Assessment of snow lopards and their corridors in Nepal's East Himalayan Eco-region.

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Introduction, goal and objectives:

Few protected areas, worldwide, are large enough in themselves to contain viable populations of large predators such as the snow leopard and wolf that are considered important for maintaining ecosystem integrity. None of Nepal's protected areas, including Sagarmatha (or Mt Everest) National Park, is large enough in itself to contain a viable population of snow leopards estimated at around 50 breeding individuals[1]. Current conservation strategies, therefore, call for protecting habitats both within and outside of protected areas, creating landscapes where protected areas can be linked through dispersal corridors and patches of suitable habitat for maintaining breeding pools. In this era of tightening resources, the identification, delineation and conservation of [source and sink] corridors, however, is a challenge, both technically and socio-politically. Such is the case with Nepal's snow leopards and their potential corridors.

Snow leopards disappeared from Sagarmatha National Park in the 1960s, but with the onset of the millennium, in the early 2000s, the cat returned to the park. While the snow leopard is declining in many parts of its range in Asia, snow leopard's discovery in Sagarmatha for the first time in forty years attests to species resilience[2]. Although the snow leopard's return to the top of the world is encouraging, it raises several management-questions. Will this re-established population serve as source for re-colonizing adjacent areas outside the park? Are these remote highlands suitable for dispersing snow leopards? Anecdotal reports from villagers indicate that snow leopards from Mt. Everest are travelling to adjoining valleys. Snow leopards' scrapes, found at the base of Tesi Lapcha pass (5749 m), suggest that they may have dispersed into Rolwaling valley[3]. We know very little about snow leopards in areas such as Rolwaling that connects Sagarmatha and Langtang, and together they form the "Everest–complex", one of the three important land-clusters, identified by Nepal Government for the long-term conservation of snow leopards. Elderly Sherpa herders from Mt. Everest claim that snow leopards occasionally pass from Mt. Everest over high Amphu Laptsha Pass (5845 m) to high base camps (above 5000 m) to the valleys of Makalu – Barun National Park. These high passes and adjacent remote lands, lying in the eastern flank of Mt. Everest, may serve as another important refuge for dispersing snow leopards.

In this project, we intended to explore the western reaches of Mt. Everest, with the broad project goal, that is, to assess snow leopards -- using techniques of field biology -- GIS and other non-invasive methods, to identify, create and validate snow leopard corridors in areas outside of Nepal's protected areas. The goal fits well with Nepal Government's holistic snow leopard

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[1] Jackson R. M. and Ahlborn G. 1990. The role of protected areas in Nepal in maintaining viable population of snow leopards. Intl. Ped. Book of Snow Leopard 6, 51-69. Soule M. E. 1987. Viable populations for conservation. Cambridge University Press.

[2] http://www.cnn.com/2005/TECH/science/05/23/snowleopard/; Ale S. B. & Boesi R. 2005. Snow leopard sightings on the top of the world. Cat News 43: 19-20. Ale et al. 2007. Recovery of snow leopard in Sagarmatha (Mt. Everest) National Park, Nepal. Oryx 41: 89-92; Wolf and Ale. 2009. Signs at the top: Habitat and snow leopard activity in Sagarmatha national park, Nepal. J. Mammal. 90: 604-611.

[3] Wolf M. and Ale S. B. 2009. Signs at the top: Habitat and snow leopard activity in Sagarmatha national park, Nepal. J. Mammal. 90: 604-611.

conservation program that requires critical information on snow leopard status, distribution and dispersal routes across the landscape. Over 65% of Nepal's snow leopards, estimated at 300-500, are reported to reside outside of protected areas along generally human-dominated corridors[4]. This project, upon the completion, will identify the best snow leopard locales and dispersal routes for management interventions along the landscape outside the protected areas.

Undertaking a project of this breadth requires a multitalented team, diverse resources and multiple years, so a number of institutions and scholars are involved including Dr. R Jackson (Snow Leopard Conservancy) for snow leopard ecology, Dr. J. Janecka (Texas A & M) and D. Karmacharya (Center for Molecular Dynamics Nepal) for genetics, and Dr. K. Johnston (ESRI) for habitat modeling and GIS-mapping. The project involves several local experts and country biologists. Such local, national and international collaboration brings diverse skills, and merges science with local or traditional knowledge.

Four field trips were organized – one in Sagarmatha (Mt. Everest National Park) and three in adjoining Rolwaling valley, from October to November 2009, and three weeks each in May and November in 2010, to achieve the objective 1 -- Create corridors for metapopulation movements between the Everest and Annapurna region. The first task was to know the status of snow leopards in areas between Everest and Annapurna.

We employed non-invasive techniques (e.g., camera-trapping, scats collection for DNA analysis[5]) and mud-and-boots field biology[6], e.g., sign surveys and habitat characterization (see Annex I for detail methods) to collect the initial data (1) to find out the status of snow leopards (in Rolwaling) and (2) to initiate the first steps of corridor modeling. We have the information on snow leopard distribution from Mt. Everest to help us map snow leopard habitat preference in relation to livestock grazing, but little biological information exists in Rolwaling.

