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Diet and habitat use of the endangered Persian leopard (*Panthera pardus saxicolor*) in northeastern Iran*

Mohammad TAGHDISI[1], Alireza MOHAMMADI[2], Elham NOURANI[2], Shirko SHOKRI[2], Ali REZAEI[2], Mohammad KABOLI[2,*]
[1]Iran Department of Environment, North Khorasan Province, Esfarayen, Iran
[2]Department of Environment, Faculty of Natural Resources, University of Tehran, Karaj, Iran

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Abstract: A 2-year study of the food habits of the Persian leopard was conducted in Sarigol National Park in northeastern Iran, North Khorasan Province. Based on an analysis of 52 leopard scats, the principal prey was wild sheep (*Ovis orientalis*: prey frequency of occurrence = 61.5%; prey relative frequency of occurrence = 47.05%; relative biomass = 53.96%), followed by wild pig (*Sus scrofa*: frequency = 23.07%; relative frequency = 17.64%; relative biomass = 25.38%) and wild goat (*Capra aegagrus*: frequency = 13.46%; relative frequency = 10.29%; relative biomass = 6.64%). The high proportion of medium- and large-size prey in leopard diet indicates favorable feeding conditions in the study area. Habitat use of the Persian leopard was determined using presence data, including direct observation points and where scats, tracks, prey remains, and territory marks were recorded. The landscape preference ratio and Jacob selectivity index were used for habitat preference analysis. Our results suggest that the Persian leopard prefers mountainous habitats followed by small undulating hills and rough terrain, where prey species are most abundant. Effective conservation of the leopard in Iran calls for further studies on the status of major prey populations, competition with sympatric carnivores, and methods to mitigate human–leopard conflicts.

Key words: *Panthera pardus saxicolor*, diet, habitat use, scat analysis, Sarigol National Park, Iran

1. Introduction

The leopard, a territorial felid with a wide distribution in Africa and Asia, selects habitats based on prey biomass and prey density (Karanth and Sunquist, 1995). It is highly tolerant of variations in elevation, temperature, and precipitation (Ramesh et al., 2009). The leopard is a successful predator because of its large size and adaptability to a variety of habitats, enabling it to prey on an array of prey species, ranging in size from small rodents to cervids and bovids weighing hundreds of kilograms (Ramesh et al., 2009). The Persian leopard (*Panthera pardus saxicolor*), categorized as Endangered (EN) in the IUCN Red List of Threatened Species (http://www.redlist.org), is the largest felid in Iran. The larger Persian lion (*P. leo persica*) and Caspian tiger (*P. tigris virgata*) (Ziaie, 2009), which occurred in Iran, are extinct. Known as the leopard stronghold of the Middle East (http://www.redlist.org), Iran supports an estimated 550 to 580 leopards distributed over half of the Iranian plateau (Kiabi et al., 2002).

Landscape parameters and prey abundance are the 2 main resource selection criteria of carnivores (Balme et al., 2007). Predators hunt in habitats with high prey abundance (Hopcraft et al., 2005) and prey availability (Hebblewhite et al., 2005). Scat analysis is a widely used technique for studying carnivore behavioral ecology (Breuer, 2005; Ott et al., 2007; Bianchi et al., 2011) and provides information on food habits, food competition, niche breadth, and niche overlap among sympatric large carnivores. It also provides data on distribution patterns of prey species (Khorozyan and Malkhasian, 2003).

Sarigol National Park (SNP), with sufficient security cover and abundant prey populations, provides excellent habitats for the leopard in northeastern Iran (Farhadinia et al., 2009). However, ecological data on the diet, seasonal variations in diet, and habitat selection of leopards in SNP are lacking. The present study was conducted to determine the diet and habitat use of leopards in SNP using scat analysis and analysis of presence data.

2. Materials and methods

2.1. Study area

This study (carried out in 2009 and 2010) was conducted in the 7037-ha SNP (36°55′N–37°08′N, 57°36′E–57°47′E), located 24 km east of the city of Esfarayen in North Khorasan Province, Iran. Elevations range from 1400 to 2940 m a.s.l. With a semiarid temperate climate, this area

* Correspondence: mkaboli@ut.ac.ir

has an average annual precipitation and average annual temperature of 273 mm and 14 °C, respectively.

