Chapter 18
Using Geographical Mapping and Occupancy Modeling to Study the Distribution of the Critically Endangered Leopard (*Panthera pardus*) Population in Armenia

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18.1 Introduction

Space limitations arising from human activities affect demographic structure and performance of mammalian populations and thus reduce their viability. This is especially true for wide-ranging wild cats (family Felidae) which generally lead solitary lives and require large tracts of good-quality habitats for survival (Sunquist and Sunquist 2001). As human activities leave more and more mosaics of modified lands behind, felid populations become fragmented and further impaired by the small and often unviable size of patches necessitating more complicated dispersal of individuals between patches (Reed 2004).

Prey abundance is the key factor determining the structure of female home ranges, whereas availability of females is most important for male home ranges (Stander et al. 1997). Thus, prey abundance determines felid requirements in space. However, space itself is also an important factor since solitary life and generally

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exclusive home ranges of the same sex individuals in most felids force their populations to occupy large tracts of good habitats above some threshold to maintain viability. For example, leopard (*Panthera pardus*) population needs to number at least 31 individuals and the area at least 412 km^2 to remain viable (Smallwood 1999). That is why small and densely populated countries experience problems in maintaining viable leopard populations, even though prey densities can be high in some hotspots (Khorozyan et al. 2008).

Geographic range size is the principal factor of viability of carnivores, even though some exceptions, e.g. African wild dog (*Lycaon pictus*), do not always guarantee that wide range means conservation security for a population (Cardillo et al. 2004). The decline and extirpation of top carnivores from fragmented ecosystems may generate trophic cascades that alter the structure of ecological communities, so the persistence of these keystone species can indicate the levels of ecosystem health (Crooks 2002). These aspects are particularly relevant to big cats subsisting almost exclusively on wild ungulates which are vulnerable to human pressures, whereas the smaller felid species may even benefit from landscape fragmentation by feeding on rodents and other small prey thriving in human-dominated landscapes (Tigas et al. 2002).

Survival of fragmented felid populations relies heavily on the ability of sub-adults to successfully disperse, establish their own home ranges and then mate with non-relatives. Dispersal is an energetically costly process which forces sub-adult individuals to move long distances through the lower-quality habitats or hostile man-dominated inter-patch landscapes to reach the destination areas (Stander et al. 1997). Mortality of dispersing sub-adults accounts for a significant portion of overall population mortality (Stander et al. 1997; Haines et al. 2006). Hence, the maintenance and preservation of habitat integrity through the network of natural movement corridors used by cats has been among the most viable solutions to avert their extinction (Beier 1993).

The patchy pattern of populations is common among today's wild cats which tend to respond to anthropogenic pressures by retreating to inaccessible and less optimal habitats and to protected areas (Weber and Rabinowitz 1996). However, most countries cannot allocate sufficiently large tracts of undisturbed land for protected areas so cats, especially larger representatives, occasionally move outside zones of safety and die from human persecution (Woodroffe 2001). Generally, wild cats and other carnivores are intrinsically more prone to extinction than other mammals because of their position at top trophic levels which require large hunting areas and determine low densities and because of longer gestation lengths which underlie low capacities for recovery (Cardillo et al. 2004).

Hence, research on the spatial issues of felid ecology becomes an essential conservation tool as it enables to designate the priority conservation areas and corridors for the species of interest. At the global meta-population level, priority is given to preservation of sufficiently large and viable resident populations where prey resources, good habitats and ample lands suffice and human impact is minimal or none (Sanderson et al. 2002). At the national population level, the priority conservation areas are those which contain sufficiently large populations or sub-populations in the most pristine environments and/or those based on (in decreasing order of importance) breeding female home ranges, breeding male home ranges, temporary land tenures of dispersing sub-adults, landscape linkages and buffers against human disturbance (Ferreras 2001). The priority conservation areas designated for large mammals, such as big cats, can be used to identify and preserve the most representative biodiversity-rich areas and corridors between them (Allen et al. 2001). Also, the build-up of knowledge on relationships between felid distribution and environmental factors enables to predict the wide-range patterns of species distribution across the unstudied and less studied areas (Edwards et al. 1996).

In this paper, we apply scat counts to study the spatial issues of distribution and detection of the rare Caucasian leopard (*P. p. ciscaucasica*), synonym Persian leopard (*P. p. saxicolor*), in Armenia by using GIS mapping, occupancy modeling and analysis of multiple-season detection probability. Guesstimates show that no more than 10–15 leopards survive today in southern and south-western Armenia (Khorozyan et al. 2005). In the 2007 IUCN Red List of Threatened Species this cat is classified as globally "endangered", but in Armenia and elsewhere in the Caucasus it should be listed as "critically endangered" (IUCN 2003, 2007). We discuss distribution of the 16 habitat variables over the 16 study areas, their correlation and difference between the areas where leopard scats were found and not, leopard detection and habitat selectivity patterns across the range. Ultimately, we use this information to identify the Priority Leopard Conservation Areas (PLECAs) and propose the improved presence–absence survey design for this vanishing big cat.

