Snow Leopard Conservation Grants Program

FINAL REPORTS FOR 2009 PROJECT

1. Executive Summary:

Many studies report relatively high contribution of livestock to the diet of the snow leopard leading to the proposition that local livestock may be playing an important role in sustaining the populations of this endangered carnivore. However, whether livestock, by forming a food resource, are beneficial to the snow leopard, or whether livestock use of an area reduces snow leopard density by compromising habitat quality, is not clearly understood. This understanding is further complicated by the occurrence of retaliatory killing of snow leopards in response to livestock predation in many areas. The broader goal of the project is to assess whether livestock is crucial for the survival of the snow leopard and if yes, then to what extent.

During the reporting period, we photo-captured 5 different snow leopards in an area of 70 sq km. Although the sampled area was small, we nevertheless estimated their density using a spatially explicit capture-recapture framework and obtained a figure of 0.68 $\pm$ 0.40 snow leopards/100 sq km. Our sampling space appears to represent an area where the habitat, topography and prey are relatively favourable and is shared by several individual snow leopards.

At the scale of our study, we found out that distance from village was the most important factor governing the snow leopard use of the landscape (in terms of capture rates). Livestock presence and other landscape variables such as ruggedness, altitude and slope had negligible contribution to snow leopards use of the area. Thus human presence (in the form of villages) and the associated disturbance factors appeared important for determining the snow leopard use of the landscape. Comparing data from two groups of camera traps based on distance to villages showed that the capture rates and the number of unique snow leopards captured were significantly lower in the camera traps close to the villages. Data on movement statistics of snow leopards derived from spatial trapping process also indicates the need to sample at a larger spatial scale by increasing the sampling area and inter-trap distances.

2. Objectives:

What was the purpose of the project?

The purpose of the project was to find out whether livestock benefits snow leopards by examining snow leopard response along a density gradient of domestic and wild ungulates. To address this issue, we had posed following questions.

1. Does snow leopard density and use of an area vary in response to the relative abundance of livestock and wild prey across a disturbance gradient?
    - Is livestock crucial for the survival of snow leopards? If yes

- What proportions of livestock to wild prey support higher snow leopard densities?

2. Is there any change in the activity patterns of snow leopards to fit the needs of operating in a human dominated area?

In order to achieve the long term goals of the project stated above, it would be important to address some basic issues. These issues were

1. Reliable estimation of the response variable viz. population and density estimates of snow leopards.
2. Appropriate sampling scale: What should be the appropriate scale to sample in order to address the long term questions?

How was it expected to contribute to the knowledge or conservation of snow leopards, their prey, or habitat?

Many studies report relatively high contribution of livestock to the diet of the snow leopard (Bagchi and Mishra 2006), leading to the proposition that local livestock may be playing an important role in sustaining the populations of this endangered carnivore. However, whether livestock, by forming a food resource, are beneficial to the snow leopard, or whether livestock use of an area reduces snow leopard density by compromising habitat quality, is not clearly understood. This understanding is further complicated by the occurrence of retaliatory killing of snow leopards in response to livestock predation in many areas.

Designing effective snow leopard conservation strategies would depend upon our understanding of their ecology and critical needs. For instance, if wild prey populations in a given area depleted and snow leopards have a high dependence on livestock for food, making livestock unavailable by improving anti-predatory livestock management may prove detrimental for this endangered carnivore. It is important to understand how snow leopards respond to a gradient of relative abundance of livestock, human disturbance and wild prey to take informed management decisions.

3. Methods: *Describe the methods you used in detail, so that someone else could repeat the work, or, avoid problems you later encountered.*

A. Field Methods:

1. **Reconnaissance survey:** We carried out a reconnaissance survey covering an area of 350 sq. km. area for placing camera traps in a systematic 2x2 km grid based design in four camera trapping blocks based on potential wild-domestic ungulate ratios (Figure 1). We selected the best location within a grid based predominantly on the age and frequency of scats and scrapes. These locations were generally on landform edges particularly on ridgelines and along cliffs.
2. **Camera trap sampling:** Single side camera traps were then operated for a period of one month (July 2009) at 20 locations in a systematic 2x2 km grid design forming a Maximum Convex Polygon (MCP) of 50 sq. km. Analysis of 1 month

of data from this survey called for a change in the design of the camera trap sampling. The details of the design followed and the reasons for change are given in results and discussion sections. From August to November 2009, we deployed double side cameras at 10 locations, forming a MCP of 60 sq. km (Figure 2).

3. **Sign Surveys:** We carried out sign surveys at 13 walks of 2 km each within the block I. We recorded snow leopard signs along with the signs of wild prey and livestock. All signs were classified into age categories and habitat attributes such as dominant topographic feature, dominant substrate, ruggedness, slope, grazing status and major vegetation type were recorded for each sign along with the associated GPS (Global Positioning System) location. The sign surveys were carried out in conjunction with the camera trap sampling exercise. These sign survey walks were repeated three times for each one month sampling periods.
4. **Livestock surveys:** We conducted a door to door census in the five villages which grazed their livestock in the sampling block I. To understand the spatial use of the landscape by the livestock, we conducted a daily interview of the herders of these villages mark the pastures where the livestock was taken out for grazing for a particular day.
5. **Wild prey survey:** We attempted double observer sampling for wild ungulates, though it could not be completed.

B. Analytical Methods:

Identifying snow leopards

Snow leopards were identified from their distinct pelage patterns. This approach has been used to identify bobcats (Heilbrun, Silvy et al. 2003) and snow leopards (Jackson, Roe et al. 2006). Photographs obtained during the day were most easy to identify, whereas photographs obtained at night required some basic photo-editing to make them amenable for identifications.

Building capture histories

Snow leopard capture histories were built using the standard X-matrix format (Otis, Burnham et al. 1978) for the purpose of population estimation and in a unique spatial capture framework for the density estimation using spatially explicit models (Borchers and Efford 2008).

