Distribution Agreement

Patterns of conflict and coexistence between agro-pastoralists and snow leopards (*Panthera uncia*) in Ladakh, India

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Abstract

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As an apex predator and flagship species, conservation of *Panthera uncia* is important for numerous species and landscapes throughout Central Asia. Conservation can also be contentious among traditional agro-pastoralists, however, who often feel they are unwillingly subsidizing efforts with no benefit to themselves. The objectives of this study were to contribute to knowledge of snow leopard distribution in Ladakh, to describe patterns of livestock depredation by snow leopards, to identify potential socioecological correlates, to test terrain ruggedness as a predictor of depredation, and to test the effectiveness of basic field methodology. In total, 48 1-km transects were surveyed for animal sign, 48 1-hour vantage point scans were conducted for live animal sightings, and 59 households were interviewed. My results suggest that neither terrain ruggedness, snow leopard sign, livestock ownership, nor number of households in an area, are strongly correlated with snow leopard depredation rate of domestic livestock. Small livestock were killed most frequently (82.8%), and most livestock were killed in corrals (65.5%), in spring (65.5%), and early summer (13.8%). This suggests that damage to agro-pastoralist livelihood can be greatly diminished by fortifying livestock enclosures. I emphasize, however, that any underlying depredation correlates or patterns might be obscured in this study by the small sample size, and by the rapid social restructuring of Ladakhi communities and inherent socioecological heterogeneity in the system.

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1. Introduction

Depredation of domestic livestock by wild predators is the largest source of human-wildlife conflict worldwide, followed by destruction of agricultural crops by wild herbivores (Graham et al. 2005). Depredation often also creates conflict between conservationists and farmers, ranchers, and herders (Miller et al. 2016b). Wild predators are often considered keystone species, important to the health and structure of entire ecosystems (Terborgh et al. 1997). The snow leopard (*Panthera uncia*) is a charismatic, geographically wide ranging carnivore in central Asia classified as endangered by the International Society for the Conservation of Nature (IUCN) primarily as a result of habitat loss, dwindling wild prey populations, and retaliatory killing by pastoralists (Jackson et al. 2008). Trophy hunting for the illegal wildlife trade is also a threat in some parts of its range (Ahmad et al. 2016). Of all big cats, the snow leopard is one of the largest contributors to human-carnivore conflict worldwide (Graham et al. 2005).

Snow leopards are important umbrella, flagship, and potentially keystone, species in Central Asia, because they are charismatic apex predators with large home ranges capable of supporting many other species and ecosystem services (Cardinale 2012). Home territories can range from 10 to over 600 square kilometers based on the quality of habitat and food availability (Fox et al. 1991; Johansson et al. 2016). Some species benefited by the umbrella of snow leopard conservation, however, also can exacerbate conflict with humans (Alexander et al. 2016a). Local attitudes towards snow leopards are nevertheless becoming more positive, and snow leopard conservation is generally more widely accepted than conservation of other predators such as grey wolf (*Canis lupus chanku*) (Bagchi and Mishra 2006; Oli et al. 1994).

The main diet of the snow leopard is large ungulates such as Asiatic ibex (*Capra sibirica*), Tibetan argali (*Ovis ammon*), and blue sheep (*Pseudois nayaur*), marmots (*Marmota spp.*), various plants species, and domestic livestock (Bagchi and Mishra 2006; Namgail et al. 2007a; Sharma et al. 2015; Shehzad et al. 2012). Dependence on livestock varies in different regions throughout the twelve countries snow leopards are known to inhabit (Figure 1a, b) (ISLT and WCS 2008; Jackson et al. 2008). It is also unclear whether abundance of wild prey increases or decreases the risk of domestic livestock depredation (Graham et al. 2005; Khorozyan et al. 2015; Miller 2015). Some studies indicate that wild prey are the preferred food source for snow leopards and therefore help divert depredation away from livestock (Bagchi and Mishra 2006; Khorozyan et al. 2015). Wild prey populations can also indicate healthier or more well-managed pastures, and less competition with domestic herds (Namgail et al. 2007b; Sharma et al. 2015). Other studies, however, have found that domestic livestock are preferred because they are easier to kill, and that wild prey abundance intensifies livestock depredation by attracting predators to the area (Miller et al. 2016a; Suryawanshi et al. 2013).

Snow leopard presence, especially in the south of its range, is strongly correlated with terrain ruggedness, but it is still unknown how either relates to depredation of domestic livestock by snow leopards (Alexander et al. 2016b; Jackson and Hunter 1995; Sharma et al. 2015). It is often assumed by both herders and researchers that depredation is directly related to predator abundance, but few studies, especially involving snow leopards, have actually tested this hypothesis. If snow leopard abundance were directly related to livestock depredation, terrain ruggedness within known snow leopard range might prove a useful predictor of high-risk areas. Rugged terrain provides ideal camouflage and shelter, as well as an agility advantage for snow leopards over domestic livestock in the pasture (Fox et al. 1991; Jackson et al. 2006). If, however, depredation is not directly related to snow leopard abundance, and is instead potentially characterized by killing sprees and certain “problem” individuals, terrain ruggedness would not be a helpful predictor of depredation but could still be useful for other aspects of ecological studies and conservation (Jackson et al. 2008).

Conservation programs (led internationally by the International Snow Leopard Trust, Panthera, World Wide Fund for Nature, Snow Leopard Conservancy) have been increasingly successful throughout the snow leopard’s range, with early efforts being conducted in India and Nepal (Fox et al. 1994; Jackson et al. 2010; Mishra 1997). The largest Indian snow leopard populations are believed to be in Ladakh, but are still believed to be less than 400 (Fox et al. 1991; Jackson et al. 2006).

Ladakh is a semi-autonomous region within the northernmost Indian state of Jammu and Kashmir, currently involved in border disputes with both Pakistan and China (Figure 1c). There is a large military presence, in addition to migrant workers and traditional Buddhist and Muslim traders and agro-pastoralists. It is an environmental, historical, and cultural gem that has become an internationally popular tourist destination (Norberg-Hodge 2009). Many tourists come to Ladakh to experience its landscapes and wildlife, including the endangered snow leopard and black necked crane (*Grus nigricollis*), but tourism also brings development which Ladakhis are finding difficult to manage effectively (Goeury 2010).

Despite rapid modernization and development throughout Ladakh and especially concentrated in the capital city of Leh, most Ladakhis continue to live in small villages and engage to varying degrees in the traditional agro-pastoralist lifestyle (LAHDC 2010). They herd a mixture of goats, sheep, cattle, yaks, horses, donkeys, and cattle-yak hybrids called *dzo* (depending on region, climate, and local practices), typically leaving larger livestock in high mountain pastures almost entirely unattended for the warm summer months, and herd the small livestock to nearer pastures daily. Communal herding, where villagers take turns grazing the entire village herd, is becoming increasingly common as more people move to the city or have more than one occupation. In the village herders keep their livestock in small stone wall enclosures, or on the first floor of their houses (Figure 2). Many of these enclosures are vulnerable to carnivore attack from above, and local conservation organizations are trying to minimize corral attacks by "predator proofing" with chain-link ceilings (Jackson et al. 2010; Namgail et al. 2007a).

Unlike much of the snow leopard's range, retaliatory killings in Ladakh have virtually ceased. This is due to the strong influence of Tibetan Buddhism (even in Muslim and Christian communities), wildlife laws, and the initiatives of local NGOs such as the Snow Leopard Conservancy-India Trust (SLC-IT), and the Snow Leopard Trust (SLT) (Jackson et al. 2010). Villagers continue to suffer the negative effects of snow leopard depredation, while ecotourism benefits mainly go to tour operators in Leh and elsewhere (Namgail et al. 2007a; Norberg-Hodge 2009). To make wildlife conservation sustainable it is imperative to build strong community support and initiative (Treves and Karanth 2003). This is one of the primary tasks of SLC-IT and SLT, but still so little is known about the nature of human-snow leopard conflict in Ladakh that many such conservation efforts are not systematic in nature (Jackson et al. 2010).

Ladakh is a vital conservation area for snow leopards, both because of the ongoing initiatives already in place and its location within the snow leopard's range (Figure 1a, b). It is both at the south-eastern periphery of the snow leopard's range, and a high-altitude connection to other range areas that can serve as refugia even during anticipated global climate changes (Channell and Lomolino 2000; Li et al. 2016; Riordan et al. 2016). Furthermore, human-predator coexistence, for mutual benefit through land-sharing and ecotourism, is possible more than almost anywhere else (Bennett et al. 2006; Chen et al. 2016; Fischer et al. 2008; Jackson et al. 2010; Sharma et al. 2015). Moreover, an important part of community conservation is adequate and ever-increasing knowledge of the system (Treves and Karanth 2003).