18.2 Study Area

This study was carried out across the leopard range in south-western and southern Armenia within the Ararat, Vayk and Zangezur physico-geographical regions (Fig. 18.1). The Ararat region comprises 4 study areas: Kakavaberd (40°03′N/44°53′E), central and eastern Khosrov Reserve (39°58′N/44°57′E), Kharaba (39°55′N/44°59′E) and the Urts Ridge (39°49′N/44°49′E). The Vayk region holds 3 study areas: Elpin (39°48′N/45°06′E), Noravank (39°39′N/45°18′E) and Artavan (39°35′N/45°30′E). The Zangezur region includes the remaining 10 study areas: Salvard (39°28′N/45°55′E), Dastakert (39°20′N/46°01′E), Sisian (39°23′N/46°07′E), Ajubaj (39°15′N/46°02′E), Darmanadzor (39°15′N/46°10′E), Kapan (39°15′N/46°19′E), Khustup (39°08′N/46°19′E), Zangezur Ridge in Meghri district (38°53′N/46°09′E), central and western Meghri Ridge (38°57′N/46°19′E) and Nuvadi (38°57′N/46°26′E).

Vegetation zones within the leopard range are distributed as follows: (a) arid grassland: phrygana, tragacanths and tomillares at elevations 390–1,800 m above sea level; (b) xerophilous sparse forest: junipers (*Juniperus* spp.), almond (*Amygdalus fenzeliana*) and other trees with dense thorny scrubs at 800–2,240 m; (c) mesophilous broad-leaved forest: oaks (*Quercus* spp.), European ash (*Fraxinus excelsior*), Caucasian hornbeam (*Carpinus caucasica*) and shrubs at 800–2,400 m; (d) mountain grassland and subalpine meadow: cereals, dicotyledons, honey plants and other herbs at 1,000–2,800 m; and (e) alpine meadow: herbaceous vegetation at 2,800–3,100 m. Climate is continental, mean air temperature ranges from −10–13°C to 0.9°C in

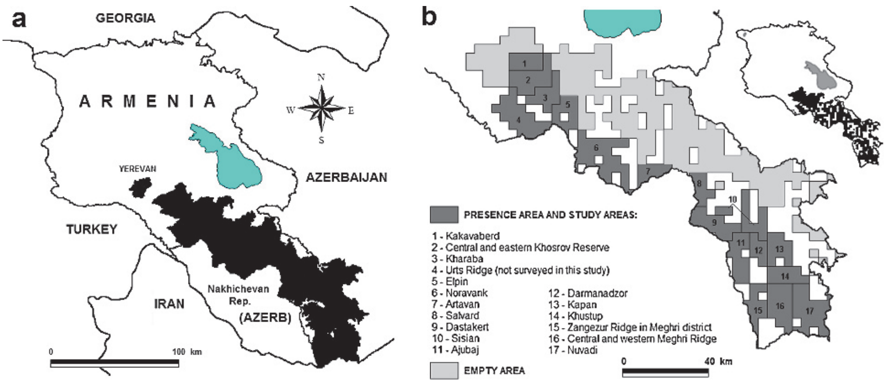

Fig. 18.1 The basic map of the leopard (*Panthera pardus*) range (**a**) and location of study areas (**b**) in Armenia

January and from 12.8°C to over 25°C is July depending on landscapes. Annual precipitation varied from 250–400 mm/year in arid grassland to 600–900 mm/year in alpine meadow (Aivazyan 2006).

We do not consider semi-deserts, nival and harsh nival belts which fall beyond the leopard range.

18.3 Material and Methods

The 1:200,000 georeferenced topographic map, recommended elsewhere for big cat studies (Stith and Kumar 2002), was used as the basis for our GIS map. We produced a GIS map of south-western and southern Armenia which included the landscape belts, dirt roads impassable for vehicles and main roads passable for vehicles, settlements (villages and towns), isohypses and slope aspects. We employed the software ArcView 3.2 and its extensions 3D Analyst and Spatial Analyst and then upgraded it to ArcGIS 9.2 (ESRI Inc., USA). The range boundary was delineated along the boundaries of semi-desert, nival and harsh nival landscapes (see above) and the national borders. Thus, we have produced the basic leopard range map of Armenia (Fig. 18.1a). Then, a specific map of the leopard range was produced by overlaying the basic range map with the cartographic layer of grid of 4 × 4 km cells and removing those grid cells which contained inhabited settlements as they are spatially exclusive with leopard distribution (Khorozyan 2003).

Using our field experience and information from local people, we created two areas: empty area – which is not used by leopards, but occasional penetrations during dispersals and displacements are possible; and presence area – which is inhabited constantly. The presence area was divided into 17 study areas according to their topographic and geographic distinctiveness, of which 16 were surveyed during this study (Fig. 18.1b). The Urts Ridge was not surveyed as its ownership status was unclear.

