

Movements and activities of snow leopards in Southwestern Mongolia

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Abstract

Four adult (2M:2F) snow leopards (*Uncia uncia*) were radio-monitored (VHF; one also via satellite) year-round during 1994–1997 in the Altai Mountains of southwestern Mongolia where prey densities (i.e., ibex, *Capra siberica*) were relatively low ($\sim 0.9/\text{km}^2$). Marked animals were more active at night (51%) than during the day (35%). Within the study area, marked leopards showed strong affinity for steep and rugged terrain, high use of areas rich in ungulate prey, and affinity for habitat edges. The satellite-monitored leopard moved more than 12 km on 14% of consecutive days monitored. Home ranges determined by standard telemetry techniques overlapped substantially and were at least 13–141 km² in size. However, the satellite-monitored individual apparently ranged over an area of at least 1590 km², and perhaps over as much as 4500 km². Since telemetry attempts from the ground were frequently unsuccessful ($\bar{x} = 72\%$), we suspect all marked animals likely had large home ranges. Relatively low prey abundance in the area also suggested that home ranges of $>500 \text{ km}^2$ were not unreasonable to expect, though these are >10 -fold larger than measured in any other part of snow leopard range. Home ranges of snow leopards may be larger than we suspect in many areas, and thus estimation of snow leopard conservation status must rigorously consider logistical constraints inherent in telemetry studies, and the relative abundance of prey.

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1. Introduction

Snow leopards (*Uncia uncia*) are one of the least known of the large cats, due in large part to the remote and rugged habitat of the central Asian mountains where they occur. Prior to the 1980s most information on snow leopard ecology was anecdotes gleaned from reports by naturalists and hunters visiting the region. Schaller (1977, p. 155) speculated that snow leopard home ranges must be very large, given the time interval

between observing fresh pugmarks in certain valleys in the Himalayas. Jackson (1996) recognized that the cat's "almost legendary secretiveness and camouflage" meant that radio-telemetry offered the "only realistic option for gathering information on snow leopard movements, home range, patterns of habitat utilization, social organization, and activity". His pioneering work with radio-tagged snow leopards in Nepal in the early 1980s provided much of our current knowledge of the species and has not been repeated. Although radio-collared snow leopards have since been the subject of studies in India (Chundawat, 1990), Mongolia (Schaller et al., 1994), and again in Nepal (Oli, 1997), these investigations were of short duration (less than 3 months) and had small sample size (1–3 cats). Importantly, by the

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early 1990s no long-term study of the cat's ecology had been conducted outside of what is considered the prime habitat of the Himalayan region (Fox, 1989).

The status of snow leopards in Mongolia had been only superficially dealt with prior to 1989 (Bannikov, 1954; Bold and Dorzhunduy, 1976; Mallon, 1984; Zhirnov and Ilyinsky, 1986; O'Gara, 1988) and most information concerned distribution, abundance, and basic food habits. In 1990, Schaller et al. (1994) initiated an ecological study of snow leopards in the Altai Mountains of southwest Mongolia and monitored a single radio-collared male for just over a month in early winter. The study was suspended during the ensuing years of economic and political uncertainty as Mongolia shifted from communism to a democratic market economy. During 1994–1997, we reinitiated and expanded studies of snow leopards in Southwestern Mongolia. Specifically, we captured and radio-marked four leopards to obtain year-long information on movements and activities in an area where prey densities were relatively low and probably representative of much of snow leopard range in Central Asia. We suspected that calculated home ranges of such animals would be much larger, and thus densities much lower, than previously reported for the species. We also suspected that we would find more nocturnal activity than that reported in less human-disturbed areas (e.g., Jackson, 1996), and habitat selection favoring areas of high prey density and low human disturbance.

2. Study area

The Altai Mountains to the north of the Great Gobi National Park (GGNP) are a stronghold of snow leopards in Mongolia, and we focused research there with the logistical assistance of the Park (Fig. 1). Our study site was on the southern flank of the Altai range in

Gobi-Altai aimag (province), about 80 km south of where Schaller et al. (1994) followed their radio-marked leopard. The study area borders were laid out along ecologically meaningful landform edges and contained most of the potential snow leopard habitat that could be reasonably accessed and mapped from the ground. This area encompassed 277 km² and was centered on the Saksai River drainage at about 96°E, 45°N. Elevations range from 1450 to 2600 m. The Saksai and Tugrog Rivers, which bisect the area, are the primary year-round water sources within 50 km. While portions of the area are extremely steep and broken by cliffs, steep-walled valleys and sharp ridgelines, just over 60% is rolling plateau or hills. The southern edge of the study area is bounded by the mountain and desert–steppe interface. Temperatures in the area range from –20 °C to +25 °C with less than 400 mm of precipitation annually. Snow is ephemeral in winter and quickly sublimates or is blown from the slopes and accumulates in shaded valleys. The region is included in the desert–steppe geobotanical region of Mongolia and is characterized by steppe and desert plants (Shirevdamba, 1998, p. 54). About 30% of the area is barren, the remainder consists of grass, or grass–shrub types. Some high-elevation meadows support a grass–sedge complex.