The objectives of this study were to contribute to ongoing conservation efforts in the Ladakh by 1) adding to knowledge of snow leopard distribution, 2) describing patterns of livestock depredation by snow leopards, 3) identifying other potential socioecological correlates of depredation, 4) testing terrain ruggedness as a predictor of depredation, and 5) testing the effectiveness of basic field methodology to accomplish the above goals. Field methods were designed using the Snow Leopard Information Management System (SLIMS) approach in collaboration with SLC-IT, to maximize financial and personnel efficiency and to ensure cohesiveness with ongoing local research and conservation efforts (Jackson et al. 2006).

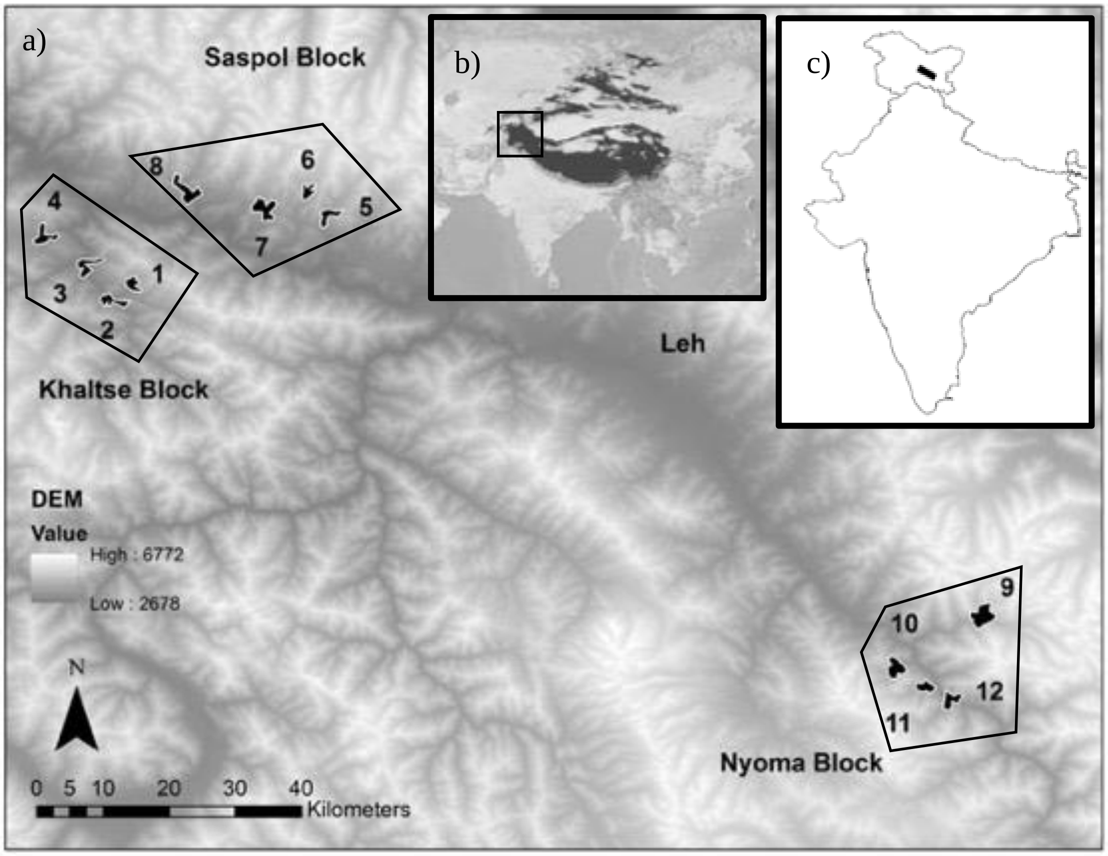


Figure 1. Map of Ladakh study area (a), located around the capital of Leh, within the snow leopard's range (inset b) and in northern India (inset c) (Jackson et al. 2008). Three survey blocks were selected based on qualitative assessments of terrain ruggedness: Khaltse Block (low ruggedness), Saspol Block (moderate ruggedness) and Nyoma Block (high ruggedness). Four search sites were established within each block, sequentially numbered 1-12. Polygon shape indicates approximate visual survey area at each site, using both vantage point scans and transects. Base map derived from a digital elevation model; gray scales represent elevations, with darkest grey representing lowest elevations (2678 m), white areas depict highest elevation (6772 m).

a) b)

Figure 2. Photographs of typical Ladakhi villages: a) Ulley village family household, showing yak livestock (foreground), stone fence and corral/house (background, right); b) Predator trap in Himya village. To trap a predator a small animal such as a goat or a calf is placed in the depression as bait, and the predator is killed after it cannot jump back out.

2. Materials and Methods

2.1 Study Area

Ladakh (34°N 78°E, ~87,000km^2) is almost entirely characterized by the jagged peaks of three parallel northwestern Himalayan and Karakoram mountain sub-ranges, the Ladakh, Zanskar, and Himalayan (Figure 1a). Altitudes range from 3000m to over 6000m, with human habitations occurring in valleys as high as 5000m. Climate throughout Ladakh is typically dry (less than 300mm of rain annually), with extreme temperature fluctuations. The easternmost part of Ladakh is the western edge of the Tibetan Changthang plateau, where a nomadic lifestyle is continued to this day. In the rest of the region people live in small villages in the valleys, where they herd livestock in mountain pastures and grow sufficient amounts of barley (main crop), peas, turnips, and potatoes (Figure 2). The surrounding mountains are arid, steep, and rocky, but support a diverse assortment of plant and animal life. Apex predators are the snow leopard, grey wolf, and Tibetan brown bear (*Ursus arctos*). Other predators are the red fox (*Vulpes*

vulpes), Tibetan sand fox (*Vulpes ferrilata*), Eurasian lynx (*Lynx lynx*) mountain weasel (*Mustela altaica*), and golden eagle (*Aquila chrysaetos*). There is also a growing population of feral dogs, which compete with wild predators and have been known to attack wildlife, domestic livestock, and people. Since 1972, all wildlife in Ladakh have been legally protected from hunting (Mallon 1991; Mishra et al. 2006; Namgail et al. 2007a; Rizvi 1998).

Following the Snow Leopard Information Management Systems (SLIMS) protocol, I selected three survey blocks of approximately 300 square kilometers each (Jackson and Hunter 1995; McCarthy et al. 2008). These survey blocks—Khaltse, Saspol, and Nyoma—were selected in collaboration with SLC-IT to study three levels of qualitative terrain ruggedness (low, medium, and high, respectively), maximum accessibility, and minimal permitting requirements. The blocks were at least ten kilometers apart and were separated by a physical barrier (e.g. the Indus River). Four search sites, located at small villages or hamlets and approximately ten square kilometers each, were selected in each survey block, and were approximately 5 kilometers apart. Four transects, four vantage point scans, and five household depredation surveys, were conducted in each search site (Figure 3). For the duration of the study I was accompanied by the same local Ladakhi guide who served as translator and collaborator. In each search site we stayed in a local homestay, frequently sponsored by SLC-IT or another Ladakhi NGO. All field data were collected in June and July 2016.