Findings in Rolwaling:

Running east-west for approximately 30 km, Rolwaling's value as a biological refuge derives partly from its location and physical isolation. It is separated from Tibet by a stretch of the Himalayas that includes Gauri-Shankar (7,134 m). The Rolwaling River flows into the Bhote Kosi. Simigaon, at the confluence of the Rolwaling and the Bhote kosi, is about 90 km east of Kathmandu, that can be reached by a 4 or 5 day trek from Barabise which lies on the road to Tibet in the next valley to the west.

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[4] Jackson R. M. and Ahlborn G. 1990. The role of protected areas in Nepal in maintaining viable population of snow leopards. Intl. Ped. Book of Snow Leopard 6, 51-69.

[5] Janecka, J.E., *et al.* 2008. Population monitoring of snow leopards using noninvasive collection of scat samples: a pilot study. Animal Conservation 11: 401 - 411; McCarthy, K. *et al.* 2008. Assessing Estimators of Snow Leopard Abundance. Journal of Wildlife Management 72: 1826-1833; Jackson, R. M. 1996. Home range, movements and habitat use of snow leopard (Uncia uncia) in Nepal. Ph.D. dissertation. University of London, London.

[6] Schaller, G. B. 1977. Mountain Monarchs: Wild Sheep and Goats of the Himalaya. Chicago: Univ. Chicago Press; Jackson, R. and D. O. Hunter. 1996. Snow leopard survey and conservation handbook. International snow leopard Trust and U. S. National Biological Service.

Rowaling valley lies in Guarishankar village development committee, Dolakha district, which falls within Gaurishankar Conservation Area (GCA) [85° 47.4', 86° 34.8' E and 27°34.2', 28°10' N]. According to Nepal Gazette dated July 19, 2010 – the responsibility to manage Gaurishankar Conservation Area has been entrusted to the National Trust for Nature Conservation (NTNC) for the next 20 years. The GCA covers an area of 2,179 square kilometers and encompasses 22 Village Development Committees spanning across three districts. NTNC promotes GCA as the "wildlife corridor" that connects Langtang National Park and and Sagarmatha (that is, Mt. Everest) National Park, and also as the "carbon-neutral" tourism destination. Annually, while over 30,000 visit nearby Sagarmatha, merely 1,000 tourists visit GCA. The region is relatively unexploited. It supports Himalayan tahr and musk deer [not blue sheep though] as the large wild ungulate prey that may constitute the food base of the snow leopard whose presence, population and conservation status this project would soon assess. Sacherer[7] estimated over 300 different plant species in Rolwaling. Partially shielded by its southern wall from the monsoon, Rolwaling has characteristics of the dry inner Himalaya; the region's flora akin to those found in Tibetan steppe and in Eastern Himalayan Ecosystem. Rolwaling's ecosystems vary dramatically from the broad glaciated valleys to the chiseled fluvial channel downstream. The sharp contrast between north- and south-exposed slopes affects the distribution of species. The east-west orientation of the valley may make it a convenient corridor for mobile fauna.

Rolwaling -- comprising two villages, Bedin and Na -- is sparsely populated, that is, less than 300 people, with double the number of livestock. Community forestry user group, with a wide network under the umbrella of Federation of Community Forestry Users Nepal, is formally active for natural resource utilization and conservation in the region. Informal women's groups and youth clubs are responsible for organizing social and religious ceremonies. Many individuals from households are engaged in trekking and climbing, in Sagarmatha or elsewhere, making tourism the main cash income enterprise of the region.

To obtain the initial data for objective 1, in October 2009, we organized a three-week survey in remote Rolwaling to assess the status of snow leopards.

A thousand of years ago in the foothills of the Himalayas, Padma Sambhava, the Indian yogi who brought the teachings of Buddhism from India to Tibet, plowed a valley out of the mountains to serve as one of eight beyul (Shangri-La) in Nepal, Tibet and Sikkim, the refuges that were to remain hidden in a time of unprecedented religious crisis protecting dharma until the misfortune passed. One beyul in Nepal went by the name of Rolwaling in the shadow of the lofty mountain Tseringma (7181m), or Gauri Shankar, which is believed to be the eldest of five divine sisters (one of them is reputed to reside on the summit of Mt. Everest). It is here, not Khumbu, as most believe, the notorious and celebrated yeti made its home. The sacred land today maintains Buddhist bans on hunting and slaughter, elsewhere observed less scrupulously.

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[7] Sacherer J. 1977. The Sherpas of Rolwaling Valley, North Nepal: A Study in Cultural Ecology. Ph.D. dissertation submitted to the Ecole Pratique des Hautes Etudes, Paris. Ann Arbor, MI: University of Michigan. Sacherer J. 1979. The High Altitude Ethnobotany of the Rolwaling Sherpas. Contributions to Nepalese Studies, Vol. VI, No 2. Kirtipur, Nepal: CNAS, Tribhuvan University.

