# Snow leopards and Himalayan tahr of Sagarmatha (Mt. Everest) National Park, Nepal 

## Progress Report

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## Executive summary

The endangered snow leopard Uncia uncia disappeared from the Everest region in the 1960s, but by the late 1980s anecdotal reports noted the presence of transient snow leopards visiting from adjacent Tibet. In 2004, this survey team documented the confirmed return of the snow leopard in this world heritage site. The subsequent 2005 survey focused on 1) the distribution and abundance of tahr and snow leopards, and 2) the indirect impacts of snow leopards on tahr population.

We systematically walked altogether 29 sign transects covering over 19 km in length and recorded all snow leopard sign encountered. We made a census of Himalayan tahr Hemitragus jemlahicus and assessed their herd structure. The mean snow leopard sign density in 2005 ( 4.5 all sign/km and 3.2 scrapes/km) was similar to that recorded in 2004 ( 4 sign/km and 2.4 scrapes/km). At least 6 different cats inhabit ca. $85 \mathrm{~km}^{2}$ along with a minimum number of 277 Himalayan tahr.

Besides assessing the abundance of snow leopards and tahr directly, we used the anti-predator vigilance behavior of Himalayan tahr to infer indirectly the status of snow leopards. Our study revealed a tight association between Himalayan tahr vigilance behaviors and the presence of snow leopard sign.

## Introduction

Snow leopards disappeared from the Everest region in the 1960s. Tourism has flourished since the first ascent of Mt. Everest in 1953, bringing both prosperity and adverse ecological impacts to the region (Sherpa 1985, 1987; Brower 1991). Visitors have increased from a few thousands per year in the 1970s to over 20,000 in 2005. These visitors exceed the local population by a factor of six (Ale and Boesi 2005). In 1976 the Everest region (area of 1,148 $\mathrm{km}^{2}$ ) became Sagarmatha (Mt. Everest) National Park (E 86 ${ }^{\circ}$ 30' 53" - E $86^{\circ} 99^{\prime} 08^{\prime \prime}$, N $27^{\circ} 46^{\prime}$ 19" - N $27^{\circ} 6^{\prime} 45^{\prime \prime}$ ). By the late 1980s, reports (Ahlborn and Jackson 1987) indicated the presence of transient snow leopards visiting from adjacent Tibet. After almost three decades of effective protection, the virtual cessation of hunting and the recovery of the endangered Himalayan tahr (hereafter tahr) and musk deer Moschus chrysogaster in the park since its establishment, snow leopards seem to have made a comeback to the world's highest national park (Ale and Boesi 2005, Lovari et al. 2005).

The Sagarmatha National Park lies in Solu-Khumbu district of the northeastern region of Nepal. It encompasses the upper catchments of the Dudh Kosi River system. The upper Sagarmatha is locally known as Khumbu. Our survey area consists of four survey blocks $15-33 \mathrm{~km}^{2}$ in size, a total of $\mathrm{c} .85 \mathrm{~km}^{2}$, the survey blocks which represent the four main valleys of Sagarmatha: Namche, Phortse Gokyo and Thame. Apart from assessing the status of snow leopards and tahr,
one of the main goals of 2005 survey was to tease apart predator (snow leopard)-prey (tahr) interactions, a focus which may yield information pertaining to managing and monitoring snow leopards.

With modifications to meet our particular field conditions and data needs, we employed the techniques of the Snow Leopard Information Management System (Jackson and Hunter 1996), a standardized approach widely used in snow leopard research. For each sign (scrape, scat, pugmarks or spray/urine) encountered, we recorded the date, global positioning system (GPS) location, and terrain and habitat types within a radius of 20 m . Such information was also recorded for tahr herds whenever we located them. Prior to walking each transect, we randomly selected $6-8$ sites per $1,000 \mathrm{~m}$ of transect (total sites, 160) to characterize the frequency of each terrain and habitat type. This random frequency could then be compared with the frequency of snow leopard sign sites.