Major ungulate species in SNP include wild sheep (*Ovis orientalis*), wild pig (*Sus scrofa*), and wild goat (*Capra aegagrus*). Apart from the leopard, 7 other carnivore species have been recorded: wolf (*Canis lupus*), golden jackal (*C. ureus*), red fox (*Vulpes vulpes*), wild cat (*Felis silvestris*), Pallas's cat (*Otocolobus manul*), stone marten (*Martes foina*), and striped hyena (*Hyaena hyaena*). The area supports a number of small mammals, notably Persian jird (*Meriones persicus*), lesser Egyptian jerboa (*Jaculus jaculus*), pika (*Ochotona rufescens*), European hare (*Lepus europaeus*), southern white-breasted hedgehog (*Erinaceus concolor*), southern mole-vole (*Ellobius fuscocapillus*), and porcupine (*Hystrix indica*), as well as ground-dwelling birds such as chukar (*Alectoris chukar*), see-see partridge (*Ammoperdix griseogularis*), black-bellied sandgrouse (*Pterocles orientalis*), and small buttonquail (*Turnix sylvatica*). Domesticated sheep, goats, donkeys, dogs, and horses are other mammalian species in the area.

In SNP, there is a gradual increase in elevation and slope from south to north, marking 4 broad habitat categories including plains, small undulating hills and rough terrain, mountainous areas, and high rocky, precipitous mountains (Figure 1). The plains (slope = 10%; elevation = 1400–1500 m), constituting 5% of the area, are the least common habitats in SNP. Vegetation here consists of perennial shrubs like *Artemisia aucheri*, *Astragalus* spp., and *Salsola rigida*. Various shrub species associated with deserts, such as *Haloxylon* spp. and tamarisk (*Tamarix* spp.), also occur. These habitats lack permanent water sources and have a vegetation density of less than 25%.

Small undulating hills and rough terrain (slope = 10–30%; elevation = 1500–1700 m) constitute 39% of the area and consist of undulating hills of clay, marl, and silt. Highly affected by frequent badland erosion, this habitat provides suitable escape terrain for wild sheep. Vegetation consists of perennial *Artemisia aucheri* and *Astragalus* spp. shrubs. Mountain almond (*Amygdalus scoparia*) and mountain pistachio (*Pistacia atlantica*) grow in higher rocky terrain, while stands of tamarisk are common along stream banks in valleys.

Mountainous areas (slope = 20–50%; elevation = 1700–2600 m), consisting of hills and mountains with open valleys, wide streams, and slopes varying from gentle to steep, make up 46% of the area. Annual grasses are abundant on slopes and perennial *Artemisia aucheri*, *A. sieberi*, and *Astragalus* spp.; mountain almond; barberry (*Berberis vulgaris*); and juniper (*Juniperus excelsa*) grow on highland slopes. Stands of willow (*Salix alba*) and nettle tree (*Celtis australis*) grow along stream banks. Abundant permanent and seasonal water sources and structural diversity in these habitats support the highest diversity of fauna and flora and the highest vegetation density in the park.

High rocky, precipitous mountains (slope = greater than 50%; elevation = 2600–2940 m) make up about 10% of the study area. High mountains with steep slopes and scree support a variety of cushion plants such as *Acantholimon* sp., *Acanthophyllum* sp., *Onobrichis* sp., and *Astragalus* spp. *Artemisia sieberi* and barberry also grow in the foothills and junipers are found on slopes. These habitats contain little vegetation and scarce water sources.

2.2. Sampling method and scat analysis

Scat analysis is a common technique in determining diets of terrestrial carnivores (Rajaratnam et al., 2007; Ramesh et al., 2009; Bianchi et al., 2011; Klare et al., 2011). We collected 52 Persian leopard scats between 2009 and 2010. Scats were identified and distinguished from those of other carnivores such as wolves based on shape, size, and adjacent sign of leopard presence such as tracks and scrapes. Scats were washed over a sieve with a mesh width of 0.5 mm and remains such as hair, bones, and hooves were removed. The hair content was compared with an identification key of hairs from different body parts of sympatric mammals, including the 8 carnivore species found in the area,