Population estimation

Population size was estimated using program CAPTURE which provides a test for population closure, a goodness of fit test based model selection criteria and population estimates using various closed population models (Otis, Burnham et al. 1978; White, Burnham et al. 1978)

Density estimation

Density estimates were derived using the traditional ½ MMDM (Mean of Maximum Distances Moved) and full MMDM models wherein a strip width ($\hat{W}$) is added to the Maximum Convex Polygon enclosing the camera traps to estimate the effective trapping area [A ($\hat{W}$)]. The density $\hat{D}$ is then computed by dividing the population estimate ($\hat{N}$) by the effective trapping area i.e. $\hat{D} = \hat{N}$ /A ($\hat{W}$).

Sub-sampling capture-recapture data

The 90 days of the capture-recapture data was sub-sampled to explore the issues of effort required to obtain a desired level of estimate precision. This data was also sub-sampled in a spatially explicit manner to explore a range of movement statistics and the issue of sampling scale.

Multiple regression

We used multiple regression to explore the individual contribution of various factors such as distance of nearest village from camera, livestock occurrence instances in the camera trap grids, altitude, slope, ruggedness, dominant topographic feature and dominant substrate on the capture rates of snow leopards.

4. Results: *Describe in detail the results of your project. Show clearly how well you did in meeting your stated goals and objectives. You may wish to include tables or graphs in this section if appropriate. This section will be very important to explain the value of these grants to funders of the Snow Leopard Conservation Grant Program. Be clear, concise, and thorough.*

We provide the results of two phases of sampling. Phase I involved deploying single side cameras as it would have increased sampling efficiency by enabling us to have twice the number of trap stations compared to using both side cameras. We expected to be able to sample more intensively and increase our chances of capturing individual snow leopards as well as obtain high recapture rates. The phase II involved deploying both side camera traps and slight change in the design as well following the preliminary results of Phase I data. These are described in greater detail in subsequent sections.

Phase I

Photographic captures of snow leopards:

In the preliminary survey of Phase I, 20 single side camera traps placed in a systematic grid based design enclosed an area of 50 sq km in the Maximum Convex Polygon. We divided the survey days into occasions with each occasion comprising of 5 days for the purpose of capture-recapture analysis. We obtained 12 captures of 4 individual through a survey effort of 600 trap days. Using the heterogeneity model, the average capture probability per sample was 0.36 and the corresponding population estimate ($\hat{N}$) was 5 with a standard error ($SE\,\hat{N}$) of 1.23. Snow leopard density ($\hat{D}$ (SE [$\hat{D}$]) per 100 sq km using the traditional ½ MMDM model was 2.47(.76, using full MMDM was 1.22(.49) and using the MLSECR model (Maximum Likelihood based Spatially Explicit capture Recapture) was .93(.76).

We lost one camera trap owing to vandalism that was very much unexpected. Out of 19 camera traps thus deployed, we obtained snow leopard captures at 9 trap locations.

It was difficult to identify snow leopards with confidence from the single side photographs. Both side photographs obtained from the sampling done in Phase II finally enabled us to identify snow leopards captured in Phase I.

Phase II

Results from the single side camera trap exercise in phase I had indicated that single side photographs of snow leopards were not conducive for individual identification, necessitating the use of both side cameras at each of the trap stations.
The 10 double side camera traps were placed in a systematic design to obtain maximum coverage of the sampling block and to maximize the capture and recapture rates. We obtained 33 captures of 5 unique individuals from a trapping effort of 900 trap days, spread over a 90 day period. We pooled data from every five days of survey to form a single sampling occasion, thus leading to 18 sampling occasions in total. This is a recommended approach for making data amenable for capture-recapture analysis as it helps to generate sufficient captures and maximize the number of sampling occasions without violating population closure assumptions (Jackson, Roe et al. 2006). We divided this 18 occasion dataset representing 90 days of sampling into 5 independent datasets, starting with a dataset of 6 occasions (30 days) and then adding an increment of 3 occasions (15days) to each subsequent dataset to explore various issues, discussed in detail later. All of the 10 camera trap locations recorded snow leopard captures.

An exhaustive reconnaissance combined with an intensive search for suitable locations resulted in all of the trap locations to capture snow leopards. Both side camera traps ensured unambiguous snow leopard identification.

Capture rates

The test for population closure implemented in program CAPTURE supported our assumption that population was closed during the survey period (z=1.52, P= 0.93) even for the entire 90 day survey period.

The test for behavioural response did not provide evidence in support of model Mb for any of the five sampling periods. Similarly the test for time specific variation in the capture probabilities did not provide any evidence in support of model Mt

The test for closure in program CAPTURE however is not considered to be statistically robust and hence we also used a more rigorous test implemented in program CloseTest which specifically tests the null hypothesis of closed-population time model against the open population Jolly-Seber model as the alternative (Stanley and Burnham 1999). The test is most sensitive to permanent emigration, least sensitive to temporary emigration and has intermediate sensitivity towards permanent or temporary immigration. The CloseTest also supported our assumption that the population was closed (Chi square=19.20, d. f. = 15, *P*= 0.20).

The model selection procedure of program CAPTURE consistently selected the null model Mo as the best fit mode closely followed by the model incorporating individual heterogeneity Mh.

Using the heterogeneity model, the average capture probability per sample varied from 0.19 to 0.25, while the corresponding population estimate ($\hat{N}$) varied from 5 to 6 with a standard error ($SE\,\hat{N}$) ranging from 1.4 to 2.6 (see Table 1 for details).

The detailed results of trapping effort, goodness of fit tests, model scores, population estimates and coefficients of variance are provided in Table 1. Snow leopard density ($\hat{D}$ (SE [$\hat{D}$]) per 100 sq km using the traditional ½ MMDM model, full MMDM model and the MLSECR model (Maximum Likelihood based Spatially Explicit capture Recapture) are provided in Table 3.

Snow leopard population remained closed for the entire duration of study area i.e. no new individuals were added to the sampled population, nor did of the sampled individuals moved out of the study area. Selection of the null model indicates a rich capture history without much variation in the individual capture probabilities.