## Results

## Distribution and status of snow leopard

Snow leopards inhabit all four main valleys of Sagarmatha: Gokyo, Namche, Phortse and Thame. Cats prefer broken terrain with cliffs (Ahlborn and Jackson 1988, Fox et al. 1991, Jackson 1996, McCarthy et al. 2005), but they may also traverse relatively gentle terrain, village trails and agricultural fields if vegetation patches and rock outcrops offer cover and especially if cliffs grade these landforms. The range of snow leopards in Sagarmatha encompasses roughly 160 km 2 or $13 \%$ of the total national park (Ale et al. in prep.). Our effort, however, was concentrated on ca. 85 km 2 area of Khumbu. Upper drainages of Imja, Bhote Koshi and Dudh Koshi ( $>4,500 \mathrm{~m}$ ) are arid and wildlife is sparse. In contrast, the lower much greener region (3,000-4,500 m) supports relatively abundant wildlife including the snow leopard.

Considering Gokyo valley, proper Gokyo and Thagnak provide a poor habitat for snow leopards whereas the much rugged lower Gokyo (e.g., Thore) adjoining Phortse offer a quality habitat. In Namche, we found evidence of snow leopards throughout our survey area, and so is the case with Phortse. Most Thame, in particular the upper region on the way to Tibet, is flanked with broader valleys much less suited for snow leopards although it may have been the travel route for the first snow leopards entering to Sagarmatha. Most Thame thus does not support snow leopards but the lower Thame and the area between Thame and Thamo offer the best cliffy (thinly forested) slopes for cats to hunt tahr. We traveled all the way to Lung ( $5,090 \mathrm{~m}$ ) on the way to Tibetan plateau and recorded no snow leopard sign but herders at Khusum (4,500 m) reported that they sometimes lose their stocks to snow leopards. Cats may roam up to Marulung $(4,210 \mathrm{~m})$ and its surrounding slopes $(>4,500)$ perhaps to hunt baby yaks (tahr are uncommon here) and may cross Renjo pass ( $5,340 \mathrm{~m}$ ) leading to Gokyo. That we encountered only two signs on the way to Renjo pass despite
our intensive search for five full days indicates that snow leopards are indeed rare visitors in this part of Thame.

As yet we have not surveyed the north-east region beyond Pangboche, but local herdsmen claimed that cats are known to be rare in Pheriche, Chukhung and Lobuche, the areas towards the Everest base camp. This large chunk of arid land of Everest massif is farthest from the source if we consider Nagpa-La the travel route of the first snow leopards to Sagarmatha and Tibet as the source of snow leopards (Jackson et al. 1994). Cats may wander up to Pheriche ( $4,300 \mathrm{~m}$ ) which harbors some tahr in summer, but further beyond snow leopards are unlikely to occur.

Snow leopards tend to move, bed and mark along linear geographical features such as crests, major ridgelines, at the base of cliffs and in gullies (Ahlborn and Jackson 1984, Mallon 1984, 1991, Fox et al. 1991, Jackson 1996, McCarthy et al. 2005). Monitoring for signs along these features is therefore the best possible way at present of estimating snow leopard population trends in an area (Jackson and Hunter 1996). Indeed, the number of scrapes, feces and other sign in an area give an indication of the cat's presence and distribution (Table 1), but such data along "one-time" transect may contain biases. Differential presence of topographical features in different areas can affect sign density, thus hampering comparisons of density indices from different areas (Fox et al. 1991). For example, snow leopards in Namche and Phortse traveled along the maze of sharp ridges that characterize these two valleys. Therefore, transect data revealed more sign here in Namche and Phortse than in Gokyo and Thame with relatively fewer ridges and cliff-bases. Gokyo and particularly Thame are flanked by hills with broad ridges where snow leopards rarely patrol in search of tahr but rather follow regular human or livestock trails. The cat's travel routes were less well defined in these massifs of northeastern Gokyo and Thame, making it difficult to locate spoors along ridges.

Table 1: Distribution of snow leopard sign across valleys

| Valley | Transe <br> ct $(\mathbf{k m})$ | Scrap <br> $\mathbf{e}$ | Fece <br> $\mathbf{s}$ | Pugma <br> rk | Oth <br> er | Tot <br> al | Sign/k <br> $\mathbf{m}$ | Scrape/k <br> $\mathbf{m}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Gokyo | 4.6 | 9 | 0 | 1 | 1 | 11 | 2.4 | 2.0 |
| Namche | 3.6 | 21 | 6 | 4 | 3 | 34 | 9.4 | 5.8 |
| Phortse | 5.8 | 25 | 4 | 2 | 1 | 32 | 5.5 | 4.3 |
| Thame | 5 | 6 | 2 | 0 | 0 | 8 | 1.6 | 1.2 |
| Total | 19 | 61 | 12 | 7 | 5 | 85 | 4.5 | 3.2 |