The local fauna with which snow leopards likely interact was identified by direct observation, sign, or local government records, and includes wolves (*Canis lupus*), red foxes (*Vulpes vulpes*), ibex (*Capra siberica*), lynx (*Lynx lynx*), Tolai hares (*Lepus tolai*), marmots (*Marmota bobac*), pikas (*Ochotona pallasii*), and various small rodents. Numerous old horns found in the study area indicate that argali sheep (*Ovis ammon*) were previously resident, but we never observed them. There also are resident populations of chukar partridge (*Alectoris chukar*), and Altai snowcock (*Tetragallus altaicus*). Numerous raptors occur, most notably lammergeyer



Fig. 1. Location of Saksai River study area in relation to snow leopard range in Mongolia.

(*Gypaetus barbatus*), cinereous vulture (*Aegypius monachus*) and steppe eagles (*Aquila rapax*).

The study area is occupied by semi-nomadic herders and their livestock. At least 13 families use the area seasonally and graze upwards of 3500 head of stock, primarily sheep and goats. Large livestock, such as horses, camels, yak and cattle, number no more than 300 cumulatively. Most local residents travel by camel or horse. Access to the area is possible by motor vehicle on dirt tracks from the south and north, but no through passage is possible. The western edge of the study area is bounded by a well-traveled dirt road that leads to the nearest som (local administrative center) 60 km to the northwest.

3. Methods

3.1. Capture

Leopards were live-trapped using Aldrich-type foot snares (Novak, 1980) placed in blind sets on trails (Ahlborn and Jackson, 1988). Snares were usually placed within a few meters of leopard scrapes or scent sprays which are often found along cliff-base trails and ridgelines (Jackson et al., 1990). Occasionally, snare sites were baited with live sheep or goats, or with commercial lynx urine (Hawkbaker and Sons, Ft. Loudon, PA). Snare cables were fitted with positive stops at about 15 cm to avoid over-constriction on the limb. Snare cables were attached to heavy scrap-metal drags (60–80 kg) or large boulders. Use of drags reduced risk of leg injury, and when boulders were used we incorporated a heavy spring into the cable, again to reduce injury potential. We normally ran a trap line of 10–18 snares along 8 km of cliff-bottom trails, or ridgelines. Snares were checked each day at dawn or more frequently.

3.2. Handling and marking

Snow leopards were immobilized with a mixture of tiletamine HCL and zolazepam HCL (Telazol; Wildlife Laboratories, Inc., Ft. Collins, CO) administered by jab stick at a dose of about 3 mg per kg of estimated body weight. Cats were weighed, measured, eartagged (12 × 30 mm plastic), and inspected for parasites, wounds, and signs of current or previous lactation. We estimated age roughly by body size and tooth wear (Jackson, 1996). A tooth (I_1) was extracted for cementum aging (Fancy, 1980) unless extreme cold prevented working with ungloved hands for extended periods. For ease of identification, cats were given identifying “names” that corresponded to sex and ear-tag color (e.g., M-Red).

Each cat was fitted with standard 450-gVHF radio-collar equipped with a motion sensor (Telonics, Inc., Mesa, AZ), except for one cat that received an 800-g ST-10 satellite transmitter (Telonics). The ST-10 collar

was pre-programmed to transmit twice a day at times corresponding to overpasses by Argos 12 and 14 satellites. To maximize collar life, it was set to transmit daily for the first 30 days and alternate days after that until battery depletion. The satellite collar also had a VHF transmitter to allow ground telemetry, but was not equipped with a motion sensor.

3.3. Activity monitoring

Cat activity, either sedentary or active, was recorded for each location. On several occasions we also monitored activity of individuals for 24-hour periods. Snow leopards occasionally were able to move with enough stealth to not trigger the motion sensor. In those instances the change in signal strength as the collar moved through signal-blocking obstacles indicated the cat was active despite an “inactive” pulse rate. When we observed one cat visually for an extended period we found that actual activity corresponded well with telemetry data.

3.4. Telemetry locations

We tried to locate each cat daily by ground-based telemetry using standard triangulation techniques (Samuel and Fuller, 1996). The period during which we conducted telemetry was discontinuous due to demands of country-wide surveys (McCarthy, 2000). We recorded locations to the nearest 100 m on 1:100,000 topographic maps.

Data from the satellite collar were not available until after most ground work in the study area was complete. The initial satellite data set included 107 locations. We defined a maximum acceptable areal extent for locations centered on the study area with an X extent of 1000 km and a Y extent of 700 km assuming no snow leopard would range this far from its capture site and that any outlying location would represent telemetry error. Five locations that fell outside this range were deleted. We decided whether to include any of the remaining locations by comparing each to its preceding and subsequent locations and making a subjective judgement on whether the snow leopard would likely have moved that much in the interval of time between transmissions. Also, if the preceding and subsequent locations were clustered, but the location itself was substantially removed from that cluster, we assumed that the location was in error. For any location that was questionable, we took into account the Argos supplied data quality fields (LC94, NLOC94, APBEST, DUR, NOPC) for that transmission in making a decision. Eventually, 91 locations were accepted.

3.5. Daily movements

When consecutive-day locations were available we calculated the minimum straight-line distance moved

from one day to the next. When multiple locations were available for the same day we calculated daily distance moved. Intraspecific distances between cats located on the same day also were calculated. We recognize that these calculations for VHF-marked animals are biased low because any movements they made out of the study area or telemetry range could not be considered.