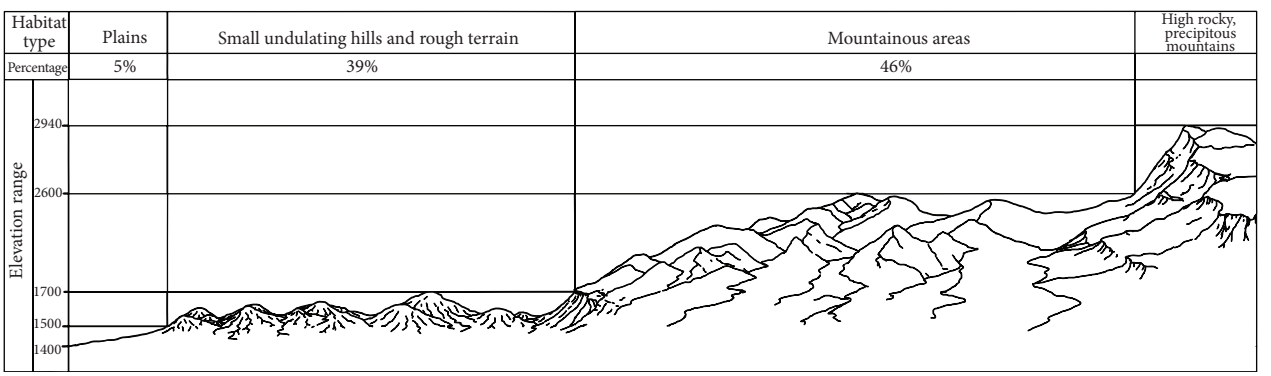

Figure 1. Elevation profile of SNP, marking 4 distinct habitat types: plains; small undulating hills and rough terrain; mountainous areas; and high rocky, precipitous mountains.

ungulates (wild sheep, wild goat, wild pig), hedgehog, hare, pika, some rodent species (porcupine, jird, southern mole-vole), and domestic animals (sheep, goat, horse, donkey, and dog). Comparisons were made based on macroscopic characteristics such as length, coloration, and thickness (Henschel et al., 2005) and microscopic characteristics such as medulla patterns (Konency, 1989; Rajaratnam et al., 2007).

Frequency of occurrence (percent of scats in which a particular prey item is found) and relative frequency of occurrence (number of occurrences of a species / total number of occurrences of all species) were determined. The greater surface-to-volume ratio in small-size prey species (birds, rodents, hares, and pika) results in an overestimation of their occurrence in diet studies (Floyd et al., 1978; Ackerman et al., 1984). To correct for this overestimation (Henschel et al., 2005; Andheria et al., 2007; Ramesh et al., 2009; Henschel et al., 2011), we used a correction coefficient developed for the cougar (*Puma puma*), an ecologically similar felid (Ackerman et al., 1984), based on the following formula:

$Y = 1.98 + 0.035X.$

The term Y is a correction coefficient and X is the live weight of prey species. Multiplying Y by the frequency of occurrence data corrects the overestimation of small-size prey species. Relative biomass consumed and relative number of prey species were estimated using the following functions:

$D = (A \times y) / (\Sigma(A \times y)),$

$E = (D + x) / (\Sigma(D + x)).$

The term D represents relative biomass, A is the frequency of occurrence, y is the correction coefficient, E is the relative number of prey species consumed, and x is the average weight of consumed prey. Since leopards often consume young prey, average weights were calculated including lambs and subadults. Correction coefficients were not applied to prey that weighed less than 2 kg (Ackerman et al., 1984).

2.3. Habitat preference

To determine habitat preference, the study area was categorized based on topography into 4 distinct habitat types including high rocky, precipitous mountains; mountainous areas; small undulating hills and rough terrain; and plains (Figure 1). We recorded presence points using a handheld GPS. These points included direct observations of leopards and locations where scats, dens, prey carcasses, and territory marks were found. Habitat preference was then determined using the formula of Mills and Biggs (1993):

$PR = U / A,$

where U is the Uh/Ut ratio and A is calculated as the ratio of Ah/At. Uh is the number of leopard presence signs counted in a specific habitat and Ut is the total signs counted in all habitats. Ah indicates habitat area and At is the total area of combined habitats.