We have measured the 16 habitat variables across the grid cells and then extrapolated them for study areas (Tables 18.1 and 18.2). The sizes of study areas, areas of landscapes, road lengths, distances to the nearest village and the areas of southern and northern slopes were measured using the ArcView or ArcGIS measuring tool. Landscape diversity (*ldiv*) was calculated as follows:

$$ldiv = \sum_{i=1}^{n} Pi \times \ln Pi \tag{18.1}$$

where *Pi* is the proportion of the area of the *i*-th landscape to the area of all landscapes (Khorozyan et al. 2005). Terrain ruggedness index (*rugg*) was calculated as follows:

$$rugg = \frac{TNC \times TNF}{TNC + TNF} \tag{18.2}$$

where *TNC* is the total number of topographic contours (isohypses) intersecting the selected transect (top-right corner to down-left corner diagonal of the grid cell) and

Table 18.1 Summarized statistical information on the habitat variables across the 16 study areas within the leopard (*Panthera pardus*) presence area in Armenia. SE – standard error, Min – minimum value, Max – maximum value, *p* – significance level of variable difference between the study areas over the mean estimated by the χ^2-test, ns – the result is not significant at $p > 0.05$

Variable	Code	Total	Mean	SE	Min	Max	χ^2	p
Size of study area, km^2	size	2641.0	165.1	19.6	79.5	375.9	231.1	*
Total route length, km	leng	1201.9	75.1	19.1	15.6	331.3	46.9	**
Route density, km/km^2	rout		0.5	0.1	0.1	1.6	1.2	ns
Mean landscape diversity index	ldiv		0.5	0.1	0.2	0.8	0.5	ns
Area of arid grassland, km^2	agra	239.0	14.9	5.9	0.0	70.9	210.0	*
Area of sparse forest, km^2	spar	595.5	37.2	13.7	0.0	203.9	445.5	*
Area of mountain grassland, km^2	moun	647.6	40.5	15.4	0.0	233.0	503.0	*
Area of subalpine meadow, km^2	suba	719.8	45.0	4.8	8.0	72.0	80.4	*
Area of alpine meadow, km^2	alpi	439.1	27.5	5.6	0.0	81.6	120.2	*
Length of dirt roads, km	dirt	1405.6	87.9	10.2	44.5	177.8	127.4	*
Length of main roads, km	main	166.5	10.4	2.5	0.0	36.0	69.5	*
Mean terrain ruggedness index	rugg		9.0	0.5	4.7	12.5	3.9	ns
Mean distance to the nearest village, km	vill		6.5	0.7	3.6	14.1	7.0	ns
Mean wild fire index	fire		1.9	0.1	0.5	2.9	1.4	ns
Area of southern slopes, km^2	sout	903.7	56.5	7.9	21.9	129.6	117.4	*
Area of northern slopes, km^2	nort	772.3	48.3	6.8	19.6	133.5	86.0	*

* the result is significant at $p < 0.01$

** the result is significant at $p < 0.05$

Table 18.2 Distribution of 16 habitat variables over the 16 study areas in this study. The areas where we found leopard scats are marked by bold. Variable codes are the same as in Table 18.1. CE Khosrov – central and eastern Khosrov Reserve, Z Meghri – Zangezur Ridge in Meghri district, CW Meghri – central and western Meghri Ridge

	Habitat variables															
Area	size	leng	rout	ldiv	agra	spar	moun	suba	alpi	dirt	main	rugg	vill	fire	sout	nort
Kakavaberd	116.7	66.9	0.6	0.8	25.3	38.9	14.3	23.7	14.5	53.0	7.8	9.6	14.1	2.2	46.3	27.4
CE Khosrov	207.9	94.6	0.5	0.5	46.2	57.3	81.7	8.0	14.7	90.7	13.1	10.1	11.5	2.3	91.0	40.4
Kharaba	160.0	79.4	0.5	0.5	4.3	0.0	81.3	62.6	11.8	118.4	5.1	10.5	8.3	2.0	55.3	45.8
Elpin	155.1	27.9	0.2	0.4	1.6	0.0	86.9	50.5	16.1	59.5	21.2	8.8	4.9	2.0	63.4	29.5
Noravank	375.9	53.8	0.1	0.3	70.9	0.0	233.0	72.0	0.0	156.0	36.0	7.8	4.2	2.1	93.6	133.5
Artavan	103.8	27.5	0.3	0.5	0.0	0.0	15.5	55.1	33.2	44.5	1.0	6.9	6.2	1.5	21.9	45.1
Salvard	108.8	23.3	0.2	0.4	0.0	0.0	40.0	45.5	23.3	57.3	14.7	6.0	7.0	1.6	26.1	37.0
Dastakert	162.9	54.2	0.3	0.7	0.0	0.0	21.1	60.2	81.6	88.6	0.0	8.9	5.6	1.3	42.7	62.2
Sisian	168.0	123.3	0.7	0.6	1.0	13.0	73.8	61.8	18.4	77.4	3.6	10.5	3.6	1.7	33.4	71.7
Ajubaj	79.5	126.9	1.6	0.3	0.0	0.0	0.0	9.8	69.7	48.7	0.0	4.7	5.8	0.5	31.8	26.5
Darmanadzor	81.5	22.0	0.3	0.7	0.0	16.9	0.0	35.2	29.4	60.9	0.0	11.4	4.5	1.6	31.4	19.6
Kapan	151.1	33.1	0.2	0.8	13.4	59.6	0.0	54.9	23.2	88.8	14.4	12.5	4.8	2.2	52.5	44.4
Khustup	138.0	15.6	0.1	0.7	2.6	68.6	0.0	49.5	17.3	92.6	8.1	10.4	5.4	2.2	29.5	56.6
Z Meghri	125.2	50.9	0.4	0.6	0.3	33.4	0.0	39.8	51.7	51.2	6.2	7.6	5.2	1.6	53.4	32.0
CW Meghri	209.7	71.2	0.3	0.6	11.9	103.9	0.0	63.6	30.3	140.2	14.2	10.3	6.7	2.1	101.8	35.4
Nuvadi	296.9	331.3	1.1	0.2	61.5	203.9	0.0	27.6	3.9	177.8	21.1	7.6	5.6	2.9	129.6	65.2
Total	2641.0	1201.9			239.0	595.5	647.6	719.8	439.1	1405.6	166.5				903.7	772.3