Sub-sampling capture-recapture data:

Since one of the goals of the study was to improve snow leopard population and density estimation methods, we sub sampled this 90 day data to address several issues such as sampling effort required to achieve the desired average capture probabilities ($\hat{p}$ **)**, overall capture probability of capturing an individual present in the sampled population ($M_{t+1}/\hat{N}$) and the desired level of precision of the population and density estimates.

Movement statistics:

These statistics summarize the movements of individual snow leopards as computed from the spatial capture-recapture data. The home range statistics include d-bar (mean recapture distance pooled across all individuals), RPSV (square root of pooled spatial variance), [P (d=0)] (proportion of recaptures in the same trap), MMDM (mean maximum distance moved), t2r2 (Schoener's ratio t^2/r^2, pooled over animals). It is important to note that each of these measures is affected by the trap layout and trapping intensity. RPSV is the preferred movement statistic for use in the computation of density using MLSECR methods. SECR (Spatially Explicit Capture Recapture) methods require a measure of home range size and RPSV is the preferred statistic as trials suggest that it is more robust than d-bar to serial correlation of capture locations. Schoener's provides an indication of serial correlation in capture location.

The details of all the home range statistics are provided in table 2. The mean recapture distance pooled across individuals (d-bar) increased with the increase in the number of sampling occasions indicating the need for sampling for a longer duration to be able to the estimate distances moved by snow leopards to be close to the actual distances moved, which can only be truly estimated from radio-telemetry data. The RPSV also increased with increase in the number of sampling occasions, but the increase was not rapid compared to the estimate of d-bar. The RPSV is a measure of how far an individual would venture from a hypothetical range centre and is more robust than d-bar to serial correlation of captures and hence is used by default by the SECR models. The values for the initial detection scale (σ) also increased with an increase in the number of sampling occasions. Proportion of recaptures in the same trap decreased with increase in sampling occasion, though even after 18 occasions, 17 percent of the recaptures of the snow leopards were at the same site. The Schoener's ratio is a statistic that decreases with increasing autocorrelation and in our case it increased with an increase in the number of sampling occasion, reaching a value of 1.73 with 18 sampling occasions. The asymptotic value for this statistic is about 2.0 when locations are independent and values less than 2.0 indicate serial correlation.

The values for the movement statistics (d-bar, RPSV and σ) did not reach a saturation even after sampling for a long duration (18 occasions, 90 days) indicating the need to sample a much larger area than we had currently sampled. Also the serial correlation between traps suggests that inter-trap distances should be much larger than in the present study (average=2.27 km) to minimize serial correlation.

The maximum distances moved by individual snow leopards were computed for individuals with at least 1 recapture event. For individual A, B and C which were recaptured more than twice, the maximum distances moved were 9.82 km, 9.09 km and 11.09 km respectively. Snow leopard E which had only one recapture had a maximum distance moved of 2.75 km. The maximum distance between the furthest camera traps was 14.62 km.

The results from movement statistics indicate the need to increase the distances between camera traps and to cover a larger area to realistically capture the actual movement distances of snow leopards.

Comparing near disturbance and far disturbance zones

The camera traps were divided into two groups. The group 1 comprised of five camera traps which were less than 3 km away (mean= 2.11 km) from the nearest village and group 2 comprised of five camera traps that were more than 3 km away (mean= 4.13 km) from the nearest village. Since we were interested in knowing whether increased level of human disturbance would influence snow leopard capture and recapture rates at cameras, we used distance from village as a surrogate of disturbance level.

In the group closer to the villages we recorded 8 independent photo-captures of three snow leopards while in the group farther away, we recorded 31 independent captures of 4 individual snow leopards. None of the camera traps closer to the villages recorded more than one snow leopard, while four of the camera traps farther away from villages recorded more than one individual snow leopard. A single camera trap in the group farther away from the villages captured 4 individual snow leopards, effectively capturing the 80 percent of the sampled population.

The snow leopard capture rates of camera traps at group 2 (away from disturbance sites) were significantly higher than that of camera traps at group 1 (cameras close to disturbance sites) (T-value= -5.06, P= 0.007).

There was only one snow leopard photo-capture between 08:00 to 18:00 hrs in the camera trap group closer to the villages, whereas 8 independent photo-capture events were recorded at camera trap group farther away from villages during the same time period indicating that snow leopards avoided moving in the area close to villages during day time.

The cumulative snow leopard captures increased linearly with sampling occasions (Figure 3). As the goodness of fit tests and model selection criteria of program CAPTURE confirmed, the snow leopards did not show a trap response towards the camera traps. During our sampling period, the snow leopards did not appear to be wary of the camera traps and were actually inquisitive as they observed a new object in the form of a cairn like structure (shielding the camera trap) in their movement paths. The number of unique snow leopard individuals captured reached a saturation on 13th sampling occasion (65 days) and no new individuals were added till the end of the sampling (18th occasion, 90 days) indicating an adequacy of sampling effort (Figure 4). However the overall probability of capturing a snow leopard ($M_{t+1}/\hat{N}$) in the study area was 83 percent for full 18 occasions.

Snow leopard activity patterns showed a bimodal peak (Figure 5), with snow leopards being most active in the early morning (04:00 to 08:00 hrs) and evening hours (16:00 to 20:00 hrs). The lapse time between a snow leopard individual being recaptured at the same location varied between 5 to 47 days, average being 23 days. This indicates that camera traps needs to be placed out for a longer duration to obtain sufficient recaptures. The desired trapping duration though depends upon several factors; it can be roughly computed by targeting a minimum capture probability value of .20.

Factors influencing snow leopard capture rates:

One of the goals of the study is to understand the response of snow leopards towards various factors operating in the landscape. We used the capture rates of snow leopards at the 10 camera trap locations as a measure of snow leopard response. We then overlaid a 2x2 k m grid cell on each of the camera trap location to measure landscape variables such as average slope, average altitude and ruggedness for each of the grid containing a camera trap. Since we hypothesized that snow leopard usage of the landscape will be influenced by the livestock spatial use of the landscape, we also recorded livestock presence in each of the grid on every day for the entire 90 days of the camera trap sampling period. We also recorded dominant topographic feature and dominant substrate type for these grids. Thus we had five continuous and two categorical variables that would potentially explain the snow leopard capture rates at each of the camera trap locations.