The Jacob selectivity index was also used to determine leopard habitat preference (Jacobs, 1974):

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

Here, r represents the ratio of number of leopard presence signs in a habitat type to the total number of signs recorded in all habitat types, and p is the ratio of area of each habitat type where signs of leopard presence were recorded to the total area of the leopard habitats in the region. This index ranges from –1, habitat avoidance, to 0, medium preference, and +1, preferred habitat.

3. Results

3.1. Diet

In a total of 52 scats collected, 68 prey items were identified with an average of 1.30 prey items per scat. Six wild mammals were the major prey items identified in leopard scats: wild sheep (61.5% frequency of occurrence; 47.1% relative frequency of occurrence), wild pig (23.07% frequency; 17.64% relative frequency), wild goat (13.46% frequency; 10.29% relative frequency), red fox, porcupine, and pika, with a total relative frequency of 91.3% and a total frequency of 91.2% (Table 1). Two scats contained bird feathers that were not identified. Livestock remains, with a frequency and relative frequency of 3.84% and 2.94%, respectively, were also found in scats. Relative to biomass consumed, wild sheep was the most consumed prey species, making up 53.96% of the total biomass. Wild pig and wild goat, with a relative biomass of 25.38% and 6.64%, respectively, were the second and third most consumed prey species (Table 2).

3.2. Habitat preference

Results of habitat preference analyses showed that mountainous areas followed by small undulating hills and rough terrain (Figure 2) were preferred by leopards (Table 3 and Table 4). The difference between preference indices calculated for these 2 habitats is small. In addition, the distribution pattern of leopard presence signs (scats, direct observations, tracks, and prey carcasses) in the study area shows an overlap with distribution of wild mammal populations in the area: 52.4%, 46.8%, 23.3%, 11%, and 2.1% with wild sheep, wild pig, pika, porcupine, and wild goat, respectively (Figure 3).

4. Discussion

4.1. Prey consumption

Scat analysis in SNP showed that ungulates, including wild sheep, wild goat, and wild pig, with weights of 34–45 kg, were the most important prey species for leopards, accounting for 85.98% of their consumed biomass. Similar dietary studies also showed that leopards take medium-sized prey of 10–40 kg (Hart et al., 1996; Henschel et al.,

Table 1. Number of prey species and frequency and relative frequency of prey species in leopard scats, northeastern Iran.

Prey item	Number of scats (N =52)	Frequency of occurrence (%)	Relative frequency of occurrence
Ovis orientalis	32	61.5	47.05
Sus scrofa	12	23.07	17.64
Capra aegagrus	7	13.46	10.29
Vulpes vulpes	7	13.46	10.29
Hystrix indica	4	7.69	5.88
Livestock	2	3.84	2.94
Birds	2	3.84	2.94
Ochotona rufescens	1	1.92	1.47
Plants	1	1.92	1.47

Table 2. X (live weight), A (corrected frequency of occurrence), Y (correction coefficient), D (relative biomass consumed), and E (relative quantity of prey consumed) for each prey item in the Persian leopard diet in northeastern Iran.

Prey item	X (kg)	A (%)	Y (kg/scat)	D (%)	E (%)
Ovis orientalis	34	48.07	3.17	53.96	40.10
Sus scrofa	45	20.19	3.55	25.38	14.31
Capra aegagrus	36	8.65	2.17	6.64	4.68
Hystrix indica	11	6.73	2.36	5.62	12.96
Vulpes vulpes	5	6.73	2.15	5.12	25.98
Livestock	35	2.88	3.2	3.26	9.31

2005; Hayward et al., 2006). The highest habitat overlap calculated for the leopard was with wild sheep (52.4%) and wild pig (46.8%), which, in concordance with the findings of Kumaraguru et al. (2011), showed that habitat selection of the leopard is shaped by the dominant prey species.

Figure 2. Preferred habitat of the Persian leopard (mountainous areas and small undulating hills and rough terrain) in SNP.