TNF is the total number of changes in topographic aspect along the same transect (Khorozyan et al. 2005). Wild fire index (*fire*) was calculated as:

$$fire = \sum_{i=1}^{n} Pi \times Fi \tag{18.3}$$

where *Pi* is defined above and *Fi* is the score of landscape propensity to burning on the basis of precipitation and wind patterns, maximum air temperatures in summer and dominating vegetation (score 3 for arid grassland and sparse forest, 2 for mountain grassland and subalpine meadow and 1 for alpine meadow – Khorozyan and Abramov 2005). The southern, south-western and south-eastern slopes were merged into the southern slopes and the northern, north-western and north-eastern slopes into the northern slopes. The mean landscape diversity, mean terrain ruggedness, mean distance to the nearest village and mean wild fire indices of study areas were calculated as the arithmetic means of the respected values over the constituent grid cells. The χ^2-test was employed to estimate the significance of variables over their means across the study areas (Quinn and Keough 2002).

The 16 study areas were surveyed on foot during at least two survey periods each with an interval of several months in the snow-free seasons from April 2004 to November 2006 (Fig. 18.1b). We walked one route per day along the wildlife trails and visually identified the origin of scats on the basis of their appearance, smell, deposit place (mostly on the ridgetops) and/or accompanying presence signs (scrapes or tracks). Earlier we have shown that our ability to visually recognize leopard scats is reliable as supported by fecal bile acid thin-layer chromatography and that relative abundances of leopards estimated from visually and chromatographically identified scats were statistically similar (Khorozyan et al. 2007).

The routes crossed all local landscapes and they were selected arbitrarily on a basis of their use by wildlife. All scat samples were collected to avoid their repeated counts during the subsequent surveys. The locations and elevations of scat sites, as well as the lengths of daily routes walked were recorded by the handheld GPS device for their plotting on the GIS map. The route density was calculated as the ratio of total route length in the study area (km) to the size of that area (km^2). Forty-four routes (36.4%) were walked in spring, 16 (13.2%) in summer, 48 (39.7%) in autumn and 13 (10.7%) in winter. In winter, the surveys were conducted only in the southernmost Nuvadi area which is the warmest subtropical area of Armenia.

To compare sampling efforts across the study areas and find possible bias (oversampling of smaller areas and under-sampling of larger ones), we studied distribution of seasons, total route lengths and route densities in study areas and used the χ^2-test. For this analysis, seasons were assigned the dummy variables, from 1 for spring to 4 for winter.

Multiple discriminant analysis was used to find differences between the areas where we found the leopard scats and where we did not (Clevenger et al. 2002).

Habitat selectivity by the leopard was estimated by Jacobs' preference index (*D*):

$$D = \frac{R - P}{R + P - 2RP} \tag{18.4}$$

where R is the ratio of the scat number found in a specific landscape to the total number of scats and P is the ratio of the area of a specific landscape to the total size of study areas (Jacobs 1974). D changes from −1 (always ignored) through 0 (indifference) to +1 (restricted to that landscape). The landscapes having the highest value of D were identified as the critical habitats (Khorozyan 2003). The values of P were calculated from total areas of landscapes presented in Tables 18.1 and 18.2.

Relative abundance of leopards was estimated as the number of scats found per 10 km of survey (Wilson and Delahay 2001). To find correlation between relative abundance of leopards and 16 habitat variables, we constructed the Pearson's correlation matrix and considered as correlated those variables whose correlation coefficient (r_p) was higher than 0.5 or lower than −0.5 (Quinn and Keough 2002).

The multi-season subprogramme of programme PRESENCE 2.0 (<www.mbr-pwrc.usgs.gov/software>) was employed to calculate the occupancy and detection probabilities of leopards in Armenia within the multiple-year frame. Occupancy (ψ) is the probability that an area is occupied by the species or, alternatively, is the proportion of an area occupied by the species. Detection probability (p) is the probability of detecting the species, given presence, in each survey within the period (T) (MacKenzie et al. 2006). As the multi-season subprogramme of PRESENCE offers the year as a reasonable unit of T for long-living animals, we used three T's (first – year 2004, second – 2005 and third – 2006).

As the model covariates, we used 6 uncorrelated habitat variables from the Pearson's correlation matrix: size of study area, mean landscape diversity index, area of sparse forest, area of subalpine meadow, mean terrain ruggedness index and mean distance to the nearest village. In the input spreadsheet, we inserted 1 if scats were found in a given survey, 0 if they were not found and – if no survey was conducted and incorporated information about the site and sampling covariates. We manipulated with occupancy and detection probability to make them change over years, depend on the selected habitat variables or stay constant. We used 10,000 bootstraps. Total statistical summary of 192 occupancy models was ranked in an order of decreasing Akaike's Information Criterion (AIC) weights, thus indicating the most important to the least important models. The sum of AIC weights is 1 and the lower the AIC value of a model, the better that model.