3.6. *Habitat mapping*

We characterized biotic and physical habitat attributes of the study area on 1:50,000 topographic maps. Biotic attributes included ibex sightings and seasonal ibex range, marmot range, large and small livestock summer and winter range, and herders' seasonal camps. Physical attributes mapped included roads, rivers, and relative habitat ruggedness (rolling, slightly-, moderately- and very-broken). Ruggedness categories followed the definitions of the Snow Leopard Information Management System field protocols (Jackson and Hunter, 1996, p. 53) as modified for our range-wide surveys (McCarthy, 2000). Mapped attributes and all leopard locations were then digitized into a geographic information system (GIS) database.

3.7. *Analyses of distribution*

We compared snow leopard habitat use with availability by comparing the proportion of each cat's radio locations that fell within a specific habitat type to the proportion of that habitat type available in the study area and in the individual's home range (Neu et al., 1974; Marcum and Loftsgaarden, 1980). Preference or avoidance was determined at both levels using Bonferroni simultaneous confidence intervals when habitat attributes were discrete variables (e.g., slope, ruggedness and aspect). For other attributes we used standard confidence intervals. At the study area level we tested for selection using 95% confidence intervals, while at the home range level where data points were fewer, we used 90% confidence intervals. Selectivity indices of "+" (selected for), "0" (no selection indicated), and "-" (selected against) were assigned for each habitat attribute.

Affinity for some habitat attributes is better tested by looking at distances between the animal and the attribute. To test the hypothesis that distances from snow leopard locations to terrain edges were random, we generated 200 random points within the study area and compared these to the mean distances of all cat locations pooled using standard paired *t* tests at $P < 0.05$. We compared cat and random point distances to the edge of the ruggedness polygon they occurred in for each ruggedness category to determine if distance to edge varied by terrain type.

3.8. *Home range calculations*

The home range identified from satellite telemetry data was unexpectedly large, much of it falling well outside the mapped study area. Analyses of these data were necessarily different than for VHF-collared cats. Three location data sets for the satellite-monitored cat were available: VHF, satellite, and combined. The combined data set was used to estimate home range size, core activity isopleths, movements and intraspecific distances. Only those locations, or portions of home range, that fell within the mapped study area were included in the use-availability and cat-to-habitat attribute distance analyses. We compared same-day locations by VHF and satellite telemetry to assess satellite data accuracy. We also examined satellite locations for days when a VHF location was attempted but unsuccessful to determine if distance or topography was more likely the limiting factor in those VHF telemetry failures.

We considered all cat locations in all area-use calculations, including same-day locations. Autocorrelation is thought to be a concern when using multiple locations from the same day in home range analyses (Litvaitis et al., 1996), particularly core activity centers, and it is suggested that only locations separated by adequate time to allow animal movement across their home range be used (Swihart and Slade, 1985). We elected to use all locations in our home range analyses for reasons explained below in the discussion of daily movements. The PC-based program CALHOME (Kie et al., 1996) was used to calculate minimum convex polygon (MCP) home ranges (Mohr, 1947), and the adaptive kernel subroutine to identify core activity centers (30% isopleths) for each cat. The results were output to the GIS database. A combination of PC-based Arcview and workstation Arc-Info (both Environmental Systems Research Institute, Redlands, CA) facilitated habitat and home range analyses.

4. Results

4.1. *Captures of study animals*

We captured individual snow leopards (2M:2F) six times during 1872 trapnights (1 capture/312 nights). One male was captured three times, the first two instances being 5 days apart and in the same snare, and the third time 8 months later. Both captured males appeared to be fully grown adults (McCarthy, 2000), weighing 41 and 40 kg, respectively. From cementum annuli counts M-Blue was 4–5 years old, matching our field estimate of 4–6 years, and based on tooth wear was judged to be younger than M-Red from whom we did not extract a tooth.

The first female we captured (F-Yellow) was of advanced age, estimated at 9 years or older; we could not extract a tooth for aging at capture due to extreme wear or previous breakage. Subsequently (after her natural death 2.5 years later) we confirmed her to then be 11 years old by tooth cementum annuli. She was in poor condition compared to all other captured cats. She had two toes missing from her right front paw, three broken canine teeth, nearly half of the right ear was missing, the lower lip had previously been torn to the gum line, and there were several old puncture wounds about the face and head. None of the injuries were fresh and all were long healed. She was the only cat that had any sign of previous injuries. Her fur was also in poor condition and she appeared emaciated, weighing substantially less than similar-sized F-Green (30 vs. 39 kg). Nipple pigmentation indicated F-Yellow had previously lactated (e.g., McCravy and Rose, 1992), although she was not lactating at capture. Given her condition, we hesitantly fitted her with the heavier satellite collar. That concern proved unfounded as we successfully tracked her over the ensuing months and even watched her for 9 hours where she had killed a large male ibex.

F-Green was estimated to be 3 years old, based in part on the lack of indications of previous lactation and otherwise mature appearance. F-Green produced her first offspring, and the only young observed during this study, in spring of 1997. She was first observed with two cubs in July 1997, and when she saw us she immediately departed, moving the cubs several kilometers. Despite numerous attempts to make additional direct observations, we were not successful. Her movements during that summer likely were modified by her being with cubs (e.g., in and near caves), although we never again saw the cubs or their tracks to confirm their continued existence.