We used stepwise multiple regression to identify the variables that would potentially explain the variability in the capture rates and thus be used in the final regression model. Categorical variables were converted into dummy variables using numeric coding.

Distance from village turned out to be the most significant predictor (T=4.38, *P*= 0.002) and explained 70.5 percent variability in the data (S= 0.016, R-square= 70.5%). Other variables in the order of their contribution were livestock presence (S= 0.029, R-sq=11.8%, *P*= 0.33), average altitude (S= 0.029, R-sq=9.3%, *P*= 0.39), dominant topographic feature (S= 0.029, R-sq=8.3%, *P*= 0.41), landscape ruggedness (S= 0.030, R-sq=2.9 %, *P*= 0.63), average slope (S= 0.030, R-sq=0.2%, *P*= 0.90), and dominant substrate (S= 0.029, R-sq=0.1%, *P*= 0.91).

The regression model thus suggested that distance from the village was the only significant predictor of the snow leopard capture rates at camera trap locations. Snow leopard capture rates were positively related to the distance from the village. Livestock presence in a camera trap grid explained just 11.8 percent of the variability in the capture rates and was not significant as were all other predictor variables.

Importance of using an appropriate scale

The results of *movement statistics* and *regression analysis* indicate one very important factor; the factor of appropriate spatial scale.

The results of movement statistic d-bar did not stabilize after 90 days of sampling and showed an increasing trend. Also the maximum distances moved by the individual snow leopards as indicated by the spatial capture history appear to have been limited by the maximum distances between the furthest cameras. The high proportion of recaptures in the same trap [P (d=0)] and an indication of serial correlation in capture locations can be alleviated by sampling a larger area and by increasing the inter-trap distances. We do not know the average home ranges of snow leopards in this area, but from the movement statistic RPSV derived from the camera trap data (though this is likely to be an underestimate owing to the limited area that camera traps covered), the average home range would be at least 55 square kilometers (assuming RPSV to be the radius of a circular home range). Following the commonly accepted criteria of placing 2-3 camera traps in an animal's home range, ideally there should be one camera trap in a 15 to 25 square kilometer area. Our data suggests that ideal camera trap density in Spiti to estimate snow leopard populations so as to provide a good coverage of the study area, without leaving much gaps to ensure that none of the individual snow leopards operating in the study area has a zero or near zero capture probability would be 4-7 traps/ 100 sq km. This however is on the conservative side from the information based on the limited camera trapping we did. This essentially means that inter-trap distances can be further increased and one could operate camera traps at even lower densities. Our data suggest that increasing inter-trap densities would reduce the serial correlation between camera traps, reduce the proportion of recaptures in the same traps and provide a better estimate of the movement statistics such as MMDM and RPSV. This would help minimize the potential problems in the analysis of capture-recapture data using spatially explicit models. However whether this would lead to increased precision in the model estimates need to be tested through actual field experiments. Since for most of the studies, the number of camera traps is a limitation, this would also help in increasing the sampled area with the limited number of traps.

None of the variables except the "distance of the camera from the nearest village" could explain the observed capture rates of snow leopards in the camera traps. We treated the capture rates of snow leopards as a surrogate of habitat use. We had expected the presence of livestock in a camera trap grid to influence the use of that area by snow leopards, but livestock occurrence did not seem to influence snow leopard capture rates. Our data suggest that at our scale of sampling (area= 70 sq km, inter-trap distance= 2.27 km) the snow leopards are unlikely to respond to most of the recorded variables (listed earlier). Though we obtained photographic captures of five snow leopards in a 70 sq km, the density estimates using the spatially explicit model was low (0.68 $\pm$0.40 snow leopards/100 sq km) suggesting that snow leopards were ranging far beyond the boundaries of our sampling area. Since snow leopard home ranges can be very large (ongoing satellite telemetry projects of the Snow Leopard Trust in Mongolia and Pakistan), our sampling area may be just a part of the home range of a single adult snow leopard.

However it would also be important to identify a biologically meaningful temporal scale while answering specific questions as seasonal variations in the predictive variables can produce confounding results. Since we have now got a fairly clear idea of the required spatial scale, we would need to define a meaningful temporal scale for achieving the goals of this project as the next important step.

Several snow leopards can share a common core area where the habitat, topography and prey is more favorable by maintaining temporal separation (Jackson 1996). Our sampled area appears to be one such core area which is being shared by several individuals as indicated by the capture of four distinct adult snow leopards at one single camera traps, while all the five photo-captured snow leopards were shared by camera traps which enclosed just 4.23 sq km area.

5. Discussion: *This is your chance to evaluate your own work.*

What did you learn that could help others wishing to do similar projects?

One of the most important thing that emerges out form this work is the need for a pre-sampling effort before a full fledged long term project is started. Pre-sampling can help understand potential limitations, provide new insights and can vastly improve the way a study is conducted. Our Phase I and Phase II work helped us understand several issues that would have otherwise undermined the long term implementation of this study. For instance now we know that photographs obtained from single side camera traps are difficult to identify and assign to individuals. A better trade off can be obtained by an exhaustive reconnaissance survey and selecting locations that would be extremely likely to capture snow leopards even when compared to similar locations within the landscape. Also given that snow leopards have large home range sizes, its better to maximize the area covered by camera traps by increasing the inter-trap distances. Though this would vary between sites, in our case 5 camera traps per 100 sq km seem sufficient provided that each of the selected location is chosen after a thorough and intensive reconnaissance. Our data also suggests that when answering ecological questions pertaining to snow leopards it is crucial to identify an appropriate sampling scale. For instance landscape variables such as altitude and ruggedness did not seem to influence snow leopard capture rates in our study. It appears that at the small spatial scale of our sampling, it would be difficult to discern the influence of these variables. Snow leopards being wide ranging animals would require sampling much larger landscapes to answer the questions that we had proposed. Thus even to understand the snow leopards response across a gradient of varying wild prey-livestock ratios, our each sampling block would be at least 400 sq km rather than 50-100 sq km's as we had earlier proposed.