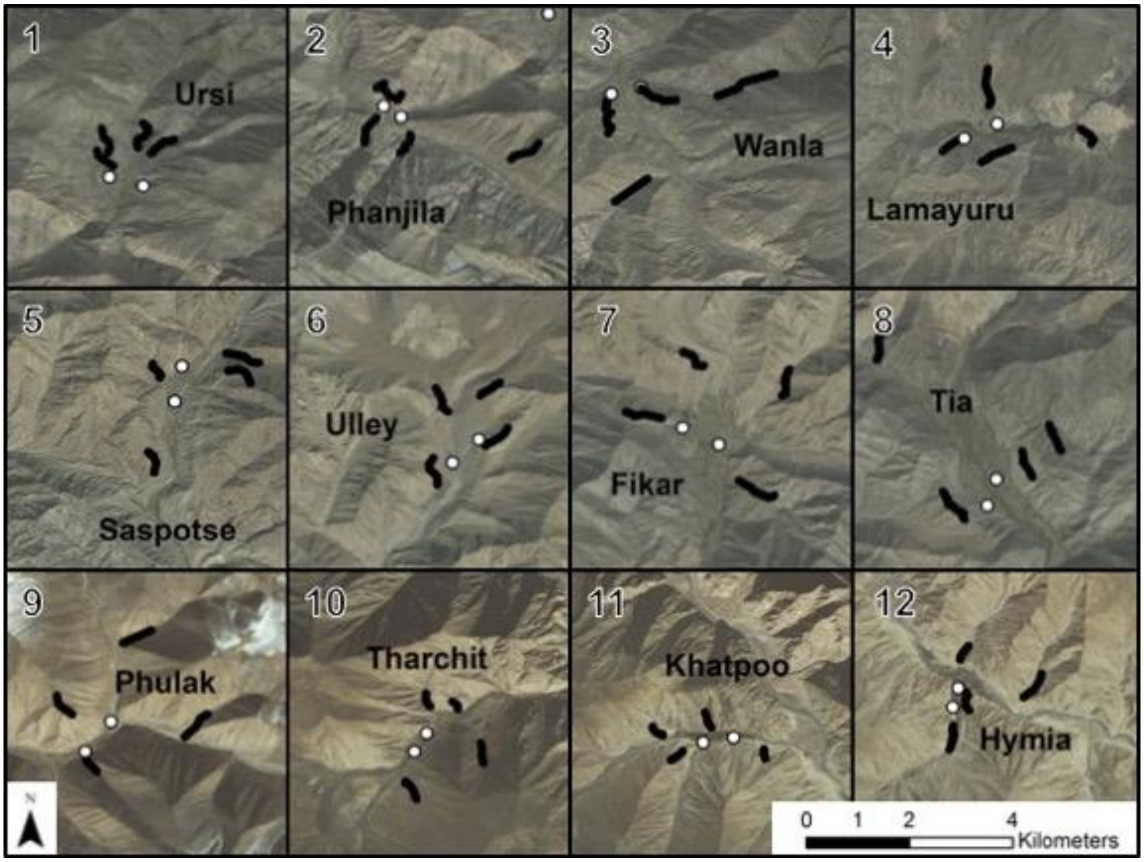


Figure 3. Twelve search sites, labeled as in Figure 1a, with Esri satellite imagery base map. Black lines represent 1km x 10m transects used to search for snow leopard sign. White dots represent vantage points used to scan for wildlife.

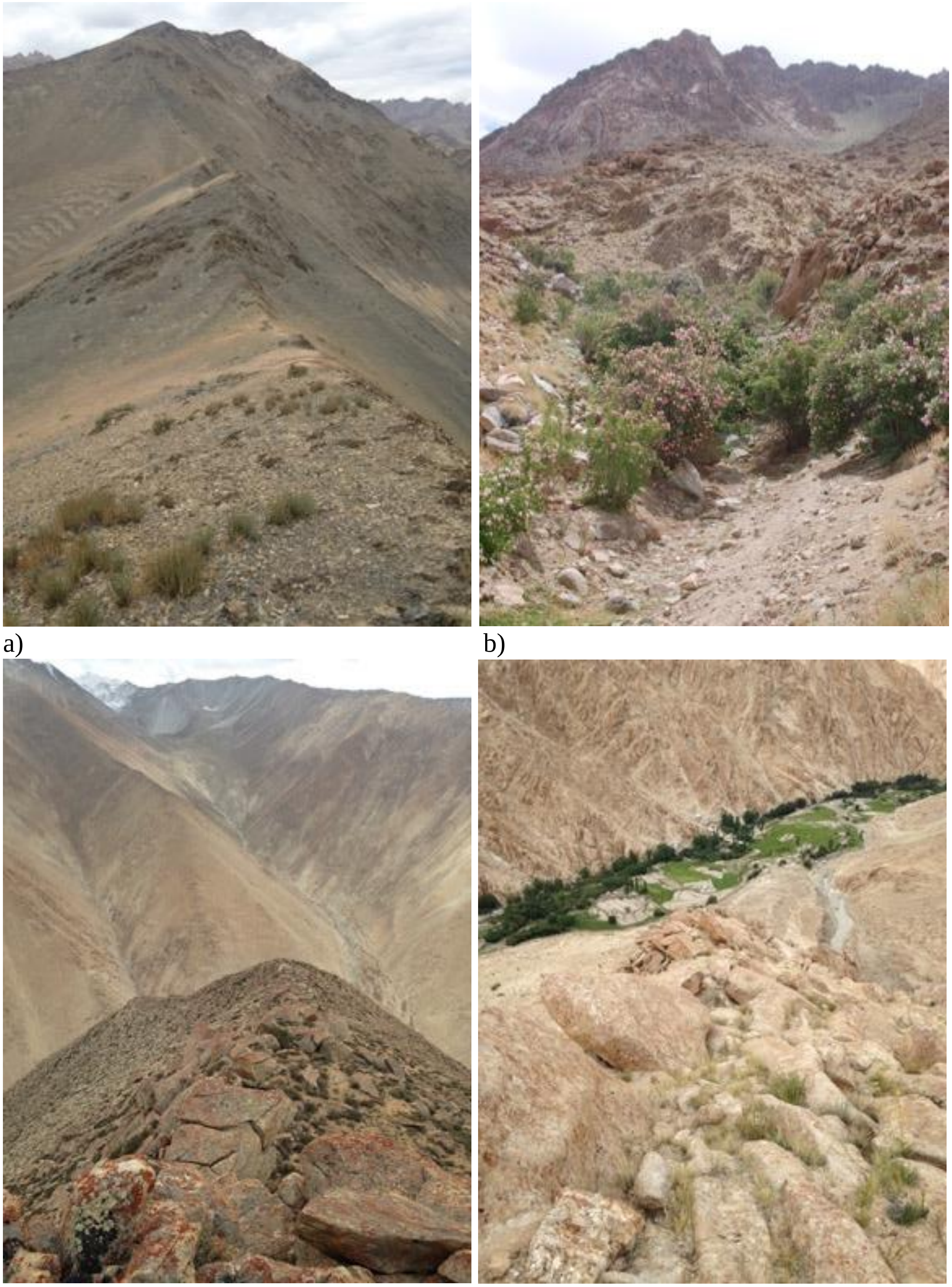
2.2 Data Collection

At each search site I walked four transects, each one kilometer long and ten meters wide, to search for animal sign (Figure 3, Appendix 1). Transects were located in areas most likely to contain snow leopard sign, which were ridgelines and narrow canyons/cliff bases (Alexander et al. 2016b; Jackson and Hunter 1995; Suryawanshi et al. 2013). All animal sign and animal carcasses were recorded, but I only focus on snow leopard sign in this study. It was too difficult to distinguish between wild and domestic sign for both canids and ungulates.

Snow leopard sign, predominantly scat and tracks, were recorded and photographed, as well as examined on site to ensure highest chance of correct identification. Scats were crushed on site with a rock or stick to examine contents and to determine approximate age based on moisture content and color. Snow leopard scats were distinguishable from canid scats because of their ovular shape and smooth, round ends, less fur and bone content, and more woody plant material (Figure 4a). Tracks were only recorded if the three-lobed heel pad and overall circular shape were obvious (Figure 4b). Sightings of other wild felines (Asiatic lynx and Pallas' cat *Otocolobus manul*) were extremely rare throughout the study area, so I was confident that any felid tracks were those of the snow leopard (Jackson and Hunter 1995). Sets of tracks (along a path or of the same age, size, and direction) were only recorded as sign once to avoid pseudoreplication. Any live animal sightings, regardless of distance from transect, were also recorded along with their distance, direction, and behavior. Transects were recorded using a Garmin GPSmap 62st, and the transect vegetative cover, slope, and brokenness were recorded qualitatively. Slope was recorded on a scale of 1 (0°-18°) to 5 (72°-90°), and brokenness on a scale of 1 (sand or smooth ground) to 5 (large boulders and jagged cliffs). Photographs were taken of each transect to maximize measurement consistency (Figure 5a-d, Appendix 2).

a) b)

Figure 4. Photographs of snow leopard sign. Scat (a) was characterized by its rounded shape and ends, woody material, and comparatively less bone and hair than canids. The tip of the walking stick at the top of the photograph is approximately 1cm wide (for scale). Tracks, or pug marks (b), were characterized by their large size (~5cm wide) and typical feline shape. Note especially the circular shape of the track, circular pads at the front (right), and three-lobed heel pad.



a) b)

c) d)

Figure 5. Variation in surrounding terrain ruggedness qualifications between four example transects. a) slope = 3, brokenness = 1; b) slope = 3, brokenness = 3; c) slope = 4, brokenness = 4 d) slope = 5, brokenness = 5. Ruggedness was qualified as an average of slope (1-5) and brokenness (1-5), with 1 being minimal and 5 being extreme (Appendix 2).