4.2. Activity patterns

The three snow leopards whose collars allowed activity monitoring were active, on average, 27–53% of the time (Fig. 2). In general, activity level was lowest between noon and 18:00 h, and only exceeded 50% between 20:00 h in the evening and about 04:00 h (Fig. 2A). A slightly crepuscular pattern was apparent, with increased activity of M-Blue earlier in the evening and later in the morning during winter (Nov–Apr), as would be expected with changes in sunrise and sunset (Fig. 2B).

4.3. Telemetry results

The four radio-collared animals were located a total of 248 times, 157 from ground-based and 91 from satellite-based telemetry (Table 1). We attempted to locate cats by ground-based telemetry on 207 days, and by satellite on approximately 199 days. Success rate ($x = 28\%$) varied by cat (11–42%). The success rate for the satellite collar was 40% after omitting likely outliers.

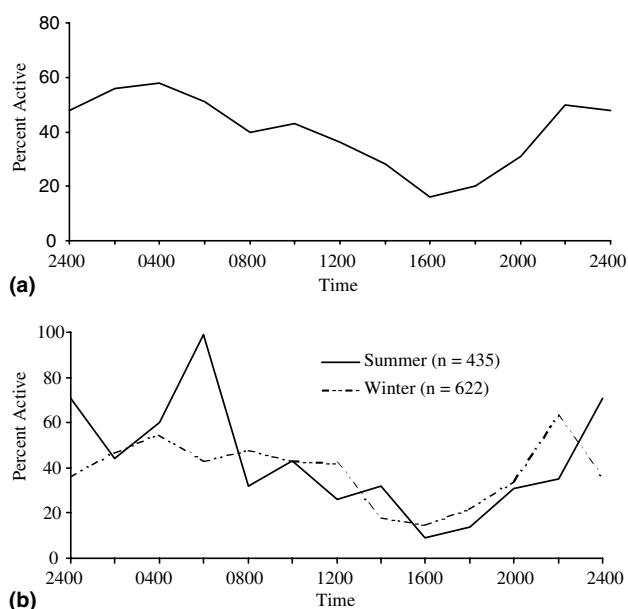


Fig. 2. Activity patterns of radio-marked snow leopards monitored in southwestern Mongolia during 1994–1997. (a) Mean percent activity ($n = 1060$) of 2 male and 1 female snow leopard during 2-hour intervals (number of observations per interval ranges from 43 to 156). (b) Mean percent seasonal activity of one of the male snow leopards during 2-hour intervals (number of observations per interval ranges from 34 to 130; total number of observations by season [Winter = November–April, Summer = May–October] indicated in parentheses).

4.4. Daily movements

The mean minimum straight-line distance between consecutive-day locations for all 4 cats averaged 5.1 km ($n = 77$, range = 0.5–10.8 km; Fig. 3). Overall, cats moved less than 2 km 59% of the time. VHF-monitored M-Blue exhibited the greatest ground-telemetry detected move of 11.8 km. However, satellite telemetry of one cat (F-Yellow) indicated that movements of >12 km were not uncommon (14%), and the greatest distance it traveled between consecutive-day locations was 27.9 km. In addition, M-Red dispersed from the Saksai study area to Mother Mountain, a large isolated massif 45–65 km to the south. This move would have required traversing 30–40 km of open steppe and was quite probably made in a single day. On average, leopards moved farther between consecutive-day locations in the summer ($x = 6.8$ km, SE = 9.1), than in winter ($x = 3.9$ km, SE = 6.3).

The mean same-day VHF-calculated travel distances for each cat always exceeded the mean consecutive-day distances (Fig. 3). The sample size was small ($n = 19$) and differences not significant ($P > 0.05$), yet these data may indicate that consecutive-day measurements underestimated 24-hour travel distances when cats travel some distance during activity periods, but return to the same rest sites.

Table 1
Telemetry data from four radio-marked snow leopards monitored in southwestern Mongolia

Individual	Capture date	Last location	Type of telemetry	No. of days located	Success rate (%)	Total no. of locations	MCP ^a home range size (km ²)	Core activity isopleths (km ²)	
								30%	75%
M-Red	3/15/94	11/24/96	VHF	22	10	24	61	2	25
M-Blue	9/10/94	11/22/96	VHF	61	32	84	142	10	120
F-Green	3/28/96	9/9/97	VHF	17	42	26	14	2	11
F-Yellow	2/16/96	8/7/97	VHF	22	26	23	58	1	43
			Satellite	79	40	91 (84) ^b	4530 (1590) ^b	28	585

^a MCP = Minimum Convex Polygon.

^b Removal of seven most distant satellite locations.