Little is known about Rolwaling given its relative inaccessibility and because it did not lie on the important China-India trade routes. On 16 October 2009, after four days of continuous trek up along the Rolwaling River, we reached Bedin (3510m), a settlement of 65 households, and Na (4120m), the summer dwelling of Bedin's Sherpas. Partially shielded by southern mountains from the monsoon, this area has characteristics of the dry inner Himalaya. Mixed stands of *Abies, Betula* and *Rhododendron* become thinner as one ascends to Na, being completely replaced by juniper and rhododendrons interspersed with alpine grasses and sedges. When the potato was introduced in the mid-nineteenth century[8], cultivation became possible at lower altitudes, so the Sherpa, who primarily lived in Na, built Bedin and other winter settlements further downstream. Unlike Khumbu, that is, the Everest region, which received protected area status since 1976, Rolwaling falls outside Nepal's protected area network.

Excessive hunting - exclusively done by outsiders - has caused Himalayan tahr *Hemitragus jemlahicus* population to plummet, unlike nearby Khumbu where tahr are relatively abundant[9] (Lovari et al. 2009). As with many hunted ungulate populations, the kid-to-female ratio here is good (>0.7, that is, over 70% mothers had young). This observation however may be premature. During our research, we were able to locate just three distinct herds comprised of only 5, 4 and 3 individuals. Although we may have missed a few herds, clearly Rolwaling supports relatively small population of tahr that may not support even a single snow leopard. In spring of 2008, a survey team sent by WWF Nepal[10] counted 76 tahr in Rolwaling and 148 in Lapche (further west to Rolwaling), at various altitudes ranging from 3057 m to 4098 m. In Rolwaling valley, the ratio of male-to-female was found 0.21, kid-to-female 0.20 and yearling-to-kid 0.55. Notice the low kid-to-female ratio. The similar low kid-to-female ratio in Khumbu was explained to have caused by snow leopard predation but the rare snow leopard is even rarer in Rolwaling at least based on our sign survey. More detail surveys on tahr may be necessary before any conclusion is drawn.

Field notes (18 October 2009) reflects the difficulty of finding snow leopard sign in Rolwaling:

The 8th day of our arduous search for snow leopards in Na - we had yet to discover a "clear" set of snow leopard-pugmarks. That day, we climbed several hundred meters up the rugged, moraine-hills, one after another, to reach the sacred, 4600 m high glacial lake, Omai Tsho, which is inhabited by invisible spirits that are half man and half serpent. Lo and behold, a clear set of footprints along the beach: an adult snow leopard (Fig. 1)! Local herdsmen reported snow leopard pugmarks in the nearby high Teshi Lapcha La pass leading to Mt. Everest. Snow leopards may cross this pass. But how do we know whether the individual in Omai Tsho traveled from Khumbu or represented a resident of Rolwaling? This is a difficult question that can be answered only by using techniques of genetics or radio telemetry. Along a nearby ridgeline, we encountered several relic scrapes and feces, an indication that snow leopards regularly visit the area. This was surprising because this rolling area - once inhabited by blue sheep some 50 years ago - supports just a few tahr. Local shepherds also occasionally collected the huge curved

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[8] Bjønness, I. M. 1980. Animal Husbandry and Grazing, a Conservation and Management Problem in Sagarmatha (Mt. Everest) National Park, Nepal. Norsk Geografisk Tidsskrift 34: 59-76.

[9] Lovari S., Boesi R., Minder I., Mucci M., Randi E., Dematteis A. & Ale S. B. 2009. Restoring a keystone predator may endanger a prey species in a human-altered ecosystem: the return of the snow leopard to Sagarmatha National Park. Animal Conservation 12: 559-570.

[10] B. Shrestha, 2008, pers. com., unpub. report.

horns of blue sheep from this terrain. Do Omai Tsho and areas encompassing glaciated Tso-Rolpa Lake (which has been in the radar of glacial lake outburst for decades), serve as snow leopard refuge? Perhaps.

Fig. 1: *Omai Tsho*, the snow leopard dwelling

Fig. 1b: Adult snow leopard pugmark, *Omai Tsho*

We randomly laid out 6 sign-transects [total length 4023 m; mean 700m, SE=75m) following standard SLIMS procedures[11]. We detected several scrapes, scats, pugmarks and tufts of hair on sites where snow leopards had rubbed against rocks, along all but one transect [13 signs in 9 sites, 3.2 signs (2.2 sign sites) per km]. Our "incidental" sign search (that is, recording signs that we encountered while walking between transects or while searching other wildlife) revealed 16 signs (11 sites with signs) in 13 full search-days from 16 to 29 October 2009 (Table 1, Fig. 2).