Vantage point scans were also conducted at each search site. Two vantage points, approximately one kilometer apart, were selected in each site. At each vantage point I scanned for wildlife, particularly wild ungulates and predators, for one hour shortly after dawn and one hour shortly before dusk (Jackson and Hunter 1995). All scanning was done with 10x32 binoculars and a 20-60X spotting scope. All wildlife spotted were identified and photographed if possible, and counted; animal behavior and surrounding landscape features such as slope, aspect, brokenness, and vegetation cover were also recorded. A panoramic video of the surrounding landscape was taken from each vantage point, and overall slope and brokenness were recorded on the same 1-5 scale as for the transects. All transects and vantage points were imported from the portable Garmin GPSmap 62st device into Esri ArcMap.

Search sites were located at villages and hamlets ranging in size from 8 to 234 households, but regardless of household number we opportunistically selected five households to interview per site, except Tharchit, where only four households were included due to unforeseen complications (LAHDC 2010). Each site in the study was a loose cluster of households separated from other clusters by distance and/or landforms. After giving a brief description of the study each interview was semi-structured and conducted with verbal consent from the subject, who was either the household head or his wife (Appendix 3). Interviews consisted of questions about total livestock ownership, total 2014-2015 livestock losses (including sale, disease, and disappearance), husbandry practices, perceived trends in livestock depredation by various carnivores, attitudes towards several types of wildlife and wildlife in general, and any known religious/cultural significance of any wildlife species (Li et al. 2013b; Namgail et al.

2007a). Interviews took between ten and thirty minutes each. If the respondent seemed uninterested or not serious their responses were not included in the study. Interviews were conducted at the respondent's convenience, in households, fields, or along roadsides, and usually toward the end of our stay in the village (Figure 3).

2.3 Analysis

2.3.1 Terrain Ruggedness

Using satellite imagery and the GPS points, vector polygons were drawn around each search site in ArcMap to reflect total approximate visual field evaluation area (Figure 1a). Several techniques were then used to calculate terrain ruggedness within this area (Chen et al. 2016; Cooley 2016; Jenness 2004; Sappington et al. 2007; Sharma et al. 2015). A Qualitative Ruggedness Measure (QRM) was calculated in by multiplying the average slope and brokenness values measured at the two vantage points (Figure 4, Appendix 2). Elevation variance and range were calculated by clipping a 30mx30m raster Digital Elevation Model (DEM) to the smallest rectangle around each site polygon in ArcMap (Figure 1a). The resulting raster summary values were divided by the smallest variance or range and multiplied by 5 to convert them to the same 1-5 scale as the QRM (NASA-JPL et al. 2009). Mean ruggedness values were also calculated from the DEM, using the Esri Vector Ruggedness Measure (VRM) tool at neighborhood sizes of 5, 25, and 55 (Sappington et al. 2007). VRM 5 and 55 raster outputs were clipped like the DEM in ArcMap, and means from the raster summaries (originally on a 0-1 scale) were multiplied by 5 to convert values to the same scale as other ruggedness metrics (Figure 3). Ruggedness values were compared graphically on a scatterplot and statistically using Welch two sample t-tests and generalized linear models (GLM).

2.3.2 Statistics

Data from transects, vantage point scans, and depredation questionnaires were consolidated. Only snow leopard scat and tracks were ultimately included in the “sign” numbers, and were left unweighted. Although different species of livestock result in different monetary losses for agro-pastoralists, each loss was counted equally as one individual. Depredation rates were defined as 2014-2015 snow leopard depredation divided by total 2014-2015 household livestock ownership (including individuals sold or killed during that period). Goats and sheep were grouped into a “small livestock” category, whereas all other livestock (horse, yak, *dzo*, cattle, donkey) were grouped into a “large livestock” category. Depredation events were also grouped into corral and pasture losses, as well as spring, summer, fall, and winter losses.

All data were normalized using both standard (data-mean/standard deviation) and log(data+1) transformations. Welch two-sample t-tests and Wilcoxon rank sum tests were then used to test for significance (at alpha ≤ 0.05) of depredation rate differences between corrals and pastures and between large and small livestock. Analysis of variance (ANOVA) and Kruskal-Wallis chi-squared tests were used for differences in depredation rates between each season, between blocks and between search sites (Wang and Macdonald 2006). Potential site-level depredation correlates were graphed on scatterplots and distinguished by survey block: snow leopard sign vs. terrain ruggedness; snow leopard sign vs. depredation rate; and terrain ruggedness, number of households, snow leopard sign, and total livestock ownership vs. depredation rate. Pearson correlation coefficients and GLMs were used to look for/confirm observed relationships, substituting the different terrain ruggedness metrics (Ahmad et al. 2016; Koziarski et al. 2016; Miller et al. 2016a; Sharma et al. 2015). All analyses were conducted in R for Mac.

3. Results

3.1 Snow Leopard Sign and Wildlife Observations

I walked 48, 1km x 10m transects looking for sign and spent 48 total hours scanning for wildlife, in twelve search sites and three survey blocks. Most snow leopard sign observed was scat, ranging in age from approximately one week to several months old (Figure 4a). Tracks were observed in both Saspol (moderate ruggedness) and Nyoma (high ruggedness) blocks, but scat was observed in all three blocks (Figures 1a and 4b). Although I did not see any snow leopards during the field season, villagers had recently seen them in the area. Only one site, Wanla (3), in Khaltse block (low ruggedness), had zero observed snow leopard sign, whereas Phulak site (9), in Nyoma block, had 52 sign observations. In total, 166 sign observations were recorded.

Live animal sightings were combined from transect and vantage point observations. Ladakh urial (*Ovis vignei vignei*) was the most abundant wild ungulate spotted in both Khaltse and Saspol blocks (Figure 6a). Asiatic ibex was also prevalent in Khaltse and Saspol blocks. Blue sheep was the only wild ungulate species spotted in Nyoma block (Figure 6b). Burrowing mammals such as Himalayan marmots (*M. himalayana*) and pika (*Ochotona spp.*) were not found in Khaltse block, though they were spotted in both Saspol and Nyoma blocks (Table 1).

a) b)

Figure 6. Most common ungulate species: a) Ladakh urial rams, *Ovis orientalis vignei*; b) male and female blue/bharal sheep, *Pseudois nayaur*.

Table 1. Total number of live mammal and bird of prey sightings from transects and vantage point scans in each survey block. Individuals seen during multiple scans were counted once per scan. For example, if a herd of ibex was spotted during a vantage point scan and then during from a transect, it was counted twice. Ungulate abundance and diversity may be used as approximate confirmation of ruggedness measurements in this study. Notably, no population surveys of Ladakh urial have been conducted in the Khaltse block before this study; more surveys in the area are recommended.

Block	Ladakh Urial	Himalayan Ibex	Blue Sheep	Other
Khaltse	151	63	1	1 weasel, 1 golden eagle
Saspol	127	33	0	1 Himalayan marmot, 1 pika, 2 golden eagle, 1 lammergier, 2 cape hare, 1 red fox, 5 feral dogs
Nyoma	0	0	139	3 Himalayan marmot, 1 pika, 3 golden eagle

3.2 Livestock Mortality

I interviewed 59 people in twelve search sites from three different areas throughout the Leh district of Ladakh about their livestock ownership and losses for 2014 and 2015 (Appendix 3). Total livestock ownership was 1170, out of which 444 were “large” livestock and 726 were “small” livestock (Table 2). Large livestock were cared for in slightly different ways depending on species, but all were left unattended in mountain pastures much more regularly than small livestock. Yak and *dzo* were most frequently kept in the pasture except for during harvest time. Horses were kept in the pasture during the summer when not on hire as trekking pack animals. Cattle were kept in corrals or pastures nearer to the village for dairy access. Small livestock were typically kept in corrals at night and herded to nearby pastures during the day. Many questionnaire respondents indicated they herded communally, with people taking turns caring for the entire village herd at once. In Khaltse block most people collected the carcasses of livestock that had been killed, but in Saspol and Nyoma blocks the majority of respondents indicated they left carcasses for snow leopards and other predators to eat.

Out of 231 head killed/lost from all causes, total snow leopard depredation was 88 head of livestock (37.7%). The average depredation rate (total individuals killed by snow leopards/total individuals owned during 2014-2015) was 7.5% across all twelve sites. Khaltse Block (lowest terrain ruggedness) had the highest depredation rate overall, followed by Nyoma block (highest terrain ruggedness) and Saspol block (Table 3). Two Khaltse sites also had two the highest depredation rates of all twelve sites (21.0 and 13.7%). Using ANOVA at the site-level scale, depredation rates were not significantly different among blocks ($p = 0.09$) or villages ($p = 0.09$). Terrain ruggedness and livestock ownership were significantly different among both blocks and sites (ANOVA, $p < 0.001$ for both). Corral kills made up 65.5% of all snow leopard kills (Welch two sample t test, $p = 0.44$, see discussion), 82.8% of all kills were small livestock ($p = 0.09$), and 65.5% of all kills were in spring (ANOVA, $p = 0.20$, Table 3). Out of 59 total households, 42% of respondents claimed depredation by snow leopards was increasing; 44% had a negative opinion of snow leopards, 5% had a neutral opinion, and 51% had a positive opinion. They typically associated snow leopards and wolves with bad karma and conflict with local earth/water spirits (*lhalu*).

