into 3 categories - 0-100m, 100-500m, >500m

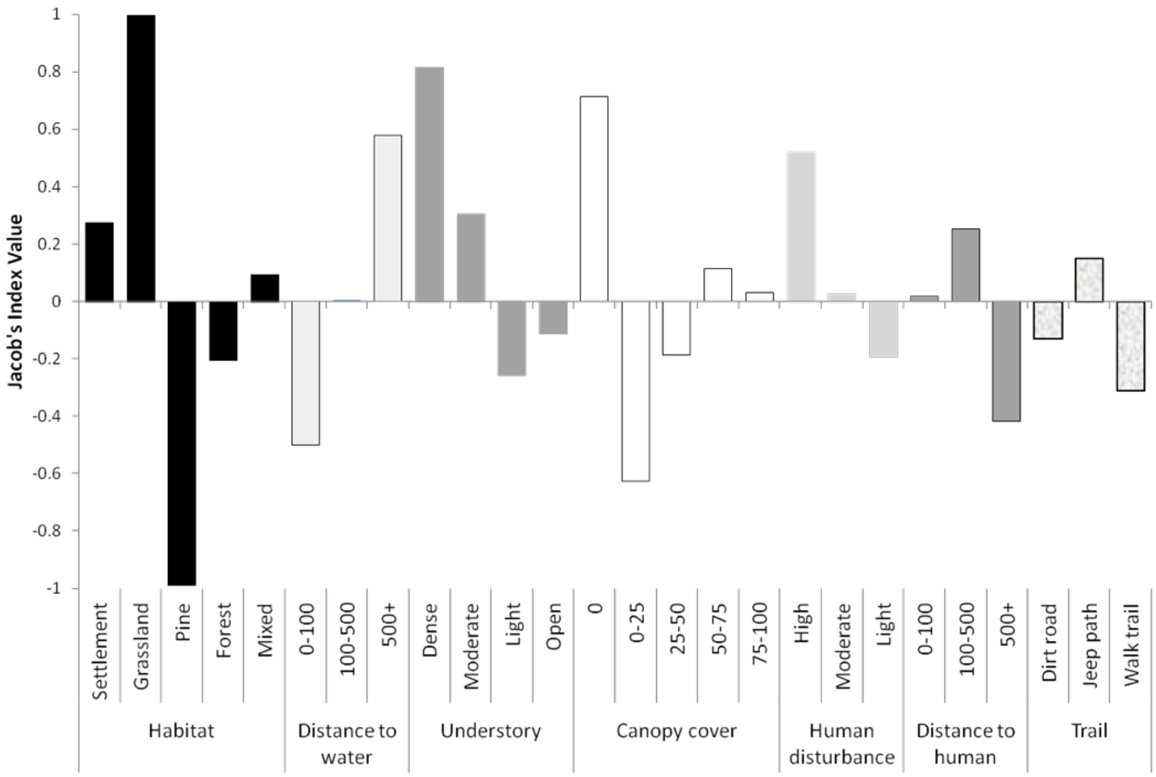

Figure 3a. Bar plots representing Jacob's selectivity index values for leopards in Dunumadalawa forest reserve in the central hills, Sri Lanka. Habitat and landscape measures are based on comparison of locations used by leopards as detected by sign or observation (N=39) and a systematic random sample of available points (N=68). Values range from -1 which indicates maximum avoidance to 1 which indicates maximum selection. No selection is indicated by a value of 0.

1974). This selectivity index minimizes bias from small sample sizes (e.g., rare food items or habitat proportions <10%; Hayward & Kerley 2005). Continuous data was not normally distributed but had equal variance (Levene's test P>0.05) so Mann-Whitney Test was used for analysis (Zar 1999).