Breuer (2005) showed that leopards, like other large carnivores, tend to feed on highly available prey. In SNP, wild sheep, with the highest density among leopard prey species (1100 wild sheep; annual survey of Department of Environment, 2012), accounted for the highest frequency of occurrence and biomass in leopard diet. Similar studies in the Central Alborz Protected Area in the Alborz Mountains in Iran (unpublished data) and studies in Armenia (Khorozyan and Malkhasian, 2003) showed that wild goat, the dominant prey species in both areas, accounted for a major portion of leopard diet. On the other hand, in Golestan National Park, northern Iran, wild pig was the most important prey for the leopard (unpublished data). Other studies (Karanth and Sunquist, 1995; Ramesh et al., 2009; Kumaraguru et al., 2011; Arivazhagan et al., 2012) found that wild pigs comprised a small portion of leopard diet, especially in forested habitats. Wild pigs, weighing 45 kg, are considered dangerous to leopards, being outside their preferred weight range (10–40 kg). However, our findings show that wild pigs were the second most important prey for leopards in SNP. Direct observations by park rangers and carcasses found in the

Table 3. Area of habitat types relative to total area (Ah/At) and number of signs of leopard presence in each habitat type relative to total signs found in the area (Uh/Ut). Habitat preference index is presented as PR.

Habitat type	Ah (ha)	A = Ah/At (At = 7037)	Uh (n)	U = Uh/Ut (Ut = 122)	PR = U/A
Mountainous areas	3220	0.457	67	0.536	1.172
Small undulating hills and rough terrain	2745	0.390	55	0.442	1.133
High rocky, precipitous mountains	736	0.104	2	0.016	0.152
Plains	336	0.047	1	0.008	0.446

Table 4. Jacob selectivity index (D) for each habitat type (R = number of signs in one habitat type / total number of signs; P = area of one habitat type / total area) in study area in northeastern Iran.

Habitat type	Area (ha)	Number of signs	R	P	D
Mountainous areas	3220	67	0.536	0.457	0.144
Small undulating hills and rough terrain	2745	55	0.442	0.390	0.106
High rocky, precipitous mountains	736	2	0.016	0.104	–0.75
Plains	336	1	0.008	0.047	–0.71

area indicate that leopards refrain from attacking mature wild pigs.

Small prey, including birds, rodents, and pikas, accounted for only about 10% of prey relative frequency in leopard scats. Although, as mentioned earlier, leopards are adapted to prey on medium-sized prey with a weight range of 10–40 kg, this adaptation depends highly on the abundance of small prey in critical periods (Hayward et al., 2006). High frequency of small prey in leopard diet suggests a decrease in medium- and large-bodied prey species in an area, possibly due to human hunting pressure (Henschel et al., 2005). Since medium- to large-size prey species constitute the major portion of leopard diet, we believe that habitat conditions, and consequently feeding conditions, are favorable for the leopard in SNP. In 2011, however, with the outbreak of an unknown disease, 300 wild sheep perished in the park. Park managers collected and burned the carcasses before burying them under a layer of lime to prevent further infections. It is unclear whether the mentioned disease had a negative impact on the leopard population because of the sudden 20% decrease in the population of their major prey. A strong reduction in the population of the major prey is believed to increase the pressure posed by predators on alternative prey species (Sinclair et al., 2006), leading in turn to reduced viability of prey populations. It is unknown whether the unexpected decrease in wild sheep numbers in SNP placed the populations of other prey, especially wild goat and wild pig, under additional predation pressure by the leopard.

Porcupine, the largest rodent in Iran, which due to its sharp quills is often avoided as prey, was also preyed upon by leopards in SNP, accounting for 5.62% of biomass consumed. Although leopards normally avoid species with antipredator strategies (Hayward et al., 2006), porcupines are believed to be complementary prey for the leopard in SNP.

Investigations on competition between leopards and sympatric carnivores such as red fox, caracal (*Caracal caracal*), cheetah (*Acinonyx jubatus*), and jackal (Hayward et al., 2006) indicate that leopard encounters with these carnivores are usually lethal. Although the reason for this behavior is not well understood (Palomares and Caro, 1999), body size difference between predators is believed to be a major driver of such interspecific mortalities among carnivores (Donadio and Buskirk, 2006). Consequently, smaller carnivores avoid such encounters by temporal and spatial niche segregation (Fedriani et al., 1999). Since foxes are active day and night and are relatively abundant in the area, fox hair found in 7 leopard scats indicates that foxes have high interference encounters with the leopard.