Table 2. 2014-2015 livestock ownership data for twelve Ladakhi search sites. Data from the Khaltse block (least rugged) are in top section, Saspol block middle, and Nyoma block (most rugged) at bottom. Names are of villages and hamlets comprising each search site, spelled phonetically and per the most common conventions. Household information is from the LAHDC "Gyurja" Report, 2010, and household interviews. All other totals are strictly from summer 2016 questionnaires without extrapolation. "Small" livestock are defined as sheep and goats; "large" livestock are defined as anything else, including yak, cattle, horse, and donkey.

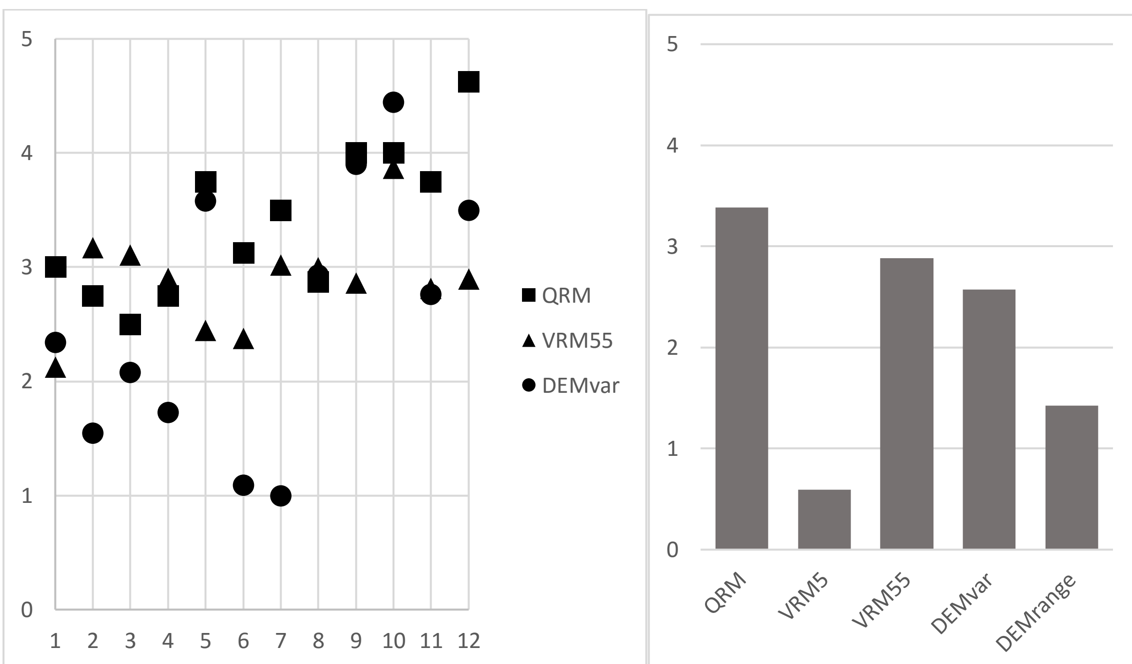
Search Site	Estimated Total Households	Total Households Interviewed	Total Livestock Ownership	Total Large Ownership	Total Small Ownership
Ursi	22	5	169	44	125
Phanjila	20	5	167	27	140
Wanla	119	5	191	35	156
Lamayuru	83	5	197	28	169
Saspotse	37	5	29	24	5
Ulley	8	5	71	57	14
Fikar	33	5	36	30	6
Tia	234	5	37	21	16
Phulak	24	5	130	88	42
Tharchit	58	4	80	27	53
Khatpoo	12	5	42	42	0
Himya	38	5	21	21	0
Total	**688**	**59**	**1170**	**444**	**726**

Table 3. 2014-2015 snow leopard (SL) depredation data for twelve Ladakhi search sites. No depredation patterns were statistically significant at a significance level of 0.05.

Search Site	SL Sign	Total Livestock Ownership	Total Mortality 2014-15	SL Depredation	Total Corral SL Kills	Total Large SL Kills	Total Winter SL Kills	Total Spring SL Kills	Total Summer SL Kills	Total Fall SL Kills
Ursi	4	169	38	11	4	5	6	1	3	1
Phanjila	1	167	40	35	18	2	0	27	7	1
Wanla	0	191	20	1	0	1	0	0	0	1
Lamayuru	2	197	42	27	27	0	0	27	0	0
Saspotse	11	29	6	0	0	0	0	0	0	0
Ulley	12	71	13	2	0	2	1	1	0	0
Fikar	15	36	6	0	0	0	0	0	0	0
Tia	42	37	10	0	0	0	0	0	0	0
Phulak	52	130	22	2	0	0	1	1	0	0
Tharchit	4	80	27	6	6	1	6	0	0	0
Khatpoo	9	42	6	3	2	3	2	0	1	0
Himya	14	21	1	1	0	1	0	0	1	0
Total	**166**	**1170**	**231**	**88**	**57**	**15**	**16**	**57**	**12**	**3**

3.3 Measures of Terrain Ruggedness

DEM and VRM calculation techniques were compared with the QRM field technique, using t-tests, scatterplots, and GLMs (Figure 7, Appendix 4). Using a Welch two-sample t-test, the VRM 5 (fine scale) and VRM 55 (course scale) neighborhood sizes, as well as their inverses, were significantly different from the QRM ($p < 0.001$ for all, except VRM 55 $p = 0.04$). DEM variance and range calculations were also significantly different from QRM ($p = 0.05$). GLMs were run for measures with the highest p-values, which were DEM variance, range, and the 55 neighborhood-size VRM. Given the t-tests, scatterplots, and GLMs, DEM variance was most compatible with QRM (QRM ~ 2.4 + 0.38x, $R^2 = 0.43$, AIC = 21.91; compare with QRM ~ 2.18 + 0.19x, $R^2 = 0.02$, AIC = 28.44 for VRM 55).



a) b)

Figure 7. Comparisons between Qualitative Ruggedness Measure (QRM) used in the field with two digital terrain ruggedness calculation techniques, Vector Ruggedness Measure at a 5- and 55-neighborhood scale (VRM5, VRM55) and Digital Elevation Model variance and range (DEMvar, DEMrange). a) variation among most similar ruggedness metrics in each village. b) Variation among mean ruggedness metrics across all twelve villages.

3.4 Correlates of Depredation

Four potential correlates—snow leopard sign, terrain ruggedness, total livestock ownership, and number of households—were utilized from original data. I grouped questionnaire and transect data into village-level points and sorted by block to have a visual representation of two scales (Figures 8 and 9). Observed snow leopard sign was positively correlated with QRM (Pearson correlation coefficient = 0.28, sign ~ -22.81 + 15.48x, R^2 = 0.08, AIC = 122.8, Figure 8a) and number of households (Pearson correlation coefficient = 0.32, Figure 8c), and negatively correlated with livestock ownership (Pearson correlation coefficient = -0.32, Figure 8b). Livestock ownership was negatively correlated with QRM (Pearson correlation coefficient = -0.67, Figure 8d).

Snow leopard sign (Pearson correlation coefficient = -0.48) and livestock ownership (Pearson correlation coefficient = 0.50) were most strongly correlated with depredation rate (Figure 9a, d). GLM indicated no strong relationships with depredation rate (depredation ~ 0.008 + 0.009QRM – 0.001sign + 0.0003livestock – 0.0001households, R^2 = 0.36, AIC = -29.25). Multiple regression yielded similar results, as did substituting VRM 55 (R^2 = 0.46, AIC -31.39) and DEM variance (R^2 = 0.36, AIC = -29.22) ruggedness measures.