RESULTS

Diet: Of the 42 scat samples collected, 35 produced results: 13 from Hantane and 22 from Agrapatana (Table 3). Porcupine was the most frequently represented species found in scat at Dunumadalawa, followed by Barking Deer, whereas Sambar was the most common species in leopard scat in Agrapatana (Table 3). Domestic species were not represented in samples from either location (Table 3).

Habitat selection: Thirty-nine used locations were compared to 68 available locations within Dunumadalawa. Leopards utilized the entire 5km² study area but showed selection for grasslands (Jacob's Index = 0.9963) and avoidance of the *Pinus* plantation (Jacob's Index = -0.9867, Fig. 2a). Areas with dense understory (Jacob's Index = 0.8158) and no canopy cover (Jacob's Index = 0.7143) were selected, whereas areas with sparse canopy cover (0–25 %) were avoided (Jacob's

Image 1. Young adult female leopard camera trapped in the Agrapatana arboretum. This photo was taken on a walking trail within a regenerating tea estate.

Table 3. Scat analysis results from Dunumadalawa and Agrapatana study sites. Results are % of total scats containing each prey species. *Herpestes* could not be discerned to species level.

Prey species	Dunumadalawa (N = 13)	Agrapatana (N = 22)
Cervus unicolor Sambar	0	59.1
Funambulus palmarum Palm Squirrel	7.7	0
Herpestes sp. Mongoose	0	4.5
Hystrix indica Porcupine	61.5	4.5
Lepus nigricollis Black-naped Hare	7.7	13.6
Macaca sinica aurifrons Toque Macaque	7.7	4.5
Moschiola meminna Mouse Deer	7.7	4.5
Muntiacus muntjak Barking Deer	30.8	0
Sus scrofa Wild Boar	7.7	0
Trachypithecus vetulus Purple-faced Langur	0	13.6

Index = -0.6277). Areas far from permanent water (Jacob's Index = 0.5790) were preferred to areas close to permanent water (Jacob's Index = -0.5014, Fig. 2b).

Neither slope (Z_w=0.537, p= 0.5907) or elevation (Z_w=1.405, p= 0.1611) were significant factors influencing fine scale habitat use, however leopards did prefer areas with lower tree density (Z_w=-2.443, p=.0147) and larger trees (Z_w =-1.919, p= 0.0554).

DISCUSSION

Diet: Sample size is too small to definitively characterize leopard diet in these areas (Mukherjee et al. 1994; Trites & Joy 2005), but given the complete dearth of dietary data from un-protected areas in the central highlands, even this preliminary information is valuable. The dietary breadth observed is wide, including 10 genera ranging in size from 112g (Palm Squirrel; Phillips 1980) to 130kg (Sambar hind; Phillips 1984). This catholic diet is consistent with leopard feeding ecology throughout its range reflecting opportunistic predation and the leopard's adaptive ability to broaden its diet beyond the preferred range of medium-sized ungulates, 23–56 kg (Stander et al. 1997; Hayward et al. 2006).

The Indian Porcupine was represented most frequently in scat (61.5%) in the small, isolated forest reserve despite it being absent from Hayward's (2006) exhaustive analysis of leopard prey preferences (111 prey species). Porcupines are potentially dangerous prey, but the prey suite available to leopards in Dunumadalawa is relatively limited (Sanjeewani 2010), so the likelihood of risking injury to secure adequate resources is increased (Brown & Kotler 2007). Alternately, leopards here may have adapted to hunting porcupines with minimum risk or a single leopard may be responsible for the majority of the scat samples collected here, although three individuals have been observed in the reserve (Kittle et al. 2012). Prey specialization by individuals within a population is not uncommon across taxa (Araújo et al. 2011) including among apex terrestrial carnivores (Ross et al. 1997; Elbroch & Wittmer 2013). Establishing whether observations are the reflection of a population-level adaptation to the suite of resources available or a case of individual specialization requires additional sampling. The implications of either can be profound (Bolnick et al. 2003).