Studies conducted in challenging areas should also keep in mind and account for potential problems that can arise from difficulty in arranging logistics and unexpected bad weather. During the three months of intensive sampling, we faced three prolonged bouts of bad weather. This really hampered our work as we could not complete the prey surveys and also could not move out of our first sampling block.

We had embarked upon an ambitious task which we were confident to do. Though we could not meet all the goals of the project, there are important lessons that we learnt. Since we knew that it may not be possible to achieve all the goals of the year in a short time period, that's why our project timeline is four years. This years study is an important pre-requisite for the long term goals of the project. With the insights and lessons from this pre-sampling we will are now in a better position to achieve the long term goals of the project.

How do you see the results being applied to conservation?

Even with our somewhat limited sampling, we have obtained very interesting insights into the snow leopard population and density estimation as well as movement and ranging patterns of snow leopards. Our results provide valuable insights into the improvement of the population and density estimation methods for snow leopards as well as the design of snow leopard population-density estimation studies. With these preliminary results, we can make several improvements in the way snow leopard populations are sampled using camera traps, thus avoiding analytical and design pitfalls.

Our results also clearly show the importance of appropriate sampling scale for answering ecological questions. It is now obvious that for an effective understanding of factors governing snow leopard abundance and distribution, we need to sample at much larger scales (minimum areas of 300-400 sq km's) as snow leopards may not respond to otherwise important variables of landscape at small spatial scales. At small spatial scales, there are too many factors that can confound the influence of various habitat and land-use variables.

Also though the snow leopards might be dependent upon livestock to a large extent, they do not seem to be following the livestock spatial use patterns at our sampling scale. On the contrary snow leopards clearly seemed to avoid the villages (surrogate for disturbance), preferring the areas away form the villages. This clearly indicates the value of setting up of grazing free reserves and no use areas in a landscape that is shared by humans and their livestock on one hand and snow leopards and their wild prey on the other. Such refugees might be crucial for the long term survival of snow leopards as well the wild prey.

What additional work is now needed based on your findings?

We need to follow up on our original plan of sampling several large areas to understand the snow leopard response along a density gradient of domestic and wild ungulates. However from our present study, it is very clear that these sampling blocks need to be relatively large (300-400 sq km's each). Also we need to keep in mind the importance of sampling at appropriate scales within the sampling area by increasing the inter-trap distances to avoid the potential problems discussed earlier.

We are yet to analyze the food habits of snow leopards for this sampling bout and that would further help us understand whether the livestock contribution to snow leopard diet in this area has decreased from the earlier reported 40-60% (Bagchi and Mishra 2006).

REFERENCES

Bagchi, S. and C. Mishra (2006). "Living with large carnivores: predation on livestock by the snow leopard (Uncia uncia)." Journal of Zoology **268**(3): 217-224.

Borchers, D. L. and M. G. Efford (2008). "Spatially Explicit Maximum Likelihood Methods for Capture-Recapture Studies." Biometrics **64**(2): 377-385.

Heilbrun, R., N. Silvy, et al. (2003). "Using automatically triggered cameras to individually identify bobcats." Wildlife Society Bulletin **31**(3): 748-755.

Jackson, R. M. (1996). Home Range, Movements and Habitat Use of Snow Leopard (Uncia Uncia) In Nepal. Ph.D. Thesis, University of London. **Ph.D.:** 233.

Jackson, R. M., J. D. Roe, et al. (2006). "Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques." Wildlife Society Bulletin **34**(3): 772-781.

Otis, D. L., K. P. Burnham, et al. (1978). "Statistical Inference from Capture Data on Closed Animal Populations." Wildlife Monographs **62**: 3-135.

Stanley, T. R. and K. P. Burnham (1999). "A closure test for time-specific capture-recapture data." Environmental and Ecological Statistics **6**(2): 197-209.

White, G. C., K. P. Burnham, et al. (1978). Users manual for program capture, Utah State University, Logan, Utah, USA.

Population estimation

			close test		Model score		Mo						Mh						
occ	Mt+1	captures	Z	P	Mo	Mh	N	SE	p-hat	lcl	ucl	CV	N	SE	p-hat	lcl	ucl	CV	Mt+1/N
6	4	7	-1.136	0.12	1.00	0.85	5	1.74	0.29	4	8	34.80	6	1.82	0.19	5	13	30.33	67
9	4	11	-0.36	0.35	1.00	0.84	4	0.42	0.3	4	4	10.50	6	2.55	0.2	5	18	42.50	67
12	4	15	0.78	0.78	1.00	0.84	4	0.21	0.31	4	4	5.25	5	1.38	0.25	5	11	27.60	80
15	5	21	2.62	0.99	1.00	0.85	5	0.19	0.28	5	5	3.80	6	1.4	0.23	6	12	23.33	83
18	5	26	1.52	0.93	1.00	0.85	5	0.1	0.28	5	5	2.00	6	1.42	0.24	6	12	23.67	83

Table 1. Results of closure test, model score and population estimates from null (Mo) and heterogeneity models derived from program CAPTURE. Abbreviations are M_{t+1} = number of individuals captured, Mo= Null model, Mh= Heterogeneity model, N= population estimate, SE= standard error, lcl=lower confidence limit, ucl= upper confidence limit, cv= coefficient of variation, $M_{t+1}/\hat{N}$ = overall capture probability of capturing an individual present in the sampled population

Home range statistics

Occ	Mt+1	captures	d-bar	se	n (d-bar)	P(d=0)	RPSV	sigma	se	MMDM	se	t2/r2
6	4	8	2750	1609	4	0.50	3692	3823	2501	5501	637	1.22
9	4	15	3484	929	11	0.36	4021	5441	1566	9122	710	1.24
12	4	20	4045	721	16	0.25	4359	6246	1992	8826	1682	1.23
15	5	26	4140	638	21	0.23	4122	5148	1427	7308	1929	1.45
18	5	33	4907	571	28	0.17	4319	6033	1950	8199	1862	1.73

Table 2. The home range statistics of the snow leopard population derived from camera trap data. Abbreviations are M_{t+1} = number of individuals captured, d-bar= mean recapture distance pooled across all individuals, P(d=0)= proportion of recaptures in the same trap, RPSV= measure of how far an individual would venture from a hypothetical range centre, sigma= initial detection scale, MMDM= mean maximum distance moved, t2/r2 (Schoener's ratio)= schoener's ratio is a statistic that decreases with increasing autocorrelation. The asymptotic value for this statistic is about 2.0 when locations are independent and values less than 2.0 indicate serial correlation.