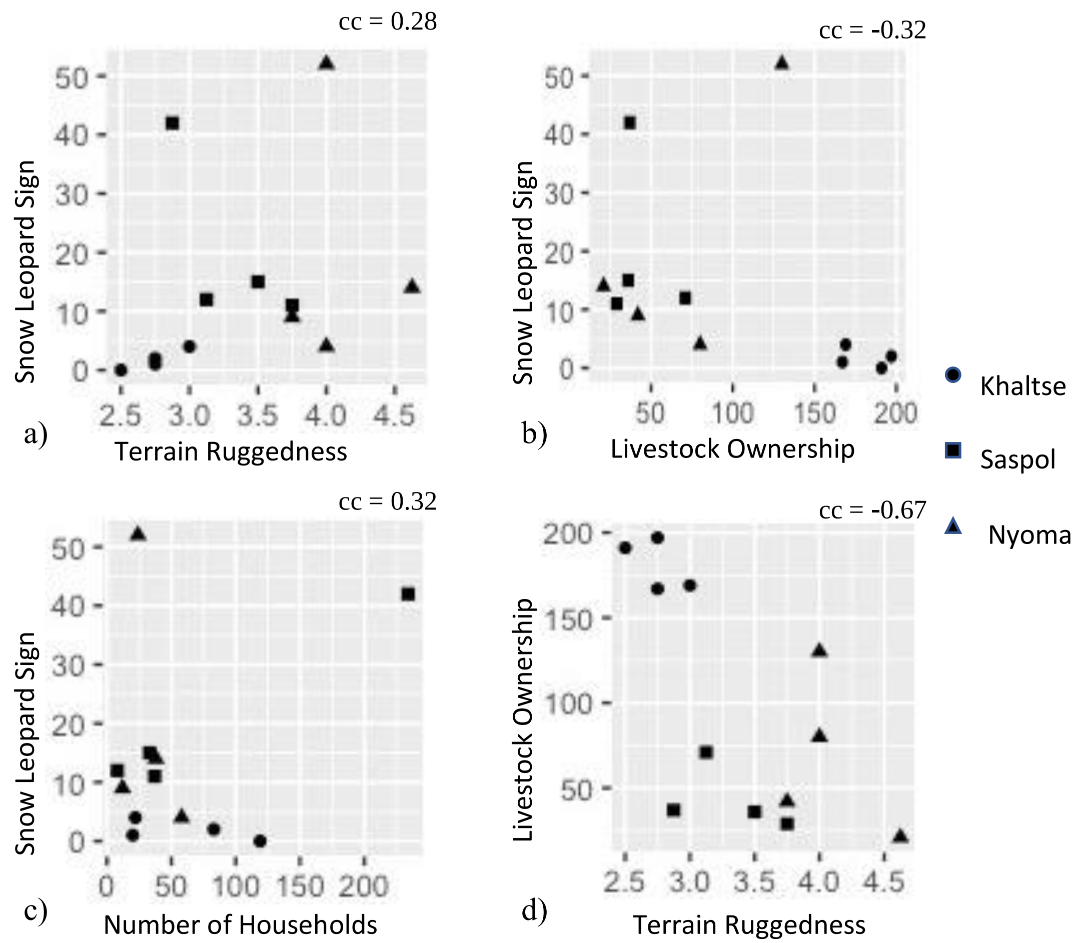


Figure 8. Scatterplots among site-level variables: snow leopard sign, terrain ruggedness, livestock ownership and household number. Each data point on the scatterplot is one search site, grouped into Khaltse Block (circles), Saspol Block (squares), and Nyoma Block (triangles). Correlation coefficients (cc) are at the top right corner of each plot. As expected, there is a positive correlation between snow leopard sign and overall ruggedness (a), and slightly negative correlations between snow leopard sign and total livestock ownership (b) as well as total livestock ownership and ruggedness (d). Unexpectedly, there is a slightly positive correlation between snow leopard sign and number of households (c).

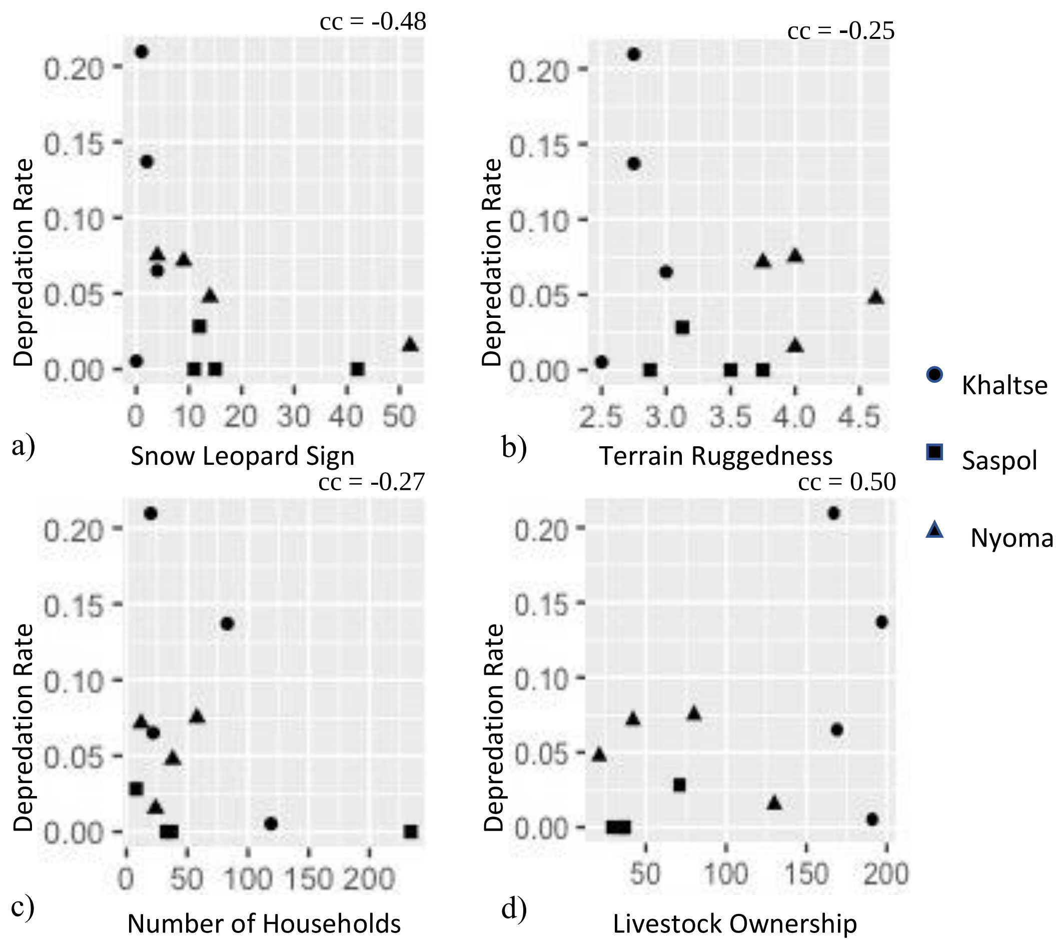


Figure 9. Scatterplots of site-level depredation rates with snow leopard sign (a), terrain ruggedness (b), number of households (c), and livestock ownership (d). Each data point on the scatterplot is one village, grouped into Khaltse Block (circles), Saspol Block (squares), and Nyoma Block (triangles).

4. Discussion

4.1. Snow Leopard Sign

For a basic, cost-effective estimate of snow leopard presence and approximate abundance, the Snow Leopard Information Management System (SLIMS) is a useful tool for basic socio-ecological research (Jackson and Hunter 1995; McCarthy et al. 2008). Accuracy of field identification, especially of scat, varies with study area and personnel, but can range from 21% to 67% (Jumabay-Uulu et al. 2014; Shehzad et al. 2012;

Weiskopf et al. 2016). Because I collected all field data during one season and in a relatively small portion of the snow leopard's range, I have assumed sign identification error to be consistent. Furthermore, this study examines only relative abundance of sign, so it is assumed that correcting for constant identification error will not change the conclusions. Estimating snow leopard population size and abundance is most reliably accomplished with camera traps, GPS collaring, and fecal analysis, but these methods require more personnel, funding, and time (Balme et al. 2009; Johansson et al. 2016; McCarthy et al. 2008).

4.2 Livestock Mortality

The data indicate both strong similarities and contradictions with previous studies. Snow leopards killed a total of 88 head of livestock (38.1% of total mortality, 7.5% of total ownership) in the study area. The highest proportion of livestock killed were sheep and goats (83%), which is strikingly similar to some studies (Ahmad et al. 2016; Mishra 1997; Namgail et al. 2007a; Wang et al. 2014). Other studies have not found such a high percentage of depredation in the spring, or in corrals, however (Ahmad et al. 2016; Alexander et al. 2015; Aryal et al. 2014; Namgail et al. 2007a; Sangay and Vernes 2008). It is important to note that none of these results were significant using post-hoc analyses and the tests I conducted, but patterns nevertheless may be practically significant. The tests could be skewed by the small sample size, and do not reflect biases in depredation reporting and predator identification in the questionnaires. Further research is necessary to gain a more thorough understanding of these patterns.