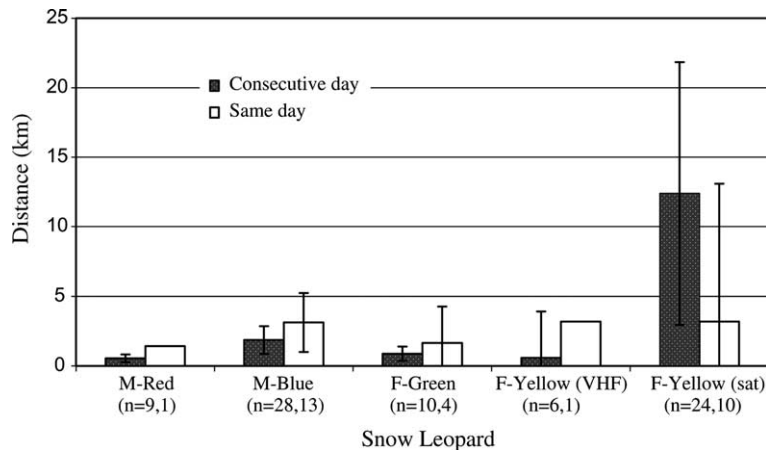


Fig. 3. Mean and SE of minimum straight-line distances moved between consecutive and same-day locations of radio-collared snow leopards in the Saksai River drainage, Gobi-Altai, Mongolia, 1994–1997.

4.5. Habitat use

Snow leopard home ranges and cores areas did not contain habitats of various physical or biotic attributes in proportion to their occurrence in the study area, although our small sample size precluded statistical compositional analysis (Aebischer et al., 1993). Rolling and slightly broken habitats appear to be under-represented in home ranges and markedly so in leopard core areas (Fig. 4), while very broken terrain appears over-represented. Habitat with slope $<20^\circ$ composed a large portion of the study area, but much lower percentages of home ranges, and relatively little of leopard core areas. All slope categories above 20° were used by snow leopards at proportions greater than occurrence. Of the biotic habitat attributes we measured, only ibex range, both summer and winter, was included in snow leopard home range and core areas in proportions substantially exceeding occurrence (Fig. 5). There was no clear trend for marmot range, or seasonal ranges of small and large livestock.

Use of habitats with specific attributes differed significantly from availability at both the study area (tested at 95% confidence interval) and home range le-

vel (tested at 90% confidence interval), as measured by snow leopard locations (Fig. 6). The selectivity indices for pooled locations of all cats statistically supports the preferential use of habitat inferred in compositional analyses. Snow leopards used steep (slope $>20^\circ$) and rugged terrain much more than expected, while using rolling terrain far less than expected. Biotic factors were less likely to influence use, with the consistent exception of ibex range, which the cats selected for, and areas used for summer grazing of small livestock (sheep and goats), which they selected against. Most of these preferences held up when we tested for selection of individual cats at the study area level, although the margin between observed and expected use were often reduced. Selection was less often apparent when locations were compared to availability within home ranges.

Snow leopards locations were not randomly distributed ($P < 0.001$) in relation to terrain type edges (Table 2). This was most apparent when cats were in rolling habitat; they were substantially closer to edge than were random points. Within very broken habitat, cat distances to edge were not different from random points ($P = 0.67$).

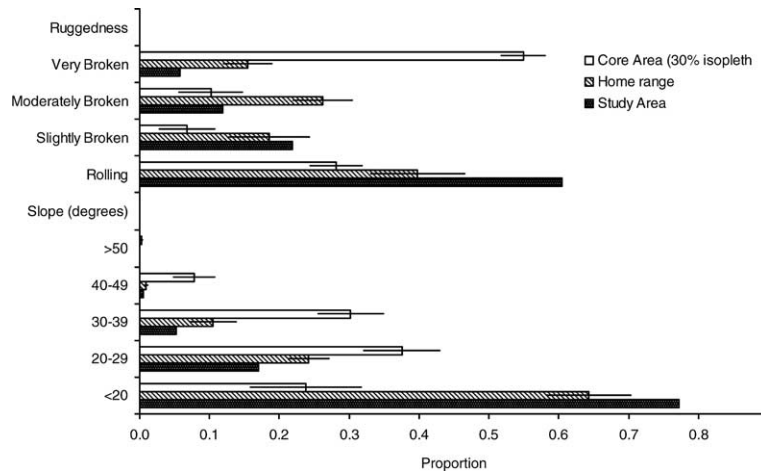


Fig. 4. Proportional composition of the Saksai River study area, snow leopard home ranges (mean and SE), and core activity areas (30% isopleth) in terms of habitat ruggedness and slope.

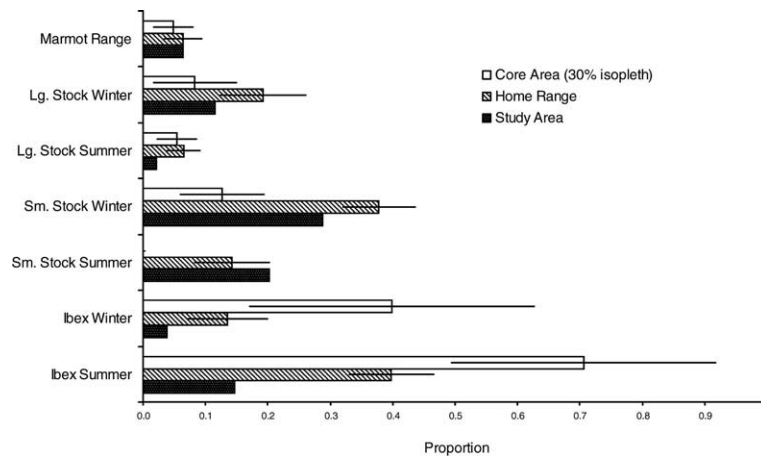


Fig. 5. Proportional composition of the Saksai River study area, snow leopard home ranges (mean and SE), and core activity areas (30% isopleth) in terms of marmot range, and seasonal livestock and ibex range.