Occasions	Model used for density computation	Effective trapping area	Snow leopard density estimate (snow leopards/100 km2)	Standard error
6	1/2 MMDM	176.50	3.21	1.07
	Full MMDM	339.70	1.67	0.58
	ML SECR	276.00	1.47	1.57
9	1/2 MMDM	278.60	2.20	1.08
	Full MMDM	627.05	0.98	0.48
	ML SECR	620.00	0.65	0.43
12	1/2 MMDM	269.48	1.82	0.62
	Full MMDM	600.00	0.82	0.31
	ML SECR	706.00	0.57	0.37
15	1/2 MMDM	224.88	2.64	0.89
	Full MMDM	472.80	1.25	0.50
	ML SECR	598.00	0.84	0.49
18	1/2 MMDM	250.63	2.37	0.77
	Full MMDM	546.02	1.09	0.41
	ML SECR	741.00	0.68	0.40

Table 3. Depicting number of sampling occasions and corresponding effective trapping area and density estimates using ½ MMDM, full MMDM and ML SECR models. Abbreviations ½ MMDM is half the mean of maximum distances moved by individual snow leopards as estimated from camera trap recaptures, full MMDM is simply twice of the ½ MMDM and ML SECR denotes the recently developed Maximum Likelihood based Spatially Explicit Capture Recapture model

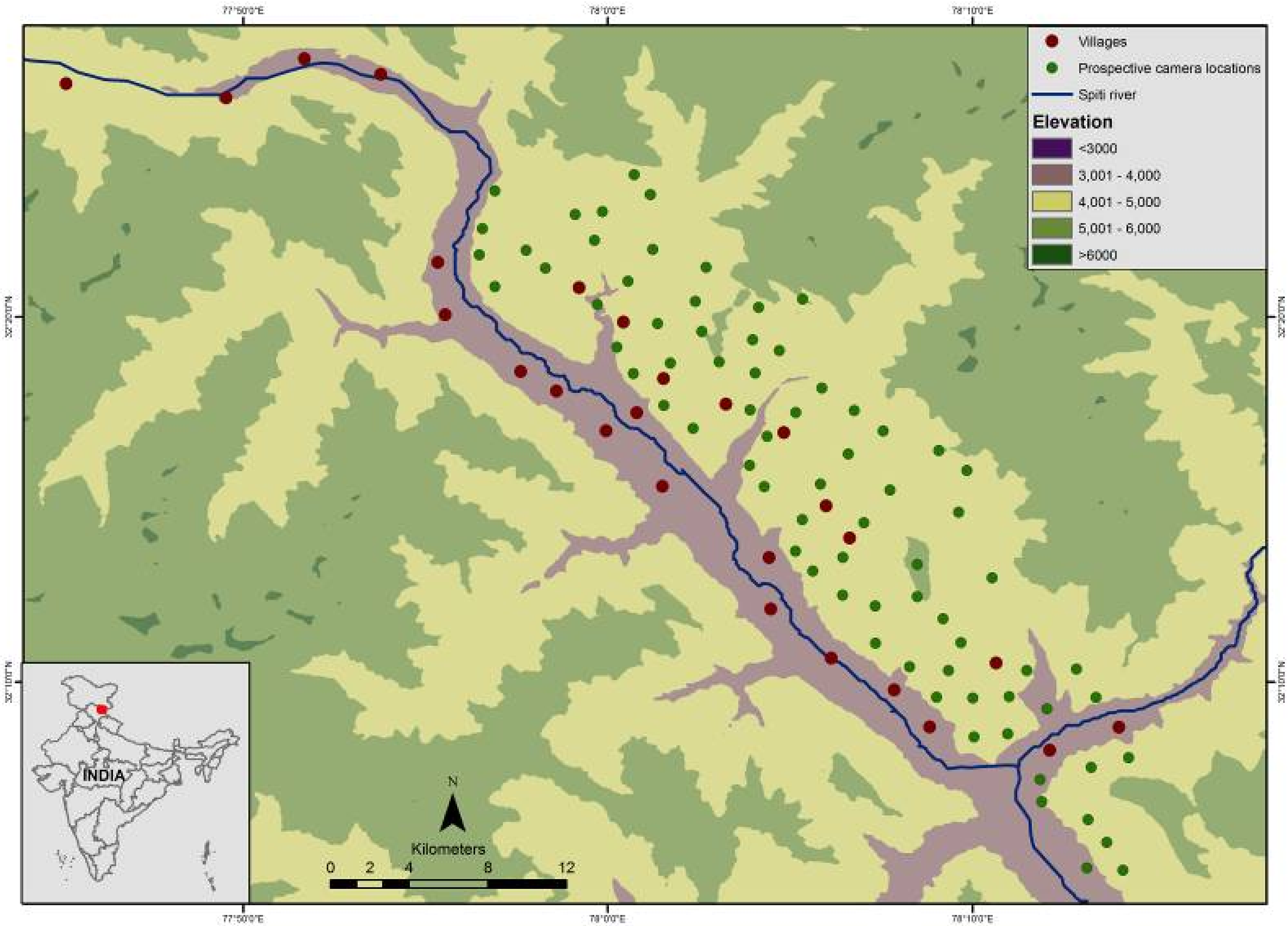

Figure 1. Map of the study area depicting the prospective camera trap locations depicted by green circles and locations of villages depicted by brown circles. The map insets show location of upper Spiti landscape in India.