4.3 Terrain Ruggedness Measurements

Qualitative Ruggedness Measure (QRM) data were not strongly correlated with any other terrain ruggedness measurement technique. Indeed, they were all statistically significantly different. This is most likely the result of not only differences in measurement techniques but in scale and map resolution. Variance from the Digital Elevation Model (DEM) was most correlated with QRM, and showed similar relationships to other variables such as snow leopard sign and depredation rate. Vector Ruggedness Measure (VRM), both at 5 and 55 neighborhood sizes, was much less related to QRM. Indeed, there are multiple methods for measuring terrain ruggedness, they might all be useful for certain tasks (Cooley 2016). For studies like this one, however, I argue that QRM is a valid way of measuring terrain ruggedness that is tailored to the study subject and is very user-friendly. It is consistent and does not require internet or computer software—an asset for many remote ecological studies.

4.4 Depredation Correlates

Livestock depredation by snow leopards is frequently assumed to be positively correlated with snow leopard abundance, and snow leopards are known to occur in highly rugged areas (Alexander et al. 2016b; Jackson 1996; Suryawanshi et al. 2014; Suryawanshi et al. 2013). One of the goals of this study, therefore, was to test terrain ruggedness as a potential predictor of snow leopard presence in its known range and thus as an indicator of depredation risk (Chen et al. 2016; Sharma et al. 2015). Snow leopard sign and terrain ruggedness were positively correlated in scatterplots, GLM and Pearson correlation analysis, but their relationship with livestock depredation remains unclear. One potential reason is the scales of terrain ruggedness measurement and of depredation reports were not identical. While the GLM indicates ruggedness might have a slightly positive relationship with depredation, correlation coefficients (which are more appropriate in this case) indicate that ruggedness and snow leopard sign are in fact both negatively correlated with depredation. Even with discrepancies of scale this pattern can further support the argument that coexistence between humans and snow leopards is possible, as snow leopard presence and landscape features may not preclude an increased risk of livestock depredation (Sharma et al. 2015).

Most studies identify wild prey abundance as the strongest indicator of livestock depredation, but different studies have found contradictory relationships (Bagchi and Mishra 2006; Khorozyan et al. 2015; Miller 2015; Sharma et al. 2015). Such contradiction is perhaps due to sampling error, differences in methodology, or, more likely, inherent spatial and temporal heterogeneity within the snow leopard’s range (Ahmad et al. 2016; Alexander et al. 2016b; Aryal et al. 2014; Chen et al. 2016; Fuller and Sievert 2001; Graham et al. 2005; Inskip and Zimmermann 2009; Jackson et al. 2006; Namgail et al. 2007a; Sangay and Vernes 2008; Suryawanshi et al. 2013). Unfortunately, prey abundance could not be adequately assessed in this study. Another potentially important factor in livestock depredation that could not be adequately assessed is the impact of carcass collection.

Perhaps even more important than actual snow leopard depredation is locals’ perceptions of the harm it causes. Depredation and perception of harm are frequently not directly related, and other factors such as lack of veterinary care and vulnerability to disease can make herders much less resilient when predators occasionally do kill (Bagchi and Mishra 2006; Koziarski et al. 2016; Li et al. 2013a; Treves and Karanth 2003).

Finally, it is difficult to assess socioecological correlates of depredation due to the rapid changes occurring in Ladakh and throughout the snow leopard's range.

4.3 Social Change in Ladakh

Ladakh is undergoing extreme, rapid change socially and environmentally, which brings both challenges and impetus to study the area and to protect Ladakh's natural heritage (Fox et al. 1994). Increased military presence due to conflicts with China and Pakistan over the last four decades have brought an influx of cheap foods, paved roads, infrastructure, and feral dogs (Takeda and Yamaguchi 2015). The tourism industry and development initiatives from the Indian government have increased the so-called economic wellbeing of Ladakhis, but have also brought an influx of migrant workers and an ever-increasing strain on already scarce natural resources. Community composition is rapidly changing as young Ladakhis are flocking to the capital Leh and other Indian cities to find jobs. Elder and uneducated relatives remain in the villages to tend to herds of livestock, which are growing unsustainably in some areas and shrinking in others. Much of this change is occurring without Ladakhis' full awareness of potential side effects (Namgail et al. 2007a; Norberg-Hodge 2009; Sharma 2012).

At the same time, however, many Ladakhis are making a conscious effort to take charge of development and modernization in their homeland, and have so far been moderately successful with the help of both local and international NGOs. As demonstrated in this study and others, overall opinion of snow leopards and other wildlife in general has greatly improved over the last two decades in Ladakh (Alexander et al. 2015; Oli et al. 1994). Environmental Education (EE) is part of formal school curricula in

Jammu and Kashmir, and Ladakhi teachers emphasize the importance of EE in their individual schools (Barthwal and Mathur 2012). Ladakhis have founded their own NGOs such as SLC-IT and the Ladakh Foundation, and over 15,000km^2 have been set aside as protected areas throughout Ladakh (Goeury 2010; Jackson et al. 2010; Norberg-Hodge 2009). As in other parts of the snow leopard's range, Ladakhis are also drawing inspiration from their Tibetan Buddhist culture (Klubnikin et al. 2000; Li et al. 2014).

4.4 Management Implications, Future Directions

There are no strong correlations between domestic livestock depredation and other socioecological factors that can be identified from this study. As expected, snow leopard sign was correlated with terrain ruggedness, but both were in fact weakly negatively correlated with livestock depredation rate. This weakly negative correlation suggests that predator presence near a village does not necessarily guarantee a higher risk of livestock depredation, and therefore a degree of coexistence is possible (Sharma et al. 2015). Villagers may be able to benefit both from their traditional agro-pastoralist livelihood and from wildlife ecotourism.

Furthermore, the majority of livestock deaths, although not statistically significant (see section 4.2), were small livestock and occurred in corrals. Of all possible causes of livestock mortality, these are some of the most preventable deaths. Small livestock are herded more vigilantly than large livestock, so improved husbandry techniques might help protect more livestock against snow leopards. Corrals, too, can easily and cost-effectively be "predator-proofed" by adding a chain-link roof. Conservation NGOs facilitate the corral improvements, which strengthens relationships between local villagers and conservationists (Jackson et al. 2010). Overall, this study provides another example of inherent social and ecological heterogeneity within the snow leopard's range.

Effective management efforts now and in the future will therefore depend on localized study and research, as well as intimate and multifaceted collaboration with local communities. Ecologically, snow leopard conservation can be beneficial to many other species through the umbrella and flagship effects. Snow leopard conservation can be positive for ecotourism and ecosystem services, but also negative in terms of increasing human-wildlife conflict with other carnivores (Alexander et al. 2016a; Cardinale 2012; Terborgh et al. 1997). Even with Ladakh's large protected areas, however, snow leopard survival will depend on its existence in shared landscapes, such as livestock pastures and agricultural landscapes (Bennett et al. 2006; Daily 2001; Fischer et al. 2008; Johansson et al. 2016). Education can be an important component of changing locals' perceptions and encouraging investment in conservation, even as livestock depredation continues (Barthwal and Mathur 2012). Additionally, improved veterinary services, sustainable and cooperative compensation schemes, and diversified income sources help reduce negative perceptions and make conservation economically sensible (Ahmad et al. 2016; Bagchi and Mishra 2006; Haasbroek 2015; Mishra et al. 2003a; Mishra et al. 2003b).

Tibetan Buddhism also has a potentially enormous role to play in conservation throughout the snow leopard's range. If monastery-based conservation existed throughout all Tibetan Buddhist regions it would cover 80% of the snow leopard's range (Li et al. 2014). Buddhism aligns closely with many conservation principles, but it is essential monastics also receive basic ecological education in order to effectively manage their surrounding environments, as is happening already through SLC-IT and similar organizations (Jackson et al. 2010). Monastics can also help address the long-term challenges of increased livestock holdings and human population growth in areas with extremely limited resources (Li et al. 2014; Mishra 1997).

Rather than a one-size-fits-all policy, a combination of the above factors, adaptive and tailored to the characteristics and needs of specific localities, is imperative for sustainable conservation (Chaffin and Gunderson 2016; Mishra et al. 2006). Instead of relying on bulky, often unsuccessful government schemes, conservation and livestock protection can be cost-effective and low-tech (Namgail et al. 2007a; Ogada et al. 2003). Reinforcing time-tested traditional livestock management practices is generally more successful in the long run, and has the added benefit of promoting cultural pride (Rao et al. 2003). Ultimately, "conservation depends on public acceptance of carnivore management" (Treves and Karanth 2003).