Table 1: Number and type of snow leopard sign detected in Rolwaling in October 2009

	Sign-transect		Incidental sign search	
	Signs	Sign-sites	Signs	Sign-sites
Feces	3	2	10	8
Hair	3	3	2	1
Pugmark	1	1	1	1
Scrape	6	3	3	1
Total	13	9	16	11

[11] Jackson R. M. & Hunter D. O. 1996. Snow leopard survey and conservation handbook. International snow leopard Trust and U. S. National Biological Service.
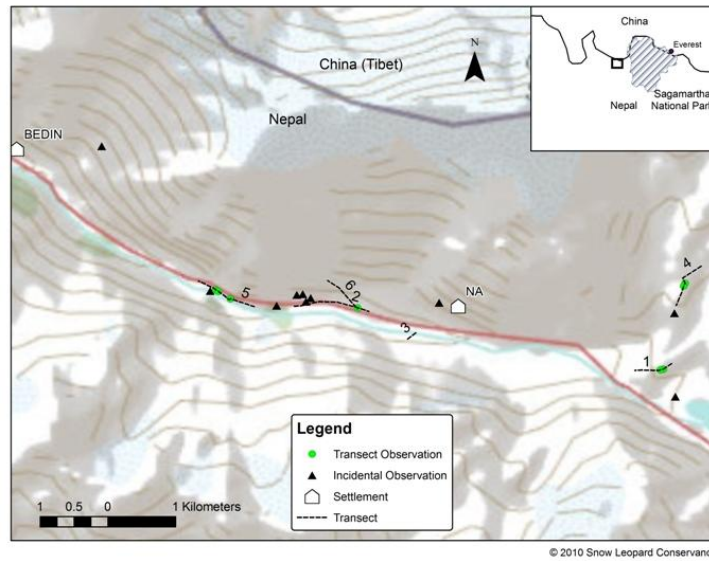
Fig. 2: Snow leopard sign transects and incidental sign in Rolwaling

The rarity of signs suggests that snow leopards are scarce in Rolwaling. To take an extreme case, Langu in west Nepal, with a snow leopard density of 8-10 cats/100 square km, revealed 36 signs per kilometer[12]. While our exhaustive interviews with local herders suggested the presence of three adult snow leopards, we obtained the evidence of just one (a set of pugmarks), but there may be more snow leopards.

We placed all snow leopard sign-transects in Na and areas beyond. Three hours up the Bedin valley lies Na, which used to be the main settlement, and has the oldest gompa. Here in one of the transects, we located fresh feces in "very broken" terrain at the entrance to Na, around the monastery area. Half way between Bedin and Na is a huge boulder, completely covered with carved *mantras*, known as Urgyen Shugtri, Padma-Sambhava's throne (Fig. 3).

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[12] Jackson R. M. 1996. Home range, movements and habitat use of snow leopard (Uncia uncia) in Nepal. Ph.D. dissertation. University of London, London.
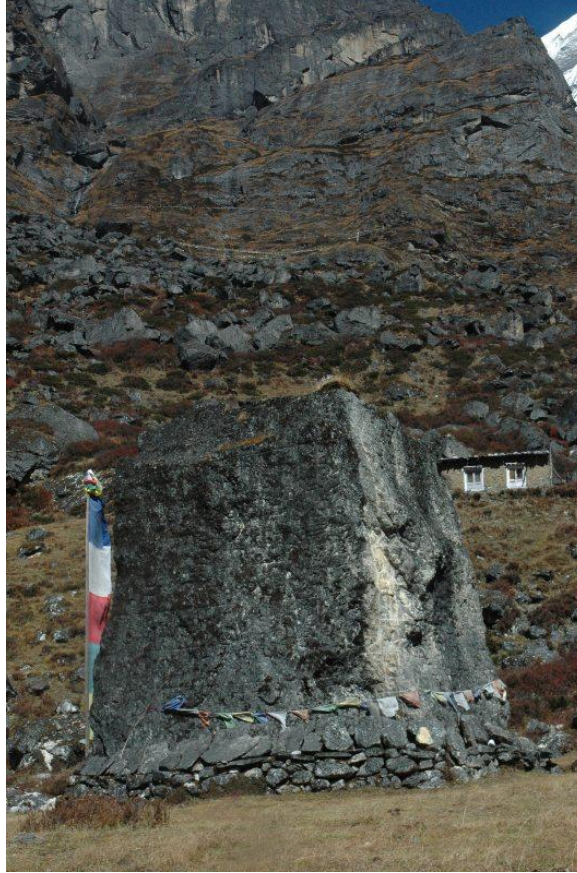
Fig. 3: *Urgyen Shugtri*, Padma Sambhava's throne

When Padma Sambhava flew to Rolwaling, in the 8th century, Tseringma (the goddess of Gauri Shankar) offered the boulder to him as his seat. The great guru, who is appeased as the second Buddha by the followers of the Nyingma, meditated here and spread the tantric school of Buddhism to the people of Tibet. On the mountain above Urgyen Shugtri is a cave where Padma Sambhava did the Phurba (magical) practice, and left his footprint. During special festivals, all the villagers go to the cave to perform ceremonies and make offerings. The scared territory around the gompa and Urgyen Shugtri is coincidentally the best snow leopard habitat in Rolwaling! So, for a week, we put four camera-traps, hoping the snow leopard would make its majestic appearance. It did not. Right across the river from this site lies a gigantic rocky cliff that the Sherpa believe is the entrance to the inner valley. Villagers told us - there are many wonderful and blessed caves, with spring inside, where wandering yogis and ascetic practitioners spend long periods of time in meditation. We made a cursory visit to this area, but these moist northerly slopes awarded us with no snow leopard signs.