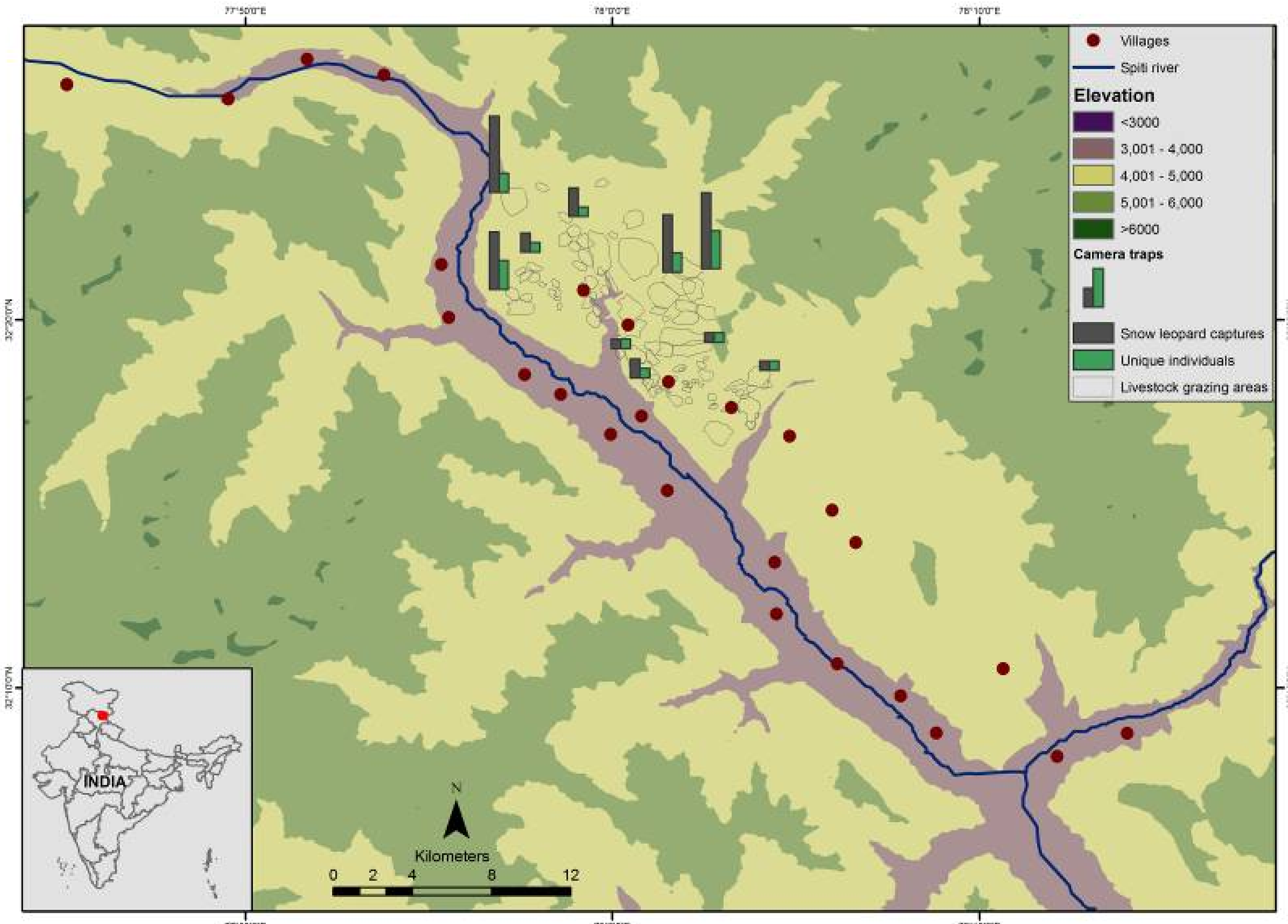

Figure 2. Map of the study area depicting camera trap locations, snow leopard captures and unique number of snow leopards captured at each locations. Note that the locations away from villages (brown circles) recorded more number of captures and unique snow leopards.