4.5 Conclusions

I found no statistically significant trends or correlates of domestic livestock depredation by snow leopards. This could be due in part to the small sample size and difficulty of data collection, but also is potentially due to the rapid change occurring in Ladakh right now. The combination of modernization and development, hyper-militarization, migrant workforce, and booming tourism industry, means Ladakhis are facing many difficult decisions about their future without having a full understanding of what's at stake. Many young Ladakhis, especially those who go to school, leave their village life behind in order to further their education and get a job in the city. This leaves only elderly and uneducated people in the villages, and there are no longer enough family members to effectively care for their livestock in a traditional way. These trends, as well as underlying ecological and social heterogeneity in the system, can affect any observations of depredation patterns. Snow leopard conservation in Ladakh ultimately depends on the commitment and vision of Ladakhis themselves. The international conservation community can help by empowering Ladakhis and giving them the tools they need to be benefited by conservation of snow leopards and other wildlife, and not disadvantaged.

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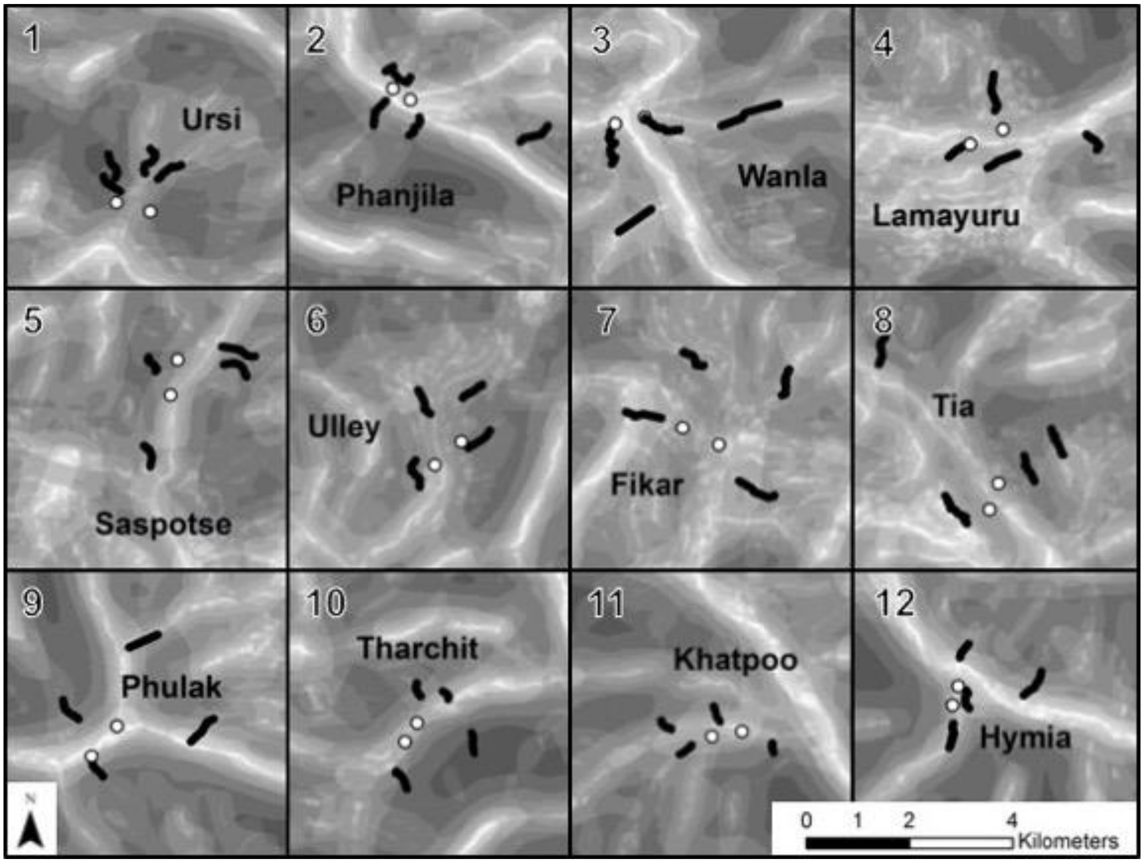
Appendices

Appendix 1. Twelve search sites, labeled as in Figure 1. Base maps are raster overlays of terrain ruggedness calculated using the Vector Ruggedness Measure (VRM) tool for neighborhood sizes of 5, 25, and 55. Least rugged areas are white and most rugged areas are dark grey in all images. Black lines represent 1km x 10m transects used to search for snow leopard sign. White dots represent vantage points used to scan for wildlife.



Appendix 2. Slope (top) and brokenness (bottom) stylized metrics, on a scale of 1 (left) to 5 (right).

Appendix 3. Livestock Ownership and Depredation Questionnaire. Note: some questions were ultimately not included in the study due to their tendency to be misinterpreted or not answered sincerely.

Disclaimer (read aloud in Ladakhi): This questionnaire seeks to obtain information on the mortality factors that affect your livestock, including depredation by wildlife and the environmental and livestock management factors influencing such loss. This information is vital to accurately assess the severity of depredation and other sources of mortality, so please be as accurate as possible when providing such information. **All information will be kept STRICTLY CONFIDENTIAL. This questionnaire is for RESEARCH PURPOSES ONLY.** Respondents will not receive any kind of direct compensation for their participation, but honest and accurate responses can inform more effective management and support in the future.

How many yak do you own? What are their approximate ages? Have you bought any in the last two years?

“ “ “ Drimo? Dzo? Dzomo? Oxen? Cows? Horses? Donkeys? Goats? Sheep? Other?

In 2014, how many yaks, of what age, did you lose? What month? What was the cause of death? What did you do with the carcass?

“ “ “ Drimo? Dzo? Dzomo? Oxen? Cows? Horses? Donkeys? Goats? Sheep? Other?

In 2015, how many yaks, of what age, did you lose? What month? What was the cause of death? What did you do with the carcass?

“ “ “ Drimo? Dzo? Dzomo? Oxen? Cows? Horses? Donkeys? Goats? Sheep? Other?

Do you herd your livestock individually or communally?

Do you guard your small livestock during the day? At night?

Do you guard your large livestock during the day? At night?

How often do you check your livestock in open pasture?

How do you know if your animal was killed by a snow leopard vs. another predator?

Do you think livestock losses to predators have increased, decreased, or remained the same throughout your lifetime?

What techniques do you find most useful in decreasing livestock losses to snow leopards and other predators? (guard dogs, household shepherd, communal shepherd, noise, smoke and fire, corrals, avoiding certain areas, trapping, etc.)

What do you think would be most helpful in decreasing the burden of snow leopard depredation? (e.g. insurance, alternative income, knowledge of risky areas and herding behaviors, etc.)

What are the most common wild animals you see? Where? (e.g. blue sheep, argali, ibex, urial, marmot, pika, snow leopard, wolf, fox, eagle, etc.)

Do you think wildlife are good or bad to have around the village? What about snow leopards in particular?

Do you know of local, cultural, or religious significance of any Ladakhi wildlife species?

Appendix 4. Ruggedness and elevation metrics for each search site. Qualitative Ruggedness Measure (QRM) was scored (on a scale of 1 to 5) based upon visual assessment in the field (see methods for explanation). Vector Roughness Measure (VRM) was calculated using the ESRI ArcMap tool, using data from a digital elevation model, using neighborhood sizes of 5 and 55. Mean, standard deviation (S.D.), maximum and minimum elevations were calculated using the 30x30m Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global DEM, Version 2.

Search Site	Qualitative (QRM)	VRM55	VRM5	Mean elevation (m)	S.D.	Maximum, Minimum Elevations (m)
Ursi	3	2.125	0.51	3895.7	197	4357, 3432
Phanjila	2.75	3.17	0.648	3512.5	160	4010, 3216
Wanla	2.5	3.11	0.695	3442.7	185.6	4008, 3113
Lamayuru	2.75	2.905	0.765	3636.7	169.2	4195, 3222
Saspotse	3.75	2.45	0.47	3988.3	243.5	4629, 3520
Ulley	3.125	2.375	0.7495	4262.8	134.5	4658, 3963
Fikar	3.5	3.02	0.885	3812	128.7	4285, 3519
Tia	2.875	2.9985	0.71	3644.8	220.4	4263, 3203
Phulak	4	2.865	0.4	4685.1	254.3	5272, 4160
Tharchit	4	2.345	0.4	4277.5	271.3	5110, 3726
Khatpoo	3.75	2.815	0.425	4075.3	213.9	4685, 3578
Himya	4.625	2.9	0.46	3971.8	240.8	4654, 3588