In May 2010 we made another three week visit to Rolwaling and collected snow leopards signs, and the third visit in November to collect additional samples of snow leopard scats (see Fig. 4 for all snow leopard sign locations).
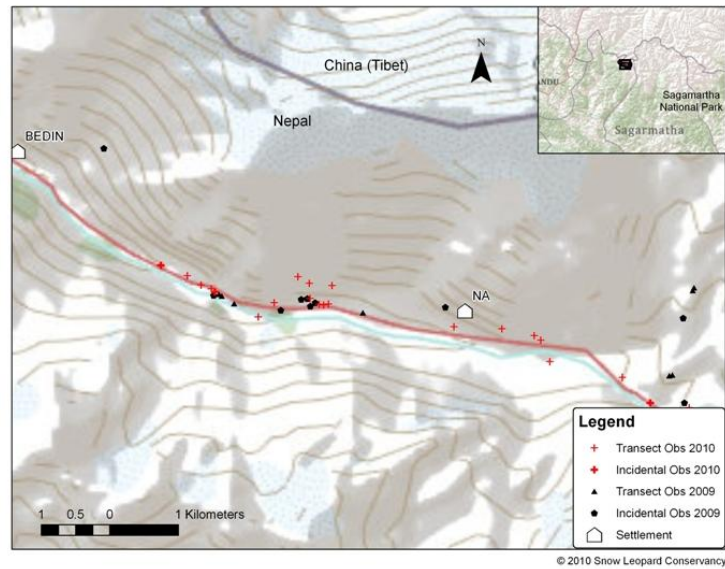
Fig. 4: Locations of all snow leopard signs (2009 and 2010)

We conclude that, despite low natural prey abundance, snow leopards survive in Rolwaling by relying on livestock. Livestock-rearing is unfortunately declining as more and more youth seek employment in lucrative trekking and climbing expeditions that entail their extended absence and even permanent emigration from Rolwaling.

Currently, only 32 of 65 households reside permanently in Bedin-Na (Fig. 5). And nowhere is the brain- and manpower-drain more visible than in the isolated Bedin-Na.
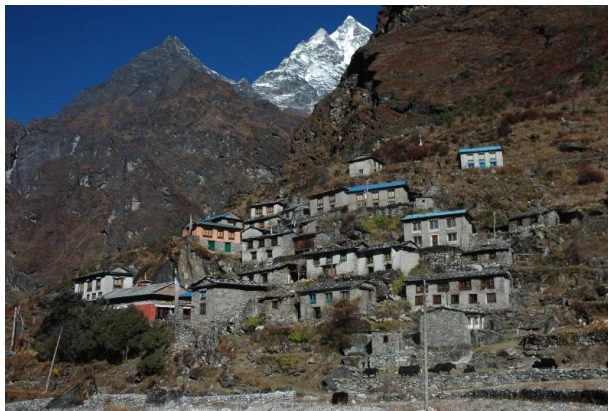

Fig. 5a: Bedin village

Fig. 5b: Typical snow leopard habitat in Na

The villages are populated by those no longer capable of strenuous labor. Agricultural fields have been abandoned and livestock ineffectively tended. Simply put – the old cohesive social Bedin may be falling apart. The absence of young-force has hit hard livestock husbandry more than any other spheres of Bedin's life, and, among others, it is grim news for continued survival of snow leopards. We counted 425 livestock (yak, cattle and mostly small ruminants, that is,

sheep and goats [69%]), three times lower than the number just a decade ago. This indicates that the snow leopards' food base has substantially declined. Across the Himalayas, livestock is helping to sustain the endangered snow leopards as native prey depletes[13]. Provided the current low prey population prevails and that livestock continues declining, snow leopard's future is bleak in Rolwaling.

From September 2008 to October 2009, amid rising tensions, 8.5% of total livestock were reported lost to snow leopards, one of the highest depredation rates in the Himalayas. During the interaction session in one of the village meetings during our field trip, over half of the livestock owners (57%) did not have specific ideas to minimize livestock depredation by snow leopards, while 23% suggested a complete eradication of snow leopards. Only 10% herders believed on mitigation measures, while the rest (10%) believed depredation could be reduced by performing religious ceremonies.