Livestock predation by large carnivores has been reported in many dietary studies (Breuer, 2005). Human–carnivore conflicts take place within and outside protected areas worldwide. The remains of domestic livestock found in protected areas where livestock grazing is prohibited (e.g., national parks) is attributed to wildlife depredation. When the area of protected land is not large enough to contain the entire home range of a carnivore, livestock depredation outside protected-area boundaries commonly occurs. Additionally, since most large-bodied carnivores are specialized in killing ungulates, their encounters with domestic livestock (e.g., in the case of illegal grazing of

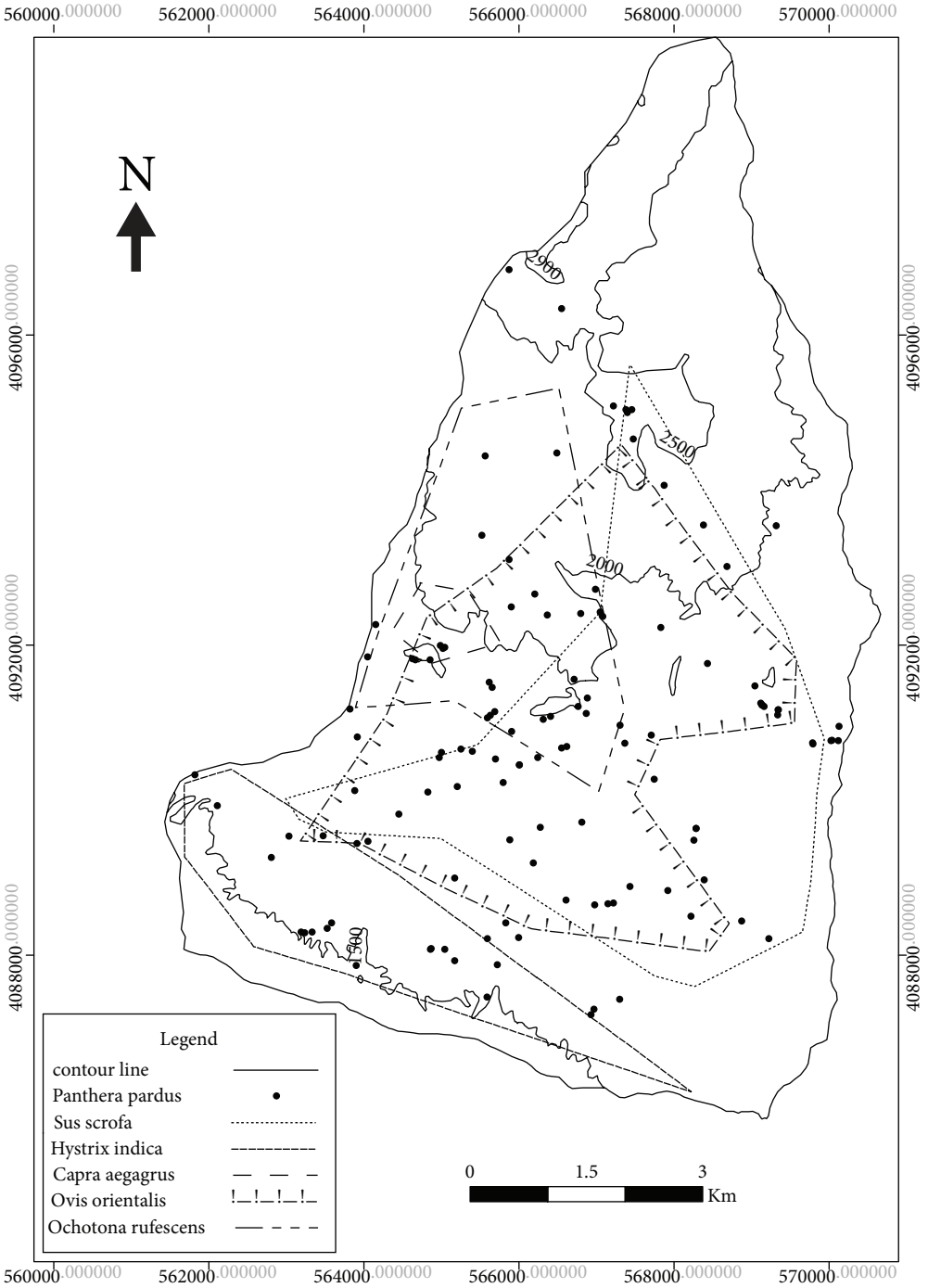

Figure 3. Leopard distribution map (based on direct observation, scat, track, and prey carcass locations) and habitat overlap of the leopard with wild pig (*Sus scrofa*), porcupine (*Hystrix indica*), wild goat (*Capra aegagrus*), wild sheep (*Ovis orientalis*), and pika (*Ochotona rufescens*) in SNP.