The number of surveys in a study area (m) required to reach the desired probability of successfully obtaining one or more detections (power of area surveys or Pa) under a given detection probability (p) was calculated as (Reed 1996; Stauffer et al. 2002):

$$m = \frac{\log(1 - Pa)}{\log(1 - p)} \tag{18.5}$$

The number of study areas within the range (n) to be surveyed to reach the desired probability of successfully obtaining one or more detections during the surveys in the entire range (power of range surveys or Pr) under a given probability of occupancy (ψ) was calculated as (Stauffer et al. 2002):

$$n = \frac{\log(1 - Pr)}{\log(1 - \psi \times Pa)} \tag{18.6}$$

Processing of statistical information throughout this study was done in SPSS 13.0 and MS Excel 2003 software.

18.4 Results

In total, 121 daily routes (surveys) of total length 1201.9 km were walked and 31 leopard scats were found. Mean daily route was 9.9 ± 0.4 (range 3.0–35.0) km which did not differ between the study areas ($\chi^2 = 0.4$, $p > 0.5$). Route density and season also were similar and unbiased across the study areas, thus indicating spatial uniformity of sampling effort (Table 18.1). The study areas significantly differed in their size and, correspondingly, in total route lengths (Tables 18.1 and 18.2).

The Nuvadi area held most of leopard scats (67.7%), followed by central and eastern Khosrov Reserve (19.4), whereas contribution of the central and western Meghri Ridge (6.5), Sisian and Ajubaj areas (3.2 each) was low. Relative abundance of leopards was the highest in the Nuvadi area and the central and eastern Khosrov Reserve (0.63 scats/10 km in each), followed by the central and western Meghri Ridge (0.28), Sisian and Ajubaj (0.08) areas (Fig. 18.1).

Relative abundance of leopards positively correlated with the areas of arid grassland ($r_P = 0.60$, $p < 0.05$) and sparse forest ($r_P = 0.74$, $p < 0.001$), lengths of dirt roads ($r_P = 0.52$, $p < 0.05$) and the areas of southern slopes ($r_P = 0.75$, $p < 0.001$). However, the lengths of dirt roads and areas of southern slopes in their turn correlated with each other and with the areas of arid grassland and sparse forest (r_P varied from 0.63 and 0.83, $p < 0.001$). The areas of arid grassland and sparse forest are uncorrelated and can be considered as principal predictors of leopard occurrence. No negative correlation was found between relative abundance and habitat variables.

The eleven areas where we did not find leopard scats and the five ones where we found them significantly differed over the three habitat variables: the area of sparse forest, mean wild fire index and mean terrain ruggedness index. The statistical results are: 100% of variance, eigenvalue = 65.3, canonical correlation = 0.99, Wilk's lambda = 0.02, chi-square value = 31.4, standardized discriminant coefficient (SDC) of sparse forest = 26.0, SDC of mean wild fire index = 21.9, SDC of mean terrain ruggedness index = 14.4, significance level $p = 0.003$. The mean wild fire index is intrinsically correlated with the area of sparse forest (see Material and Methods; $r_P = 0.69$, $p < 0.005$), but the area of sparse forest and

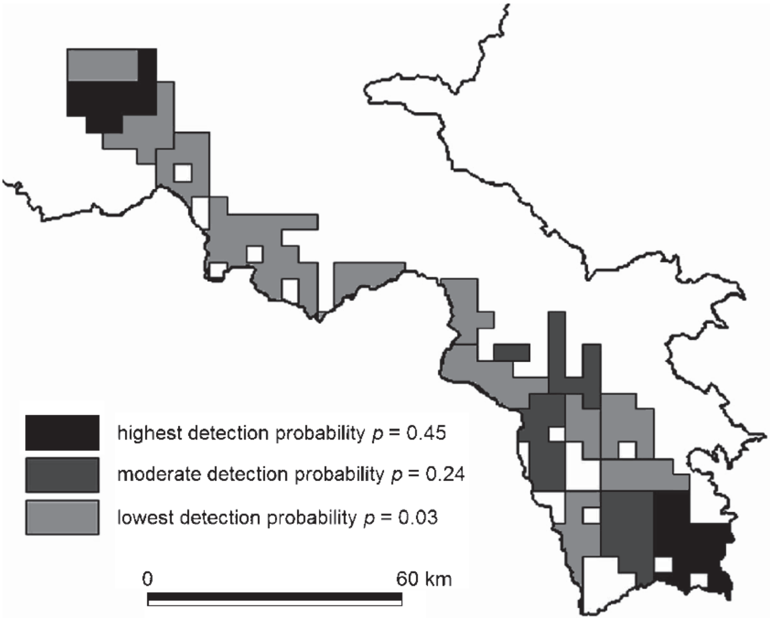

Fig. 18.2 Distribution of detection probability (p) across the study areas

mean terrain ruggedness index do not correlate (r_P = 0.16, p > 0.05). So, mean terrain ruggedness index can be considered as an additional predictor of leopard occurrence uncorrelated with the other two predictors (area of sparse forest and area of arid grassland).