Although our sample size comprised only 10 scats, analysis showed 60% livestock-remains, with 10% consisting of tahr (Fig. 6). The suggestion may seem counter-intuitive, but to conserve snow leopards in Rolwaling, conservation agencies may need to promote livestock-rearing, and develop appropriate mechanisms for compensating herders for loss of livestock, while also discouraging tahr poaching through education and patrolling or other means of increased vigilance.

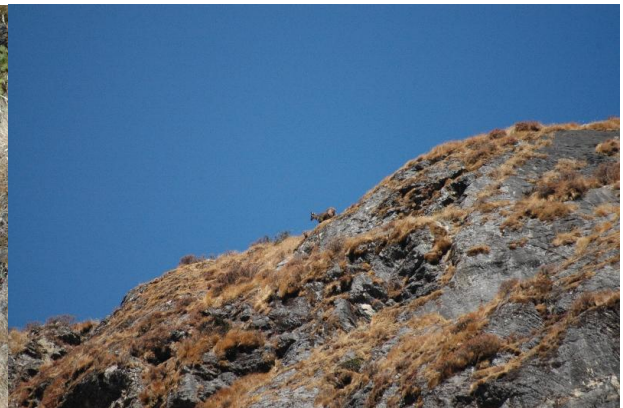Fig. 6a: Himalayan tahr   Fig. 6b: Himalayan tahr's typical habitat in Rolwaling

Rolwaling now falls within the Gaurishankar Conservation Area entrusted to the National Trust for Nature Conservation, country's prominent environmental organization. Protected status will, among others, immediately help check tahr (and musk deer) hunting, and their populations may burgeon as happened in Khumbu after the establishment of Sagarmatha National Park. Rolwaling's Sherpa community may require revitalization. Despite several religious gatherings every month, the community lacks leaderships - for conservation and developmental initiatives. One may begin with re-organizing women's committee, responsible for most traditional and religious performances, and cautiously bring them into the main stream of biodiversity conservation. Locals may need to re-vitalize the traditional "mizaar" system, similar to "nawa"

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[13] Jackson R. M., Mishra C., McCarthy T. & Ale, S. B. 2010. Snow leopards, conservation and conflict. In The Biology and Conservation of Wild Felids. Macdonald D. and Loveridge A. (Eds.). Oxford University Press, pp. 417-430.

system in Sagarmatha, which controls all land use practices, including livestock grazing. Reviving livestock-husbandry is of utmost importance to resurrect Bedin's social life, and a necessity for snow leopards' continued survival. The mizaar committee of mizaar system – which vanished a decade ago from Rolwaling, consisted of four members – Mizaar, the leader; Gorcha, the informer; and two Napa, the herdsmen. In a landscape where grazing lands are scarce and limited to a few months in summer, and that a long harsh winter exhausting the stored supplemental feed, a strict community regulation (made by Mizaar) enforces livestock to leave the village by the set date, thereby pushing livestock higher as summer begins. This ensures protection of forage around the village for the winter, thus regulating grazing that helps sustain pastoralism. The first conservation workers may need to revitalize Rolwaling's traditional systems that help the sacred valley maintain its identity until today. They also need to integrate such practices into biodiversity and snow leopard conservation.

Bedin-Na may serve as a strategic corridor for dispersing snow leopards from the Everest area. A detailed, systematic corridor assessment would help identify suitable snow leopard-corridors for implementing conservation interventions, not only in Rolwaling but also further west. By mapping seasonal livestock movements, other biological and physical variables in addition to snow leopard sign data and analyzing DNA from scats, hair and kills, it may be possible to develop agent based corridor models that can predict how snow leopards will respond to various management options. Such models can be used to explore metapopulation dynamics and devise management strategies of general application in the country and beyond.

Conclusion, Rolwaling survey:

To collect background data for the objective 1, to create corridors for metapopulation movements between the Everest and Annapurna region, we explored Rolwaling valley as the first step. The presence of snow leopards in Rolwaling was formally confirmed. An excerpt from Rolwaling findings was also sent to Cat News for publication[14]. In 2009, we established six snow leopard sign transects and one additional transect traversing higher altitudes was established in 2010. Altogether 8 scrapes, 22 scats, 14 sets of pugmarks, 3 scent-sprays and tufts of hairs from two (rubbing-rock) locations were recorded in 2010.

All fresh scats from 2009 and 2010 (n=16) were stored for genetic analysis.

Findings from Everest:

We concentrated in the Everest region to obtain the objective 2, that is, to create seasonal movement model in the Everest area (source population) to identify corridors for seasonal movements. We conducted a field trip to the Everest region, and mapped the grazing polygons in Sagarmatha National Park (c. 100 units), and collected data on the numbers of animals grazing in each polygon in each of the four seasons – spring, summer, autumn, and winter. We established upper and lower snowlines on maps for each season, and ranked snow leopard habitat preference

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[14] Ale, S. B., Thapa, K., Jackson, R. M. and Smith, J. L. D. 2010. The fate of snow leopards in and around Mt. Everest. CATnews 53: 19-21.

and habitat ruggedness from 1 to 10, (10 being the most rugged). All were digitized and put in GIS modeling.