Sign abundance along one-time transects may vary temporarily (Fig. 1). For example, the frequency of sign in August 2005 for 29 transects was lower than in October 2005 ( $\mathrm{X} 2=6.9$, d.f. $=1, \mathrm{P}<0.01$ ) because monsoon rain quickly destroys most sign during July and August. Since the production of scrapes by snow leopards is apparently greatest during the breeding seasons of January and

February (Jackson 1996), the timing of comparative surveys is important, and surveys conducted soon after breeding (April-May) on the south side of the Himalaya could be expected to have a seasonal high sign frequency (Fox et al. 1991). However, surveys conducted too early in the spring may under-estimate density because the snow can hide sign (Ahlborn and Jackson 1988). We have reserved 2006 summer (May/June) trip to Sagarmatha to test this prediction.

Fig. 1: Temporal (seasonal) variation in sign abundance across valleys


Valleys

The transect method can, however, provide reasonable assessments of change given sufficient sampling effort when repeated same site/season monitoring (Figures 2) (more sign in October 2005 than in October 2004, x2=5.9, d.f. $=1$, $\mathrm{P}<0.05$ ). Incorporation of such simple monitoring as part of protected area management in the Himalaya can be instrumental in snow leopards and their prey research.

Fig 2: Temporal (yearly) variation in snow leopard sign abundance across valleys


## Distribution and status of Himalayan tahr

Snow leopards occasionally kill such large animals as adult yaks and horses, thus making all ungulates potential prey (Schaller et al. 1988), particularly when they forage near the base of cliffs and other sites where snow leopards hunt. Tahr, musk deer and game birds share habitat with snow leopards throughout Sagarmatha and thus all are snow leopard potential prey. Here we have focused on the most conspicuous tahr. Exterminated in some areas, and decimated throughout their range, tahr nevertheless remain the most numerous and widespread ungulate in the southern range of the Himalaya (Schaller 1977, Shackleton 1997).

A total of 163 (422 individuals) sightings of tahr were made from August to November 2005 in four valleys. We assessed tahr's population structure based on (1) the known numbers (repeated total counts) and (2) all tahr seen daily in each part of the study area. The results derived by the two methods show close match (Table 2). Our count revealed a density of tahr ranging from ca. 1 animal/km ${ }^{2}$ (Gokyo) to as high as 7 animals/km² (Namche) (Table 3).

Tahr herds exhibited the average group size of 8.7 (SE=0.6) (Table 3) which was similar to that reported in 2004 (8.6, SE=0.7). Some herds contained over 30 individuals. Reproductive success was low, about $3 / 10$ of the adult females being accompanied by young (i.e. young to females' ratio, 0.3 , Table 2) by October/November in 2005. The winter mortality of young was low (yearling to female ratio of 0.2 , Table 2) which suggests that mortality other than snowy winter is responsible for the low rate of recruitment in tahr population.

Table 2: Distribution and abundance of tahr in Sagarmatha

|  | Known animals |  | All tallied (n=163) |  |
| :--- | :--- | :--- | :--- | :--- |
| Himalayan tahr | No. | $\%$ | No. | $\%$ |
| Male Class I | 8 | 2.9 | 18 | 1.3 |
| Male Class II | 5 | 1.8 | 25 | 1.8 |
| Dark Brown (Class III) | 19 | 6.9 | 49 | 3.4 |
| Pale Brown (Class IV) | 23 | 8.3 | 63 | 4.4 |
| Blond (Class V) | 17 | 6.1 | 53 | 3.7 |
| Unidentified Male | 15 | 5.4 | 148 | 10.4 |
| Total Male | 87 | 31.4 | 356 | 25.0 |
| Female | 123 | 44.4 | 770 | 54.1 |
| Yearling | 24 | 8.7 | 115 | 8.1 |
| Young | 43 | 15.5 | 181 | 12.7 |
| Total | 277 | 100.0 | 1422 | 100.0 |

Table 3: Density of tahr across valleys
\(\left.$$
\begin{array}{l|llll}\text { Valley } & \begin{array}{l}\text { Area } \\
\text { (km2) }\end{array} & \begin{array}{l}\text { No. } \\
\text { animals }\end{array} & \text { of } & \text { Animals/km }\end{array}
$$ \begin{array}{l}Group <br>