Out of 31 leopard scats found in this study, 18 were collected in sparse forest, 7 in arid grassland, 4 in mountain grassland and 2 in subalpine meadow. So, the leopard is highly selective for sparse forest (D = 0.64) and arid grassland (D = 0.50) which are the critical habitats, avoiding mountain grassland (D = –0.38) and subalpine meadow (D = –0.71) and ignoring alpine meadow (D = –1).

Mean elevation of the scat sites was 1537.6 ± 109.8 m above sea level (range 747–2767 m, n = 31). Distribution of the scat site elevations (y) against the record months (x, from 1 for January to 12 for December) was statistically strong and curvilinear ($y = -11.30x^3 + 165.65x^2 - 395.29x + 1091.19$, R^2 = 0.79, ANOVA: $F_{3,27}$ = 34.60, p < 0.001). The highest elevations were used by leopards from late spring to late autumn (1,863–2,507 m) and the lowest – from early winter to mid-spring (747–1,450 m in the Nuvadi area and 1,566–2,267 m in the central and eastern Khosrov Reserve).

Detection probability of leopard scats was year-dependent and stable across the models within the survey years, but sharply declined from 2004 (p = 0.45) to 2006 (p = 0.03) (Fig. 18.2). Meanwhile, leopard occupancy remained high and stable at 0.85 or 85% of presence area.

To calculate the number of surveys in a study area (m), we used the sequence of desired Pa (0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 0.95) and three empirical levels of p (0.45; 0.24; 0.03) for each number of the sequence. For n, we used empirical $\psi = 0.85$, p (0.45; 0.24; 0.03), sequences of desired Pr (0.8; 0.9; 0.95) and m (5; 10; 20; 30; 40; 50). The resulting graphs are illustrated in Fig. 18.3.

The number of surveys to be undertaken in a study area to reach the desired power of area surveys Pa depends on detection probability p, especially when it is the lowest. At the 95% Pa, five surveys should be carried out when $p = 0.45$, 11 when $p = 0.24$ and 130 when $p = 0.03$ (Fig. 18.3). Similar pattern is observed in the relationship between the numbers of study areas to be surveyed and the power of range surveys Pr. At the 95% Pr, one to two study areas are sufficient when $p = 0.45$ regardless of m. When $p = 0.24$, 1–2 study areas are sufficient when m varies from 10 to 50 surveys and increase to three study areas when $m = 5$ surveys. When $p = 0.03$, the number of study areas strongly depends on m. At the 95% Pr, n changes from three study areas when $m = 40$–50 surveys to 22 study areas when only five surveys are conducted (Fig. 18.3).

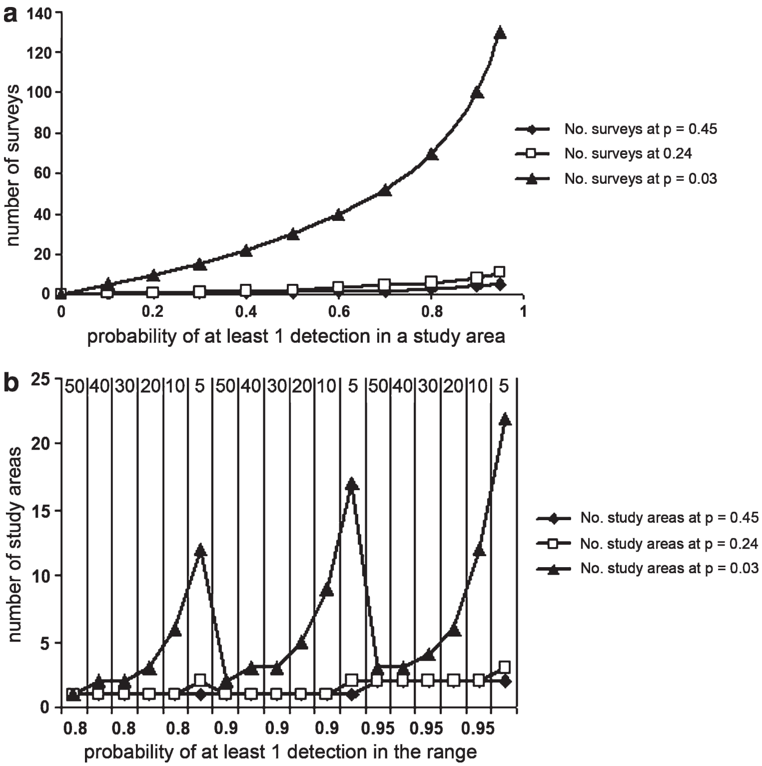

Fig. 18.3 Distribution of the numbers of surveys required to reach the desired probability of ≥1 detection in a study area (power of area surveys) at different levels of detection probability p (**a**) and distribution of the numbers of study areas to be surveyed to reach the desired probability of ≥1 detection in the entire range (power of range surveys) at the empirical occupancy $\psi = 0.85$ (**b**). The numbers of surveys per study area are indicated on the top of picture (**b**)

18.5 Discussion

The leopard is the rarest and most elusive mammal of Armenia's fauna distributed in the southern and south-western portions of the country over the presence area of 2,856.8 km^2 (2,641.0 km^2 of the 16 surveyed study areas and 215.8 km^2 of the unstudied Urts Ridge) (Fig. 18.1). So, it is essential to know the distribution of this predator and how this is related to the factors of ambient environment.