The next steps are, one, run the seasonal models, two, write the base models for the seasonal movement within Everest, and three, based on hypothesis from the model we will attempt to predict where the snow leopard activity is in the Everest area, that is, validate the models.

The objective 3 of the project is to create seasonal movement model in the Annapurna area (with suspected source population) to identify corridors for seasonal movements. We will perform the following in the upcoming years with additional funding --

Activities –
- Collect the spatial data for the Annapurna area and the areas in between Annapurna and Rolwaling, and establish where the best snow leopard populations are
- Map the seasonal livestock grazing areas which establish the lower seasonal boundaries for the snow leopards, and map the upper seasonal bound being the snow line
- Run the seasonal models
- Write the base models for the seasonal movement within Annapurna
- Based on hypothesis from the model, predict where the snow leopard activity is in Annapuna – that is -- validate the models

We will initiate work to achieve the strategy 3 in autumn 2011.

Overall Remarks and the next strategic steps:

The research goal of the snow leopard-corridor project is ambitious. We know there is a population of snow leopards in Mt. Everest area. Is there a resident population of snow leopards in Rolwaling valley? Perhaps, but snow leopards may be using Rolwaling as a corridor to move elsewhere, e.g., Annapurna and Manaslu (westwards) or Makalu (eastwards). We also believe there is another route through Tibet. Based on hypothesis from the model, we will attempt to predict where the snow leopard activity is in the Everest area. We will refine the livestock and snow line data for the area. In Annapurna, we will establish the seasonal snow lines and livestock locations to create the seasonal movement models. We need to validate both the seasonal movement models for Everest and Annapurna, create corridor models, and identify and validate the movement of snow leopards between these two source population locations. DNA analysis of scats in Everest, Annapurna and the corridors in between will establish the relationship between the scats and the two core snow leopard populations.

The next phase will be to extend the corridors to other core populations in Nepal (both seasonal and between populations). Since path distance generalizes snow leopard behavior, we then need to understand the causality of the movement through Agent-Based Modeling. All this awaits more field works in selected valleys beyond Rolwaling adjoining Langtang and valleys in between Langtang National Park, Manaslu and Annapurna Conservation Areas. This also requires further spatial and academic exploration.

Appendix I: Detail methods for the long-term Nepal snow leopard corridor project

Study area will be divided into grids 25-40 km in size representing the probable average home range size of female snow leopards (Jackson and Ahlborn 1986). Each alternating grids will be searched for sign and all fresh scats collected for genetic analysis. Camera traps will be strategically deployed to documented dominant residents, including females accompanied by young. All sites with snow leopard signs will be characterized, and snow leopard's main local prey counted, classified and distribution recorded. The vigilance behaviors of prey will be quantified following Ale (2007).

1) Snow leopard status and distribution survey:
Sign surveys will provide presence-absence probabilities for the areas surveyed. For sign survey, we will employ the techniques of the Snow Leopard Information Management System (SLIMS) (Jackson and Hunter 1996), a standardized approach widely used in snow leopard research, to locate snow leopard sign and characterize the sign site. We will use two independent sign survey methods to assess snow leopards: 1) transect method in which we will record snow leopard signs along pre-selected transects (Fox et al. 1991, Jackson and Hunter 1996), and 2) a more wide ranging incidental method in which we will opportunistically search for signs encountered (*cf.* Schaller 1977).

Sign transects will be laid out along landforms such as ridgelines and bases of cliffs where snow leopards are likely to traverse and leave signs (Fox et al. 1991, Mallon 1991, Jackson 1996). For each sign (scrape, scat, pug-marks or scent-spray), we will record the date, global positioning system (GPS) location, terrain and habitat type within a radius of 20 m. Prior to walking each transect, we will randomly select 6-8 sites per 1,000 m of transect to characterize the frequency of each terrain and habitat type (McCarthy 2000). This random frequency can then be compared with the frequency of snow leopard sign sites to assess habitat selection (habitat selection at local scales, i.e. vegetation habitat - scale, ruggedness class – scale, a simple chi-square test will reveal this). Using Resource Selection Functions and Discriminate Functions will reveal home-range scale habitat selection.

Sign survey provides an index of abundance that can be used to compare abundance between areas in space or to monitor trends in one location over time. Index values can be used to estimate population size by calibrating them with estimates derived from parallel methods (Wilson and Delahay 2001). [As part of the project, we will develop this for Sagarmatha to monitor snow leopards – a management tool for the park]. At each habitat – block, snow leopard sign transects will be conducted at a density of at least 1 km of transect/25 km2 of habitat. The guesstimate of snow leopard numbers based on sign abundance to date follows Jackson and Hunter (1996): 20 signs/km could indicate 10 individuals/100 km2 (based on the work in west Nepal: Jackson 1996).