(SE)\end{array}\right]\)| Gokyo | 33.2 | 31 | 0.9 |
| :--- | :--- | :--- | :--- |
| Namche | 15.0 | 75 | 5.0 |
| Phortse | 18.3 | 125 | 6.8 |
| Thame | 20.0 | 46 | $2.3(0.9)$ |
| Total | 86.4 | 277 | 3.2 |

Few adult males (2 years and older) were observed in Namche until November/December, the rutting season for tahr. This suggests they occupied a summer range different from that of females and subadults, located in particular in alpine scrubland above Nyasre and in almost inaccessible cliff ledges above Mong danda. The males to female's ratio was almost 1:1 in Thame, Phortse and Gokyo. In Thame and Gokyo, we located almost all males, an indication of relatively open and rolling topography. Namche is the most rugged among the four valleys. A few tahr herds were no doubt overlooked, especially in the muchrugged ravines between Namche and Phortse blocks.

All four valleys contained musk deer which, because of their secretive habits and preference for brush-covered slopes, could not be counted. Based on spoor and sightings, musk deer were most scarce in Gokyo and most abundant in Phortse (Ale in prep.). The higher number of these two mammal species and game birds in Sagarmatha in contrast to the abundance of animals before the 1976 (Green 1993) reflects the success of conservation measures undertaken by Sagarmatha National Park with the aid of the Royal Nepal Army (stationed in Namche) and local people.

Our spoor hunt in Namche revealed three different snow leopards in approx. 15 km2: Three sets of fore-pugmarks: 1) length 9.2 cm ( $\mathrm{SE}=0.06$ ), width cm (SE=0.08); 2) length $7.6 \mathrm{~cm}(\mathrm{SE}=0.1)$, width $6.6 \mathrm{~cm}(\mathrm{SE}=0.06)$; and 3) length 8.9 $\mathrm{cm}(\mathrm{SE}=0.04)$, width $8.4 \mathrm{~cm}(\mathrm{SE}=0.07)$. At this point, it is relevant to note that techniques such as remote camera trapping or DNA analysis would help establish the number of snow leopards present in the area. Do the same individuals travel to adjoining Thame and Phortse? This is difficult to answer, but they may do so by judging the size of their home range, i.e. $11-37 \mathrm{~km}^{2}$ in west Nepal (Jackson 1996) or much larger in areas with sparse prey for example in Mongolia (McCarthy et al. 2005). One snow leopard (fore-pugmark width 7.2 cm ( $\mathrm{SE}=0.49$ ) and length $7.6 \mathrm{~cm}(\mathrm{SE}=0.87)$ was active while we were in Thame. Perhaps, another (bigger) individual judging by its larger scrapes may also roam this area. Clearly, there are areas within Thame that differ in predation risk. There were 3 main herds in Thame (total tahr, 46), but at times these broke into 6 or 7 groups, mostly because snow leopards had scared them. For example, one herd of 14 was scattered into 4 groups on 31 October 2005 after a snow
leopard visited their slopes. Young to female's ratio was comparatively better in this valley, i.e. approx. 0.6 in September 2005 (the corresponding figure, 0.4, for Namche during the same month was not very encouraging). Surprisingly, the Himalayan tahr population in Thame had only one yearling out of 12 females!

In Gokyo (33 km²), one individual with the average fore-pugmark width 7.8 (SE=0.08) and length 8.5 (SE= 0.05) was active from 13-19 September 2005. Twice it walked our transect. Two other snow leopards, perhaps a mother (with characteristically distinct lobes in its hind pad) and a large cub (smaller set of pugmarks), entered the valley from Phortse crossing Khumjung Chhorten (4,250 m ). This pass, a narrow corridor that divides Gokyo and Phortse valleys, was a heavily marked site. As in Thame there was a gradation of habitats with differential predation risk in Gokyo. The areas bordering Phortse (high suitability for snow leopards), had relatively more vigilant Himalayan tahr, but the areas (e.g. Thagnak) farthest from Phortse, where we located no snow leopard signs this year (but in 2004), tahr were amazingly docile. Undulating mountainous terrains are often characteristically interrupted by abrupt cliffs which are oasis for cliff-dwelling ungulates whose presence is often so predictive in these enclaves if one spent sufficient time searching for them to make an accurate population estimate. Assuming that Khumjung Chhorten is the border between Phortse and Gokyo, Gokyo harbors only 31 tahr in five groups (mean group size 6.15, range 1-11). The young to female ratio was 0.3 as of September 2005, with a yearling to female ratio of 0.5 (the corresponding figures were 0.5 and 0.2 respectively for the tahr in adjoining Phortse). These ratios changed over the next months. For instance, the young to female ratio in Namche changed from 0.5 in June 2005 to 0.2 in November 2005.