4.6. Home range size

Home ranges of snow leopards, as calculated using minimum convex polygons for ground-based telemetry locations, ranged from 14 to 142 km² (Table 1). When F-Yellow's satellite locations were included, our estimate of her home range increased from 58 to 4530 km². When we took an even more conservative view of her satellite data and removed seven locations that represented single visits to sites well outside her core activity area, her home range was about 1590 km², still more than an order of magnitude greater than the largest home range we determined for any leopard using ground-based telemetry.

There were only three same-day locations for satellite and VHF telemetry of F-Yellow cat and these were taken several hours apart. The mean distance between VHF and satellite relocations on the same day was 6.3 km (range = 1–11.5 km) which was less than her

mean daily movement distances. There were 10 days on which VHF telemetry for F-Yellow failed but a satellite location was acquired. The mean minimum distance between F-Yellow's location and the unsuccessful ground-telemetry observer was 20.5 km (range 3.3–53.0 km). In the two instances where ground-telemetry observers were less than 12 km from the satellite location and failed to gain a signal, the cat and the observer were separated by a high ridgeline in both cases. All but two of the satellite locations for days when VHF monitoring attempts failed were outside of her VHF-generated MCP home range.

4.7. Sociality

Snow leopards exhibited substantial home range overlap, even at the MCP level. The 30% isopleth core areas also overlapped for three of the four cats. F-Green, who was with cubs during much of the period

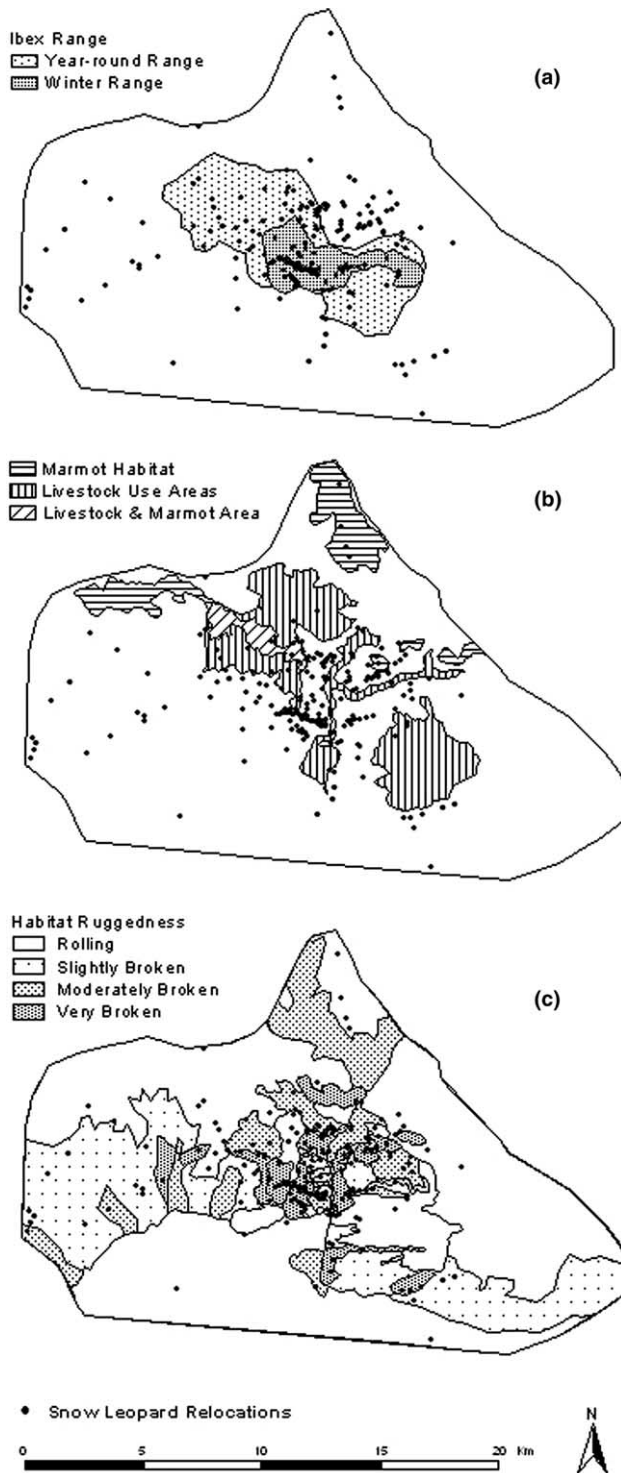


Fig. 6. Snow leopard locations in the Saksai study area compared to: (a) Ibex summer and winter ranges, (b) marmot and livestock use areas, (c) habitat ruggedness classes.

we tracked her, had a core area that did not intersect either male's and was on the periphery of the other female's. The core areas of all cats were contained within a relatively small portion (~10%) of the study area.