In Agrapatana Sambar was most frequently represented in scat samples (59.1%), consistent with probable prey availability, given that the study area is contiguous with Horton Plains National Park (HPNP) where sambar density is estimated to be 66.5/km² (Rajapakse 2003). Previous scat analysis from HPNP found sambar in 75.8% of samples (N=22) (Ranawana et al. 1998). That fewer samples contained Sambar here than in HPNP, and more contained Black-naped Hare and Purple-faced Langurs (Table 3; 13.6% compared to 6.8% and 3.4% in HPNP, Ranawana et al. 1998) hints at variation in prey availability between the core of a protected area such as HPNP and an adjoining yet peripheral area such as Agrapatana. More samples are needed to validate this hypothesis.

Scat samples included no domestic species at either site despite dogs being common at both. This suggests low human-leopard conflict in these regions despite close proximity to human populations, but given the low sample size, interpretations must be made with caution. In Dunumadalawa dogs have been predated in the past, however, these incidents may be uncommon. Questionnaire surveys here show fishing cats responsible for some predation events blamed on leopards (Kittle & Watson, unpublished data). That predation on domestic animals appears atypical is relevant from a management perspective since predators viewed as a menace tend to be increasingly persecuted (Cavalcanti et al. 2010).

Habitat selection: Leopards in the Dunumadalawa Forest Reserve may be selecting fine scale habitats offering improved hunting efficiency. Leopards and lions select areas of high prey vulnerability not high prey density at the fine scale (Hopcraft et al. 2005; Balme et al. 2007; Davidson et al. 2012). As ambush predators, leopards require at least 20cm of cover for concealment (Bothma & LeRiche 1984), so tall grasses (>30cm) and thick vegetation are sufficient. However, in South Africa hunting leopards select intermediate cover, presumably because dense cover obscures their perception of prey (Balme et al. 2007). Alternatively then, where anthropogenic disturbance is high such as in isolated forests within densely populated urban areas, dense undergrowth and long grass might provide leopards concealment from people, a potential risk in this environment. Avoidance of permanent water may also indicate avoidance of people as the reserve's two large permanent water sources are regularly monitored by Water Department personnel. However, leopards did not avoid other high human-use areas (e.g., border villages). The reserve is replete with seasonal streams and pools which allow leopards to effectively exploit areas far from permanent sources.

In summary, this research provides valuable insight into the diet and habitat selection of an endangered apex predator, in an area of its range with little existing information and where it is afforded limited protection. Avoidance of humans in these heavily disturbed landscapes may be an important consideration for leopards when making space-use decisions, as it is in parts of their African range where bush meat is an important commodity and humans and leopards engage in a form of exploitative competition (Henschel et al. 2011). Camera trap images revealed leopards and humans engaged in temporal niche partitioning in both sites, with humans detected in the day and leopards at night at the same location (Kittle et al. 2012). Temporal niche partitioning is a mechanism used to explain carnivore co-existence in Africa (Hayward & Slotow 2009) and might similarly be important in South Asia where top carnivores necessarily share space with humans (Athreya et al. 2013).

As human populations continue to increase and protected areas become more and more isolated (DeFries et al. 2005), the effective conservation of biodiversity becomes increasingly reliant on processes outside protected areas (Hansen & DeFries 2007). These areas tend towards habitat mosaics with forested areas heavily fragmented and surrounded by a patchwork of alternate land use types. Large, wide-ranging species such as top carnivores nevertheless often persist (Lyra-Jorge et al. 2008) and can be adept at exploiting semi and unprotected areas even where human density is high (Athreya at al. 2013). We are increasingly recognizing the value of these sub-optimal, shared habitats in terms of connectivity and as supplements to remaining forest fragments (Caryl et al. 2012), as well as appreciating the important role played by predators in maintaining biodiversity within such fragments (Terborgh et al. 2001). As such, the need to increase our understanding of how apex predators utilize these landscape mosaics is of paramount importance.

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