Phortse harbored ca. 125 tahr in five herds (sometimes scattered in as many as 10 groups) with an average group size of 12.5 animals (range 1-48). On the 22nd September 2005 at 10 am, we walked snow leopard transect number three, recording 9 signs at 7 sites. Then we took the vigilance data on six males. At 12, clouds cover made the tahr invisible to us, and we ambled to the nearby ridgeline. We collected a huge pile of (fresh) scat. This snow leopard was apparently well fed! Had it made a recent kill? But we saw no Himalayan griffons hovering anywhere nearby. We waited on this ridge for about two hours till 6 pm in case the snow leopard would make its appearance. As we headed to our camp, we heard a distant whistle made by an obviously alarmed tahr somewhere near our transect one. The following day at 5 am , we hurried to the site only to discover scrapes and pugmarks of a snow leopard and numerous hoofmarks hastily made by escaping tahr. We determined that our group of six males had split into two, some 200 m apart from each other. We tracked this snow leopard (which obviously scared these tahr) for 2.3 km and counted 13 scrapes. It had left one scrape per 174 m linear distance traveled. We discovered its pugmarks in two sites and a fresh scat. The cat scented an overhanging rock before disappearing into a cliff. So far this was the only one spray/urine rock we were
able to locate in Phortse (compare this with three in Namche and one each in Thame and Gokyo).

We judged three snow leopards were using our study area (ca. $18 \mathrm{~km}^{2}$ ) in Phortse. Perhaps these same individuals also traveled to Gokyo. One cat was small, with a pugmark width of 6.5 cm (SE=.06) and length 7.6 cm (SE=0.15). This may have been the same large cub that went to Gokyo accompanied by its mother. Other two were almost the same size (one fore pugmark set of width 8.6 $\mathrm{cm} \mathrm{SE}=0.08$, length $9.2 \mathrm{~cm} \mathrm{SE}=0.06$; and another with width $8.4 \mathrm{~cm} \mathrm{SE}=.07$, length 8.9 cm SE=.04). However, one individual had a distinctively distorted middle toe! All three pugmarks were on the same site but were made at different times.

Our study area ca. 85 km2 as of December 2005 had at least 6 snow leopards and a minimum of 277 tahr. A snow leopard would need 1.5 kg per day or 548kg per year (Schaller 1977). Inedible parts such as large bones and stomach contents average about one-third of the prey's total weight (Jackson \& Ahlborn 1984), making it necessary for a snow leopard to kill at least 822 kg a year to survive. Based on this, our minimum count of 277 tahr ( $16,760 \mathrm{~kg}$ - the average weight of females as 60.5 kg : S. Lovari pers. comm.), along with the current abundance of other prey (e.g. musk deer and game birds), would provide sufficient food for snow leopards to sustain themselves and build up their population in Sagarmatha.

## Snow leopard (predator)-Himalayan tahr (prey) interactions

Rare, elusive predators offer few sightings, hampering research with small sample sizes and lack of opportunities for experimentation. Consequently, field studies of large carnivores often reside outside of main-stream ecology, and our understanding of their role in ecosystems remains unclear and contentious (Terborgh et al. 1999). Unlike predators, prey species tend to be more abundant, and their behaviors can be more readily observed. Prey respond to the presence of a predator (Lima 1998, Brown et al. 1999) and these fear responses have population and community level consequences (Sinclair and Arcese 1995, Rosenzweig and Abramsky 1997, Brown and Kotler 2004). Predator reintroductions or their comeback via effective conservation measures provides "natural experiments" into how prey species behave in the presence or absence of predators (Berger 2001). Behavioral responses, such as vigilance behavior, allow us to sidestep the difficulty of direct field studies of large predators by studying them indirectly.