The leopard occurrence strongly correlates with arid grassland, xerophilous sparse forest and rugged terrain. Arid grassland and sparse forest hold sufficient prey base and prove to be the critical habitats for local leopards. Recent presence–absence occupancy modeling has shown that biomass of ungulate prey, including the bezoar goat (*Capra aegagrus*), wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), in the Nuvadi area is high (720.37 ± 142.72 kg/km^2) and capable of supporting many more leopards than actually live there (Khorozyan et al. 2008). Preference of these habitats, especially the sparse forest, by leopards agrees with our earlier data obtained from Khosrov Reserve and its vicinities (Khorozyan 2003).

Availability of precipitous rocky terrain and screes is an essential requirement for the leopard existence since they provide plenty of secluded nooks for shelters, dens and ambush sites, harbour the leopard's staple prey (bezoar goat) and limit access by humans and livestock.

On the other hand, preference of arid grassland and sparse forest can be caused by that these landscapes are distributed over the southern slopes and the leopard, being a species of tropical origin, will prefer southern exposure where snow accumulation is minimal. Gavashelishvili and Lukarevskiy (2008) have also found that snow cover is an important factor limiting leopard distribution in the Middle East, particularly in the Caucasus. Also, these landscapes are easier to be used by leopards and other wildlife as they contain most of dirt roads. Leopards live on higher elevations during the snow-free seasons, moving mainly along the narrow ridgetops, and descend to the foothills when snowfalls come. The statement by Gavashelishvili and Lukarevskiy (2008) that in the Middle East leopards avoid deserts and human settlements is indirectly confirmed in our study, as we *a priori* knew the pattern of such avoidance and excluded semi-desert (Armenia has no deserts) and inhabited settlements from the leopard distribution map.

Avoidance of mountain grassland and subalpine meadow and ignorance of alpine meadow, which are situated on plain mountaintop plateaus, are caused by prey scarcity resulting from intensive livestock breeding, deficiency of permanent water sources, shelter and adequate cover and accumulation of deep snow in the autumn–spring period (Khorozyan et al. 2005).

We failed to obtain a statistically robust logistic relationship between the leopard presence–absence data and the habitat variables, a result which hinted at a possible significant role of non-detections, also called false negatives (i.e. species is present but goes undetected) (Gu and Swihart 2004). The presence–absence models dealing with rare or elusive species, but ignoring their detection probability, suffer from overestimated absence and underestimated presence. In this case, the naïve assumption that if a species is present it would be definitely detected, i.e. its detection probability is 1, has been violated (Reed 1996; Moilanen 2002; Tyre et al. 2003; Gu and Swihart 2004; Wintle et al. 2005; MacKenzie et al. 2006).

This is a case for leopard in Armenia. Even in the best study areas, the central and eastern Khosrov Reserve and the Nuvadi area, which were surveyed in 2004 detection probability was 0.45. Then, in 2005 it dropped to 0.24 as we moved to the less optimal study areas but continued to survey the Nuvadi area and to 0.03 in 2006 when we discontinued the surveys in Nuvadi and have concentrated only on the worst areas (Fig. 18.2). The occupancy of the predator was kept high in all study years, at 85% of presence area. So, the leopard is a widely occurring, but seldom detectable predator. Despite detection probability of leopard in this study is definitely low, we discriminate three levels of it: high (0.45), moderate (0.24) and low (0.03).

Knowing detection probability and occupancy of the species, it is possible to estimate the number of surveys per study area and the number of study areas to be surveyed so that to obtain the desired probability of one or more detections of the species (i.e., power of area and range surveys, otherwise known as confidence level) or, alternatively, be sure that the species is extinct (Reed 1996; Stauffer et al. 2002). In our case, at the 95% power of area surveys the number of surveys to be undertaken is the lowest when detection probability is high, but increases moderately at the medium detection probability and sharply at the lowest level of this probability (Fig. 18.3). At the 95% power of range surveys, one to two study areas are sufficient to be surveyed at the medium and high detection probabilities regardless of the numbers of surveys in each, but their number increases to three at the medium detection probability and the least number of surveys. When detection probability is the lowest, much more study areas should be surveyed when the number of surveys is limited (Fig. 18.3). It is more efficient to increase the numbers of study areas and survey them less intensively than vice versa, especially at the lowest detection probability (Fig. 18.3; see also Stauffer et al. 2002; Wintle et al. 2005).

Detection probability, particularly in relation to scat counts, is often affected by non-random, or predetermined, bias caused by detection-favouring habitats, seasons, fecal decay and/or observers (Reed 1996; Wilson and Delahay 2001; Gu and Swihart 2004; Wintle et al. 2005). In our study, no such biases were observed as scats remain identifiable much longer in Armenia's arid mountains than other presence signs (tracks and scrapes), survey seasons did not vary between the areas, no particular habitats favoured detection of leopard scats against the others, and the observer bias was absent as the same researchers (IGK and AGM) were involved in all surveys.