livestock in a protected area) are in most cases lethal (Ott et al., 2007). Of the 52 scats analyzed in this study, only 2 (relative frequency = 2.94%; biomass consumed = 3.26%) contained domestic livestock hair (from sheep and goat). Since livestock grazing is prohibited in SNP, livestock remains in leopard scat indicate that leopards roam outside park boundaries and prey on domestic animals. Considering the relatively small area of the park (7037 ha), the chance of an increase in such human–leopard conflicts is high. In the last 2 years, 3 incidents of leopard attack

on sheep herds at park boundaries have been reported, resulting in the death of 1 goat and 2 sheep. Such events lead to negative attitudes among local people toward carnivore conservation and result in the initiation of predator control of leopards, perhaps including poisoning. Park managers attempt to prevent such actions through compensation programs, facilitating conservation of the leopard population in the park.

Plant material was observed in one leopard scat collected in SNP. Plant material recorded in many carnivore scats (Breuer, 2005; Rajaratnam et al., 2007) might be the result of accidental consumption of plants along with the main prey (Rajaratnam et al., 2007).

4.2. Habitat use

Various studies confirmed that carnivores prefer habitats with high prey availability (Hebblewhite et al., 2005; Balme et al., 2007; Rajaratnam et al., 2007); others showed that carnivore habitat selection is mainly based on prey abundance (Pike et al., 1999; Palomares et al., 2001; Spong, 2002). Landscape preference ratio and Jacob selectivity indices calculated in this study suggest that leopards in SNP mainly occur in mountainous areas and in small undulating hills and rough terrain. This preference indicates an overlap with the main habitat of the major prey, wild sheep. As pointed out in other studies (Palomares et al., 2001, Pike et al., 1999), leopards occupy habitats where their major prey is abundant, which explains the high frequency of occurrence of such species in leopard scats. Mountainous areas, with a slope range of 20%–50% and diverse topography, provide adequate escape terrain for the wild sheep (Goljani et al., 2012). With its diverse and dense vegetation and sufficient water in dry seasons, such habitat also provides suitable spring and summer habitat for wild sheep (Goljani et al., 2010). Small undulating hills and rough terrain are among the preferred habitats of wild sheep (Zimmerman et al., 2006). With its extensive gullies and slopes of more than 10%, this habitat type provides suitable escape terrain for this species (Wockner et al., 2003; Goljani et al., 2012).

Although habitat overlap of pika and leopards is high in mountainous areas, the low frequency of occurrence of this species in leopard scats suggests that in a suitable habitat, leopards avoid prey smaller than 10 kg (Henschel et al., 2005; Hayward et al., 2006).

The small population of wild goat in SNP (population of 30–40; annual survey of Department of Environment, 2012) occurs in steep, rocky highlands (slope = 70% and greater), a habitat unsuitable for wild sheep (Wockner et al., 2003; Goljani et al., 2012). In the Central Alborz Protected Area located in the Alborz Mountains, where high, rocky mountains with steep slopes and cliffs are the dominant habitat type, wild goats are abundant while wild sheep are restricted to rough terrain and undulating hills. Consequently, leopards in the Central Alborz Protected Area prey upon the most available prey, the wild goat (unpublished data).

Plains in SNP are unsuitable leopard habitats. Considering their hunting strategy that involves stalking and pouncing on prey, leopards require a densely vegetated or topographically diverse habitat such as rough terrain for ambush, and thus avoid open habitats devoid of cover (Hayward et al., 2006).

The insufficient data on the ecology and biology of the Persian leopard in Iran hampers conservation action planning, putting this species at higher risk. Further studies on the status of major prey populations; competition with sympatric carnivores such as the wolf, wild cat, and Pallas's cat; and modeling of the trends and severity of human–leopard conflicts at the park boundaries and in other protected areas in Iran are strongly needed for planning strategies to ensure viable leopard populations and to mitigate leopard–human conflicts.

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