As a new predator, are snow leopards impacting the behaviors and habitat use of tahr? To answer this question we combined old-fashioned, mud-and-boots field biology (searching for spoor and sign, Schaller 1977, Jackson and Hunter 1996), with techniques and concepts from foraging theory (Stephens and Krebs 1986). Assuming that food resources (Jarman 1974, Carbone and Gittleman 2002) and predator pressures (Hunter and Skinner 1998) govern animal distributions,
foraging theory predicts that 1) terrains and habitats exhibiting heightened tahr vigilance should reveal higher abundance of snow leopards as indicated by their sign, and 2) valleys with the most alert tahr should have the most snow leopard sign.

We followed tahr on foot, closely observing their anti-predator vigilance behaviors to increase the likelihood of actually spotting snow leopards. To infer the land use patterns and the abundance of snow leopards we quantified foraging and vigilance behaviors of tahr in different terrains and habitats across all four main valleys. We used focal animal sampling (Martin and Bateson 1986). For 20 minutes we recorded how the individual partitioned its time between foraging, scanning, moving and other. In each valley, we used two independent methods to assess snow leopards: transect method in which we recorded snow leopard sign along pre-selected transects (predictable travel lanes used by snow leopards, Jackson and Hunter 1996) (see the section, distribution and status of snow leopards), and a more wide-ranging, haphazard search technique in which we searched for sign in all possible landforms, but outside transects while locating tahr groups (Schaller et al. 1988). For elucidating habitat use patterns, we recognized three terrain types (broken, cliff and rolling), and two distinct habitats (open forest and scrubland).

Tahr exhibited the most heightened vigilance in or near cliffs $\left(F_{(2,283)}\right)=3.56$, $P=0.03$, Fig. 3a). They were more alert in open forests than in scrubland ( $F$ $(1,286)=3.64, \quad \mathrm{P}=0.05)$. Vigilance behavior corresponded exactly with the distribution of snow leopard sign within valley. Snow leopards used cliffs ( $\mathrm{X} 2=16.3$, d.f. $=2, \mathrm{P}<0.01$, Fig. 3b) and open forests ( $\mathrm{X} 2=163$, d.f. $=1, \mathrm{P}<0.01$ ) more than expected by chance. Based on their vigilance behavior, the tahr perceived a higher predation risk in areas with cliffs and in open forests. As predicted (Prediction \# 1), snow leopards biased their activity towards cliffs and open forests. They typically left their sign in open (conifer) forest edge. Both haphazard search and transect methods (no significance difference) predicted the actual risk perceived by tahr within valley. Radio-tagged snow leopards in Dolpo, west Nepal (Jackson 1996) and in Gobi, Mongolia (McCarthy et al. 2005) prefer ridgelines interspersed with cliffs, and edge habitats. Within valley, both survey methods provided a good indicator of the presence of snow leopards and their habitat preferences as indicated by variations in sign density.

Figure 3a: Effect of terrains on tahr vigilance ( $\mathrm{n}=286$ )


Fig 3b. Snow leopard terrain-use patterns
( $\mathrm{n}=85$ )


Across the areas studied, the tahr in Namche were the most alert ( $F$ $(3,282)=2.84, \mathrm{P}=0.03$, Fig. 4a), and as predicted (Prediction \# 2) the highest number of snow leopard sign per survey day and Thame the lowest ( $x 2=19.5$, d.f. $=3$, $\mathrm{P}<0.01$, Fig. 4b). Across valleys, the haphazard search method yielded abundances and distributions of snow leopard sign which corresponded closely with the recorded vigilance levels of tahr occupying the same area. Although the vigilance of tahr across valleys only slightly corresponded with the distribution of transect sign, the pattern is more or less clear. Given the rarity of sign and low density of cats, transects are generally arranged in landforms (e.g., ridgelines) and the base of cliffs where snow leopards are most likely to travel. Although the presence and the distribution of snow leopard sign in an area may equate with the presence and distribution of snow leopards, the selection of transect locations may bias the occurrence of their sign (see the section, distribution and status of snow leopard). Snow leopard studies in Ladakh, India (Mallon 1991, Fox et al. 1991) and in Qinghai, China (Schaller et al. 1988) had similar remarks. For example, in Qinghai, China cats marked primarily the base of hills in certain survey blocks, whereas, by contrast, the cat's travel routes were less well defined in others, making it difficult to locate spoors along transects. The transect,
however, should provide an effective means for comparing the abundance and the distribution of sign from one year to nother in the same survey area (Mallon 1991, Fox et al. 1991, Jackson and Hunter 1996, Fig. 2).