We suggest the optimized leopard presence–absence survey design in Armenia. To attain the 95% confidence level, 5–10 surveys per study area and 1–3 study areas are sufficient at the medium to high levels of detection probability. When detection probability is the lowest, 12–22 study areas should be studied by conducting 5–10 surveys in each to gain the same confidence level. The standardized range-wide survey could look as nine surveys per study area conducted as three surveys per survey period over three survey periods, one period per snow-free season (spring to autumn). The larger the study area, the longer routes are to be walked to keep sampling effort unbiased. The interval between subsequent survey periods should be 3–4 months to allow leopards living at low density to visit an area and leave scats there, but prevent disappearance or loss of identifiability of scats. Under this scheme, at least one detection means presence and zero detection means true absence, i.e. extinction (Reed 1996; Stauffer et al. 2002). This design is not fixed and can be reasonably manipulated to comply with constraints of survey budget.

Our results agree with those of other authors that at least three surveys should be conducted in a study area to obtain the usable estimates of detection probability and the numbers of surveys, trails and study areas should be maximized whenever possible, even at the expense of route lengths (Van Sickle and Lindzey 1991; Kendall et al. 1992; Stander 1998; Tyre et al. 2003; MacKenzie and Royle 2005). As the leopard is wide-ranging, more frequent surveys would be more expedient in its research than extension of survey period which works well for animals with small home ranges (Wintle et al. 2005).

In Armenia, relative abundance of leopards is maximal in the Nuvadi area and the central and eastern Khosrov Reserve, whereas in the other three areas (central and western Meghri Ridge, Sisian and Ajubaj areas) it is much lower. As fresh scats were recorded during all survey periods in the Nuvadi and Khosrov Reserve, we suppose these areas are constantly inhabited by leopards and propose them as the Priority Leopard Conservation Areas (PLECAs) where this predator must be protected and studied first.

In central and western Meghri Ridge, Sisian and Ajubaj areas leopard scats were found irregularly at medium detection probability, so these areas are possibly used by cats occasionally as true corridors. It is unclear whether the eleven areas where we did not find scats at all are used as corridors as we certainly surveyed them insufficiently in light of the above-mentioned survey design (potential corridors) (Fig. 18.2). Most of the true and potential corridors are situated in the Zangezur Ridge which is stretched along the state border of Armenia and Nakhichevan Republic, an enclave of Azerbaijan. This area was devastated during the Armenian-Azerbaijani war over Nagorno-Karabakh in 1989–1994 and, since 1995 when the cease-fire regime was proclaimed, it suffers from recommencement of human activities: military training and testing grounds, border posts, agriculture, mining and re-settling of previously abandoned villages. Thus, the status of the Zangezur Ridge as a suite of movement linkages for leopards and other wildlife is in jeopardy. The habitats dominating in the Zangezur Ridge and its branches are mountain grasslands, subalpine and alpine meadows which are avoided or ignored by leopards, but can potentially be used as movement conduits during the snow-free seasons.

No one of the study areas surveyed by us, as well as the Urts Ridge, are large enough to maintain the viable leopard populations since each of them is smaller than the minimum area likely to support a leopard population, 412 km^2, known as threshold area (Smallwood 1999). Even the largest protected areas of southern and south-western Armenia, such as reserves (Khosrov Reserve, 239 km^2), sanctuaries (Jermuk Hydrological Sanctuary, 180 km^2) and forest management territories (Kapan Forestry, 393.4 km^2) are below the threshold area (Aivazyan 2006; A. Aghasyan, personal communication, 2007). Meantime, all together the study areas provide an ample space capable of retaining the viable leopard population if the efficient conservation and enforcement measures would have been taken. As Armenia is small and cannot afford to set aside the large tracts of lands for protected areas or even sufficiently enlarge the existing reserves, priority must be given to development of the community-based conservation schemes. Much attention should be paid to the leopard presence–absence surveys in the true and potential corridors and the Urts Ridge. Conservation of the designated corridors should be simultaneous and large-scale to prevent insularization of the PLECAs.

Current population of leopard in Armenia is too small to be viable even in a short run. The principal threats are poaching, human disturbance and wild fire which, if continuing at current rates, can make this species disappear from the national fauna in a few years (Khorozyan et al. 2005). Historically and especially now, its survival has been ensured by immigration of individuals from Iran which is a leopard stronghold in the Middle East. The powerful borderline Arax River contains many suitable fords for immigration and the barbed-wire border infrastructure does not hinder leopard crossings (I. Khorozyan, personal observation). Maintenance of this gene flow must become a priority for development of transboundary conservation projects in Armenia and Iran.

From the most skeptical view, Armenia can be considered as the peripheral and sink part of the largest Iranian pool so conservation of its leopard population would look impractical (Peterson 2001). We argue this opinion from two viewpoints. First, despite the leopard range in Iran being vast (885,300 km^2), its guessed abundance and crude density are low (550–850 individuals or 0.06–0.1 individuals/100 km^2) (Kiabi et al. 2002), so efforts in Armenia are worth taking anyway. Second, the perception that carrying capacities of small countries like Armenia for wide-ranging carnivores are low must not detract the researchers and conservationists from taking essential actions to avert local extinction. Even small areas and countries are capable to retain good leopard populations if prey is sufficient and human pressure is minimal.

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