Information on same-day distances between snow leopards is limited. We would always attempt to locate every cat when conducting telemetry by scanning all frequencies often, particularly from ridgeline vantage points. Still, we located both males M-Blue and M-Red in the study area on the same day only three times and the mean separation distance was 1.3 km (SE = 0.5). A male and a female were found simultaneously 16 times and on average were 4.8 km apart (SE = 5.4). The two females, found simultaneously seven times, were on average 7.8 km apart (SE = 6.6). While home ranges and core areas overlapped substantially, our data suggests that leopards, particularly females, exhibit temporal separation. However, it could also be argued that the limited number of times we were able to locate male snow leopards on the same day could be due to distances between the cats.

5. Discussion

The small sample sizes obtained in this study necessitate a very cautious interpretation of the data. This is particularly true for our single satellite-collared leopard whose locations seem to indicate a home-range and movements far larger than those of our VHF-collared animals, and of those reported from other snow leopard radio-collaring studies. Our data clearly point out the need for additional research.

Snow leopards in southwestern Mongolia appear to exhibit activity, movement, and home range patterns unlike those previously documented for the species. We observed less activity during the daytime hours of 0800–1600 (35%) than what Jackson (1996) did in Nepal (44%), but our cats were more active (51%) between 2000 and 0400 than his (44%). In both Nepal and elsewhere in Mongolia (Schaller et al., 1994) a strong crepuscular activity pattern was observed, with peaks at both dawn and dusk. Our data indicate slight peaks in activity at those times, but a fairly consistent level of activity was maintained throughout the night, similar to the substantial nocturnal activity reported for other large felids, including pumas (*Felis concolor*; Seidensticker et al., 1973), tigers (*Felis tigris*; Sunquist, 1981), and common leopards (*Panthera pardus*; Bailey, 1993, p. 126).

Movement data from locations taken on the same day indicate that snow leopards move about during both the day and night, but frequently return to the same daytime rest site. Schaller et al. (1994) observed a male snow leopard in Mongolia using the same rest site on several consecutive days. Mean distances traveled by snow leopards in a 24-hour period substantially exceeded those reported elsewhere for the species (Jackson and Ahlborn, 1989; Chundawat, 1990) as well as for other similarly sized felids such as pumas and common leopards (Seidensticker et al., 1973, p. 26; Bailey, 1993, p. 145). Satellite telemetry allowed us to detect some

Table 2

Comparison of distances (m) of snow leopard radio-locations and random points to habitat edge in the Saksai River study area, Gobi Altai, Mongolia, 1994–1997

Habitat attribute	Locations (<i>n</i> = 196)		Random points (<i>n</i> = 200)		<i>Z</i>	<i>P</i>
	\bar{x}	SE	\bar{x}	SE		
Ruggedness edge ^a	198.0	227.0	500.0	467.0	8.21	<0.001
Edge of type if in ^b						
Rolling	316.4	520.1	629.4	330.8	4.48	<0.001
Slightly broken	238.1	267.2	450.1	367.8	3.29	<0.001
Moderately broken	135.0	113.6	176.7	135.6	1.36	0.91
Very broken	132.9	104.8	116.6	65.4	0.45	0.67

^a Distance to the edge of the ruggedness polygon the point or location is in regardless of ruggedness type.

^b Distance to the edge of the ruggedness polygon the point or relocation is in by type.

large movements we otherwise would have missed, but even our ground-based telemetry data include daily movements of more than 12 km, which is nearly double that previously reported for snow leopards. We suspect that snow leopards in Mongolia may be capable of larger daily movements than those in the Himalayas due in part to the less rugged terrain. Common leopards in Africa (Bailey, 1993, p. 145) moved as much as 13 km in a day, but less than 0.2% of their daily movements exceeded 10 km. Snow leopards in this study moved more than 12 km on 14% of consecutive days monitored. We suspected that snow leopards in Mongolia were capable of long-distance moves in short periods after we documented their use of isolated massifs as potential way points when crossing large expanses of open steppe and desert between mountain ranges (McCarthy, 2000). M-Red's departure from the study area for an isolated massif some 45–65 km distant confirmed this.

Habitat use determined in this study was consistent with that for snow leopards elsewhere in terms of showing a strong affinity for steep and rugged terrain, high use of areas rich in ungulate prey, and affinity for habitat edges (Jackson, 1996; Fox, 1989). The strong selection for ibex range exhibited by leopards in the Saksai was not unexpected, as ibex comprise the majority (60–70%) of snow leopard diets in Mongolia (T. McCarthy unpublished data, Schaller et al., 1994; Amarbat, 1999) and the distribution of the species is closely linked (McCarthy, 2000). Marmots make up between 15% and 20% of the diet, domestic livestock less than 5%, and other small mammals, birds, or vegetation the remainder.

The distribution of ibex within the study area may explain much variation in snow leopard habitat use, and the density of ibex may provide a clue to the home range sizes that we estimated (cf. Litvaitis et al., 1986). The required large ungulate prey to snow leopard ratio has been variously reported to be within range of 114–230:1 (Jackson and Ahlborn, 1984; Fox, 1989; Oli, 1994) varying with the diet proportion comprised of alternate prey such as small mammals and livestock. Snow leopards in the Saksai had limited access to mar-

mots, and livestock depredation amounted to only a few animals a year (Allen et al., 2002).