Figure 4a: Tahr vigilanc across valleys ( $\mathrm{n}=286$ )


Fig. 4b. Snow leopard sign abundance
across valleys ( $n=155$ )


Tahr vigilance behaviors accurately identified variation in snow leopard activity between valleys, between terrain types, and between vegetation types. Tahr behaviors accurately predicted snow leopards' whereabouts and relative abundances. Such adaptive decisions of prey reveal properties of the population and community (Rosenzweig and Abramsky 1997, Brown and Kotler 2004). The return of snow leopards and the associated fear responses of the tahr in Sagarmatha provide opportunities for academicians, managers, and tourists. A similar story has occurred with the return of wolves to Yellowstone (Ripple and Beschta 2004). The reintroduction of wolves caused rapid behavioral responses by elk (Laundré et al. 2001) and moose (Berger et al. 2001) to the novel risk. Such predation-risk altered their foraging strategies (Creel et al. 2005). Prey can be expected to bias feeding activity towards safe habitats, and while in risky habitats, they should increase their vigilance levels in response to predation risk (Lima 1998, Brown et al. 1999, Brown and Kotler 2004).

Although a recent event, the return of snow leopards to Everest is already reflected in the tahr's degree of alertness toward predators. A wealth of empirical evidence suggests that predation risk is a primary reason for alertness in animals
(Elgar 1989). Within a single generation, the prey may be able to behaviorally adjust to big changes in the type and abundance of predators (Berger et al. 2001). The idea that fear governs predator-prey interactions may be most appropriately applied to behaviorally sophisticated large ungulate species and their predators. Ungulates likely rely heavily on vigilance to avoid being killed (Elgar 1989, Brown and Kotler 2004). Our work on the snow leopard and tahr represents a direct application of these principles to communities of large mammals, and it should be possible to extend these techniques to systems with higher diversities of prey and predators.

The return of snow leopards to this world heritage site after an absence of almost 40 years represents a management success. With the establishment of the park, there has been a cessation of hunting and a recovery of the tahr. Elsewhere, snow leopards suffer much the same threats as all of the world's big cats: they occur at low densities and occupy large home ranges exposing them to poachers and other anthropogenic hazards (Woodroffe and Ginsberg 1998). Although one of the best habitats of snow leopards in west Nepal supports $5-10$ cats $/ 100 \mathrm{~km}^{2}$ (Jackson 1996), much of their range offers low density, ca. 1 cat/100 km² (Schaller et al. 1988) or lower (Fox et al. 1991). No one knows how many snow leopards survive, but estimates range from 4,500-7,350, with dwindling numbers thinly scattered over 1.8 million $\mathrm{km}^{2}$ in 12 Asian countries (Fox 1994, McCarthy and Chapron 2003). Despite the species' endangered status since 1973 (CITES, Appendix I), this regal, mountain cat is under siege. The discovery that snow leopards have re-occupied the world's highest ecosystem is exciting and encouraging.

Because snow leopards are declining throughout their range (Fox 1994), our findings have conservation relevance that goes well beyond the local level. Very few protected areas in Asia are large enough to contain viable populations of snow leopards and other large predators (McCarthy and Chapron 2003). Sagarmatha National Park together with other two parks in Nepal and Qomolongma Nature Preserve in Tibet form a large trans-frontier landscape conservation area (c. $40,000 \mathrm{~km} 2$ ) which may ensure their long-term survival (Jackson et al. 1994, Singh and Jackson 1999). As long recommended by island bio-geographers (Wilcove and May 1986), conservation strategies today rely on landscapes in and outside the national boundary encompassing larger spaces for the big predators to hunt and disperse their genes to counterbalance edge effect. Recently, top predators are heralded as both the target and the means to conserve biodiversity at landscape level (Ray et al. 2005). Given that recolonization is a fundamental goal of conservation biology either via reintroduction or returning of predators with adequate conservation (Gittleman and Gompper 2001), our work may serve as a model for areas with limited resources. Here we have shown that a predator as rare and as elusive as the snow leopard can be sighted and studied indirectly using a combination of appropriate wildlife techniques, an approach which not only generates scientific
information but also helps promote wildlife-based ecotourism to generate widely needed resources for conservation.

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