In this study, we will use two parallel (quantitative) methods: genetics (see Section 3 below) and selective camera-trapping to census and estimate snow leopard population size (Jackson et al. 2006), thus calibrating data obtained from SLIMS techniques (Jackson and Hunter 1996) and prey behavior method (Ale 2007) (section 2 below).

Individual snow leopards (in photos) will be identified by their unique pelage patterns and population can be estimated using a capture-recapture statistical model. Using photographic captures and recaptures to estimate tiger population size, Karanth (1995) and Karanth and Nichols (1998) developed a sound sampling procedures for assessing large cat population which Jackson et al. (2006) modified to estimate snow leopards in Ladakh, India. We will use this standardized field method, capture–mark–recapture (CMR) closed population models in this study, assuming a large-enough sample. Otherwise we will report the minimum number of snow leopards present within the survey area. We will maximum capture success by placing camera traps at sites showing high visitation rates. These sites are notably narrow ridgelines and valley bottoms at or immediately adjacent to frequently scent-sprayed rocks and scrape - sites. We will extensively use local expertise to identify these represented sites.

2) Prey counts, behavioral observation and prey habitat modeling:
We will locate, count and classify prey using total counts method from appropriate vantage points (Schaller 1977). We will follow herds on foot, closely observing their anti-predator vigilance behavior. Using focal animal sampling (Martin and Bateson 1986), we will record each individual's activities in four categories (foraging, scanning/vigilance, moving, and other). These observations will provide tests for the association of vigilance

behaviors with risky valleys, terrain and vegetation types ("risky" for prey because more predators are present). To infer the activity patterns, habitat associations and the abundance of snow leopard signs, we will quantify the foraging and vigilance behaviors of prey (blue sheep or Himalayan tahr) in different terrains (cliff, broken and rolling) and habitats (grassland, scrubland and open forest). Anti-predator behavior of prey may reveal the abundance and whereabouts of predators, but this behavioral indicator should be interpreted with caution because other factors influence individual's behaviors, for instance presumably vigilance levels decrease as prey become savvy to presence of predators, reducing the sensitivity of this indicator.

3) Snow leopard genetics:
Putative snow leopard scats will be identified by their spoor characteristics and associated sign at vicinity (e.g., tracks, scrapes, and scent rocks). We will record GPS locations of each site, and characterize habitat variables. Scats will be dried and stored with silica gel.

DNA will be extracted from scat samples using the Qiagen Stool DNA extraction kit (Qiagen, Valencia, California, USA) following the manufacturer's recommendations. A 100-bp region of cytochrome b will be PCR amplified, sequenced, and compared to references sequences from sympatric carnivores to obtain species identification (Farrell et al. 2000; Janečka et al. 2008). Sex-identification will be done by PCR amplifying and observing a 200-bp intronic segment of the Y-linked AMELY gene (Murphy et al. 1999). Individual identification will be done by genotyping scats at 7 -12 microsatellite loci previously found to be variable in the snow leopard (Waits et al. 2006, Janečka et al. 2008). PCR amplifications will be done with snow leopard specific primers designed by Janečka et al. (2008). Each scat will be genotyped in triplicate to minimize errors due to allelic dropout and false alleles, and additional errors will be identified with statistical methods (Taberlet et al. 1999; McKelvey et al. 2004). Samples that appear to contain errors will be re-genotyped or discarded. Population estimates for each study area will be made using the rarefaction or capture-mark-recapture methods (Kohn et al. 1999; Petit et al. 2006).

Each unique individual will be genotyped at an additional 8 variable microsatellites (Waits et al. 2006) and Fst-based tests (Goudet et al. 1996), population assignment (Wasser and Strobeck 1998), and model-based clustering (Pritchard et al. 2000) will be used to examine population structure, gene flow, and dispersal between areas. Kinship and relatedness will be estimated from the microsatellites to examine social structure, and to test dispersal and phylopatry hypotheses (Janečka et al. 2006; 2007).

4) Mapping corridors and Key Management Parameters
We will develop RSFs with a used versus available habitat sampling protocol (Manly et al. 2002). Using sign location data and RSFs, we analyze habitat selection of snow leopards. We include habitat types, annual precipitation, elevation, slope, distances from rivers, distance from its major prey as well as distance from human settlements and trails. The RSF predicts the relative probability of the selection of the GPS locations, compared to the randomly sampled locations. It is a commonly used method for analyzing presence/available data to derive species habitat-use (Boyce et al. 2002, Manly et al. 2002). To verify the models we will use the k-fold verification method (Boyce et al. 2002). Receiver Operating Characteristic curves will also be generated to test the RSF (by measuring the AUC, or area under the curve) derived from a model using the entire data set (Boyce et al. 2002). For the logistic regressions we choose the best model among a priori models using Akaike's Information Criterion (AIC; Burnham and Anderson 1998). Logistic regression models and AUC's will be calculated using SPSS™ version 13.0 (SPSS Inc., Chicago, IL) or Systat ™ version 12 (Systat Software, Chicago, IL).

Least cost path analysis will be used to identify and rank the relative suitability of alternative corridors.

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