Snow leopard home ranges in the Saksai were on average larger than the 11–36 km² (\bar{x} = 19 km²) previously reported for the species (Jackson and Ahlborn, 1989; Chundawat, 1990; Schaller et al., 1994; Oli, 1997). Home ranges in our study were larger, despite being based on relatively few locations. The male for which we had the fewest locations (M-Red with 24) had a minimum home range of 61 km² without considering his dispersal out of the study area. M-Blue, with the most VHF locations, had a minimum home range (141 km²) that was about 4 times the largest ever reported for a snow leopard. Given our inability to locate him on 68% of attempts, his range was almost certainly underestimated. Only F-Green, the female who was with cubs for most of the time we tracked her, had a home range size comparable to that reported for snow leopards elsewhere (14 km²). We suspect her range was normally larger when she was solitary, as cub rearing has been shown to reduce range size and movements in pumas and common leopards (Bailey, 1993, p. 168; Seidensticker et al., 1973, p. 24). Jackson and Ahlborn (1989) also noted increases in home range size for a snow leopard with cubs as the young became more mobile.

Both Jackson (1996) and Oli (1997) believed that movements and home ranges of snow leopards have probably been underestimated due to the difficulty of ground-based radio-tracking in the type of terrain they occupy. Using satellite telemetry Ballard et al. (1998) obtained estimates of seasonal wolf territories approximately 2- to 3.5-times that generated by standard VHF telemetry. They attributed the difference to increased frequency and number of relocations through satellite telemetry, and acquisition of locations when VHF relocations were impractical. The latter could be the primary explanation for the differences in this study. Still, the extent to which our satellite-based home-ranges exceeded those estimated using VHF telemetry was unexpected. The 4,530-km² home range calculated using the minimum convex polygon method may well overestimate F-Yellow's area of use, although neither the

movements required nor the habitat of the locations could be used to negate the estimate. When we take an extremely conservative approach and remove all potential error points from the satellite data, her range estimate still approached 1600 km² and even the 75% isopleth encompasses some 585 km², which is 16 times larger than that reported for any female snow leopard.

F-Yellow was a very old animal and not one we would expect to make large exploratory movements outside her normal home range, such as those seen by sub-adult common leopards in Africa (Bailey, 1993, p. 156). Bailey also noted that leopards in good physical condition tended to move further than less healthy animals, yet F-Yellow was in the poorest condition of all our cats at capture. Older animals, especially those in poor condition might be more easily displaced from their range and forced to explore alternate sites. F-Yellow, however, was not displaced and continued to use the core area she shared with 3 other collared leopards throughout the study, and she died in her core area. F-Yellow may not represent the “normal” snow leopard in our study area and her calculated range size could be real, but an aberration. With a single year of data for F-Yellow, we cannot determine if movements and range size were representative of her long-term habits. Despite uncertainties about our satellite telemetry results, and the movement of one male out of the study area, it is clear that snow leopards in the Saksai use larger ranges to meet their needs than snow leopards in previous studies in Nepal, India, and elsewhere in Mongolia.

From our experience in observing and noting the numbers of ibex in the study area while locating snow leopards, we mapped their distribution and estimated that about 250 lived in the 277 km² that we regularly surveyed (i.e., 0.9/km²). At this prey density, a single leopard would need a range of 126–256 km² (114–230/0.9) to incorporate enough prey to live on. If 3 leopards lived in identically sized, overlapping home ranges, then 3 times the number of ibex would have to be present/shared and this would require 378–768 km². Thus the large ranges we observed in Saksai are in line with relative prey abundance. Snow leopards in this study appear to be ranging far greater distances to secure required prey than in prime habitat with high prey densities. We believe snow leopards in the Saksai feed primarily on ibex that are most abundant in the core area, but take the occasional one from among those that occur sparsely throughout most of the study area. Peripheral sites may be less densely populated, but ibex there may be less wary due to infrequent hunting pressure by leopards.

6. Conservation implications

If range use as suggested in this study is representative of snow leopards across occupied habitat in Mongo-

lia, density and total population may be much less than previously thought. Large-scale movements and large home range sizes may be an adaptation to low prey densities that occur in many parts of the country. Lower population density and movements that take cats across habitats offering little escape cover make leopards more vulnerable. This, coupled with dependence on an ungulate population that is coming under increasing pressure from domestic stock grazing, would argue for greater protective measures. Conservation measures based on research conducted in prime habitat in the Himalayas may not meet the needs of snow leopards in Mongolia. Mongolia has expanded its protected area system dramatically in recent years, but much of snow leopard range remains unprotected. Further, many reserves are of inadequate size to afford protection to snow leopards whose ranges may exceed the size of the reserve.

The implications of our findings on snow leopard conservation in other parts of their broad range in Asia is difficult to assess. We are unaware of any studies of the species, its habitat use or home range patterns that have been completed outside Mongolia, Nepal and India, which makes extrapolation of our findings to other areas tenuous at best. However, given the endangered status of the snow leopard, we encourage conservation planners from throughout snow leopard range to consider the potential for large home-range requirements that may be indicated by our limited data.

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