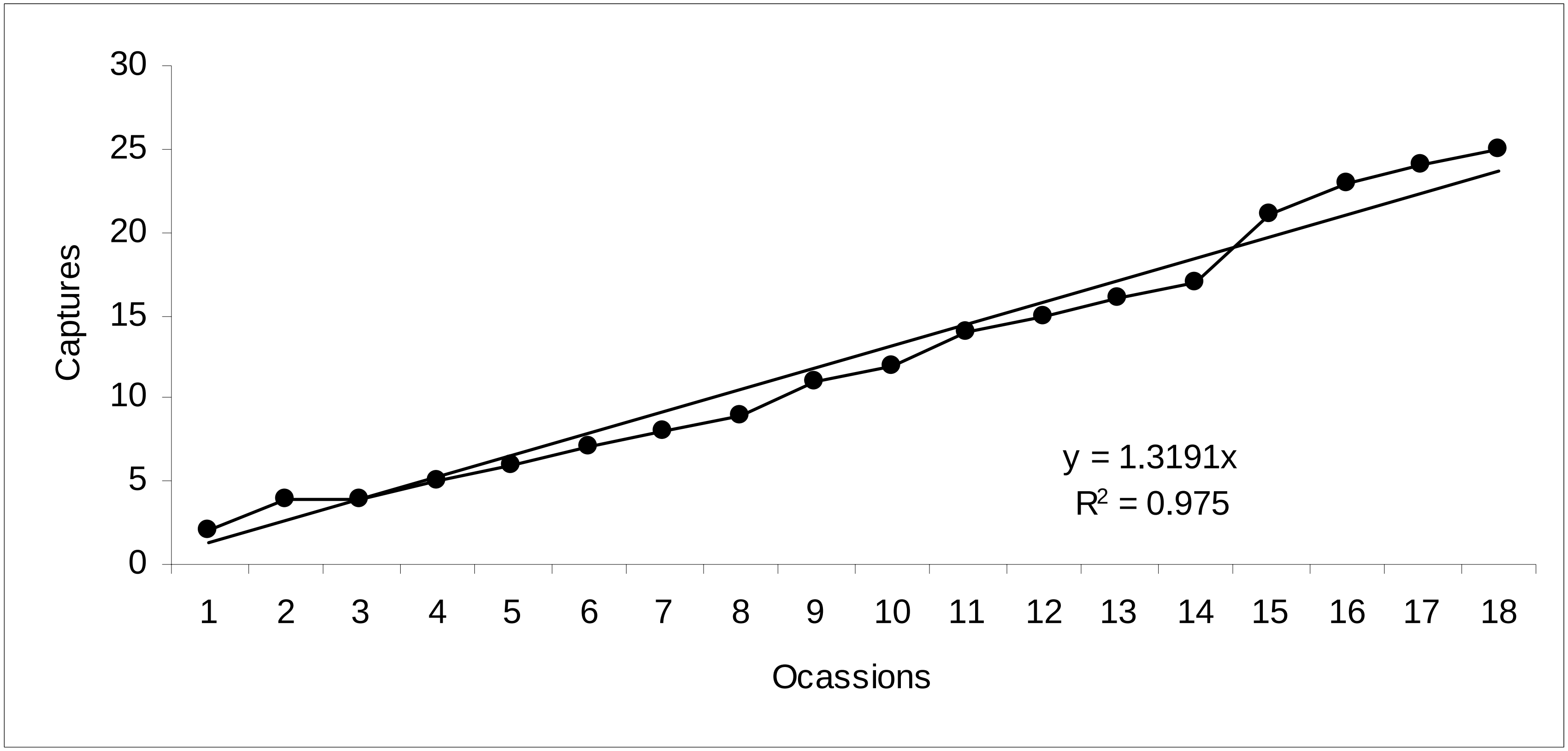

Figure 3. Snow leopard capture rates over the sampling occasions. The linear fir conforms that snow leopards did not become trap shy and capture rates were constant throughout the sampling period.

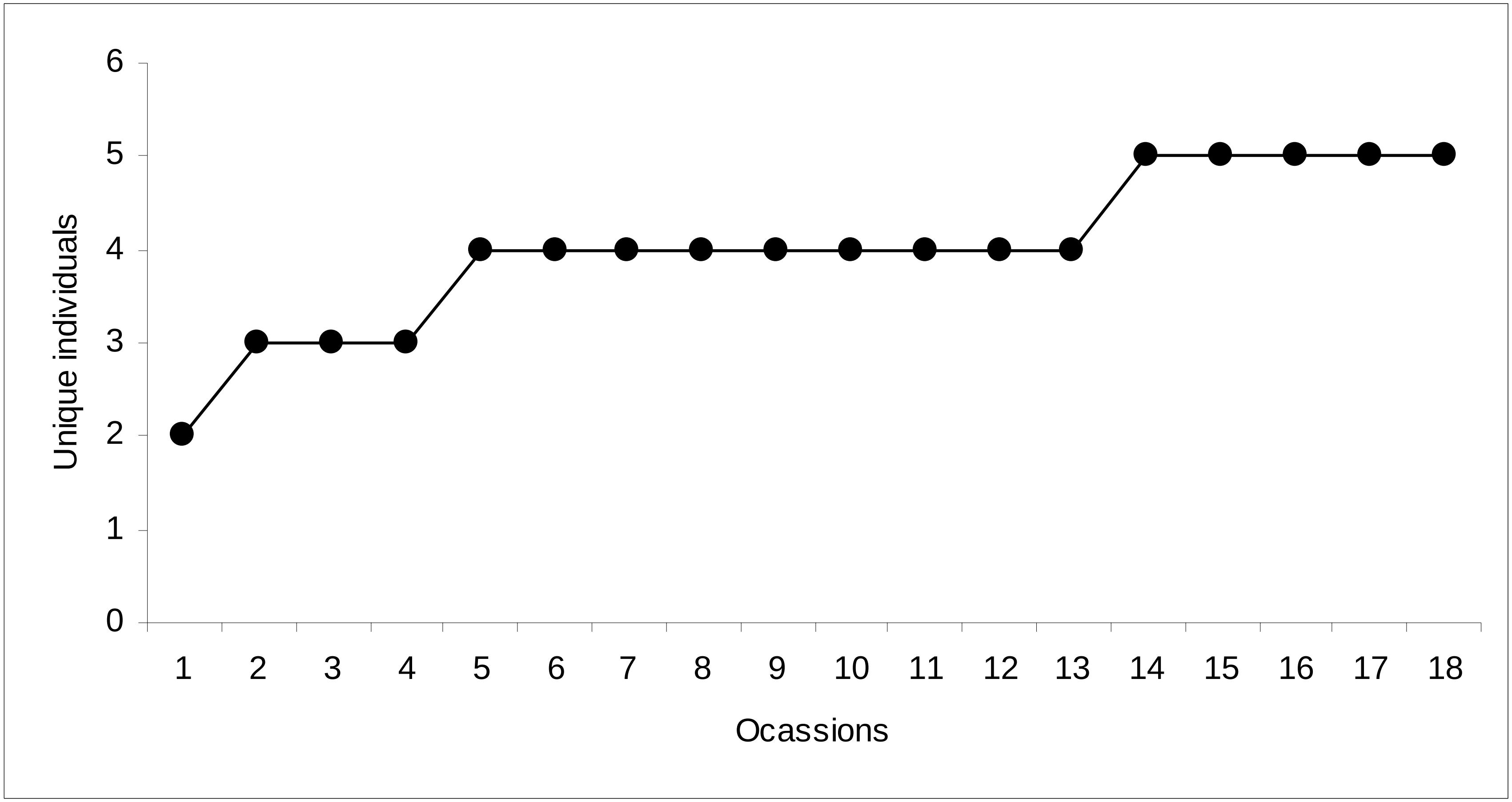

Figure 4. Number of unique snow leopards captured over the sampling period. Number of unique snow leopards captured stabilized only after 13th sampling occasion emphasizing the need for sampling over longer duration.

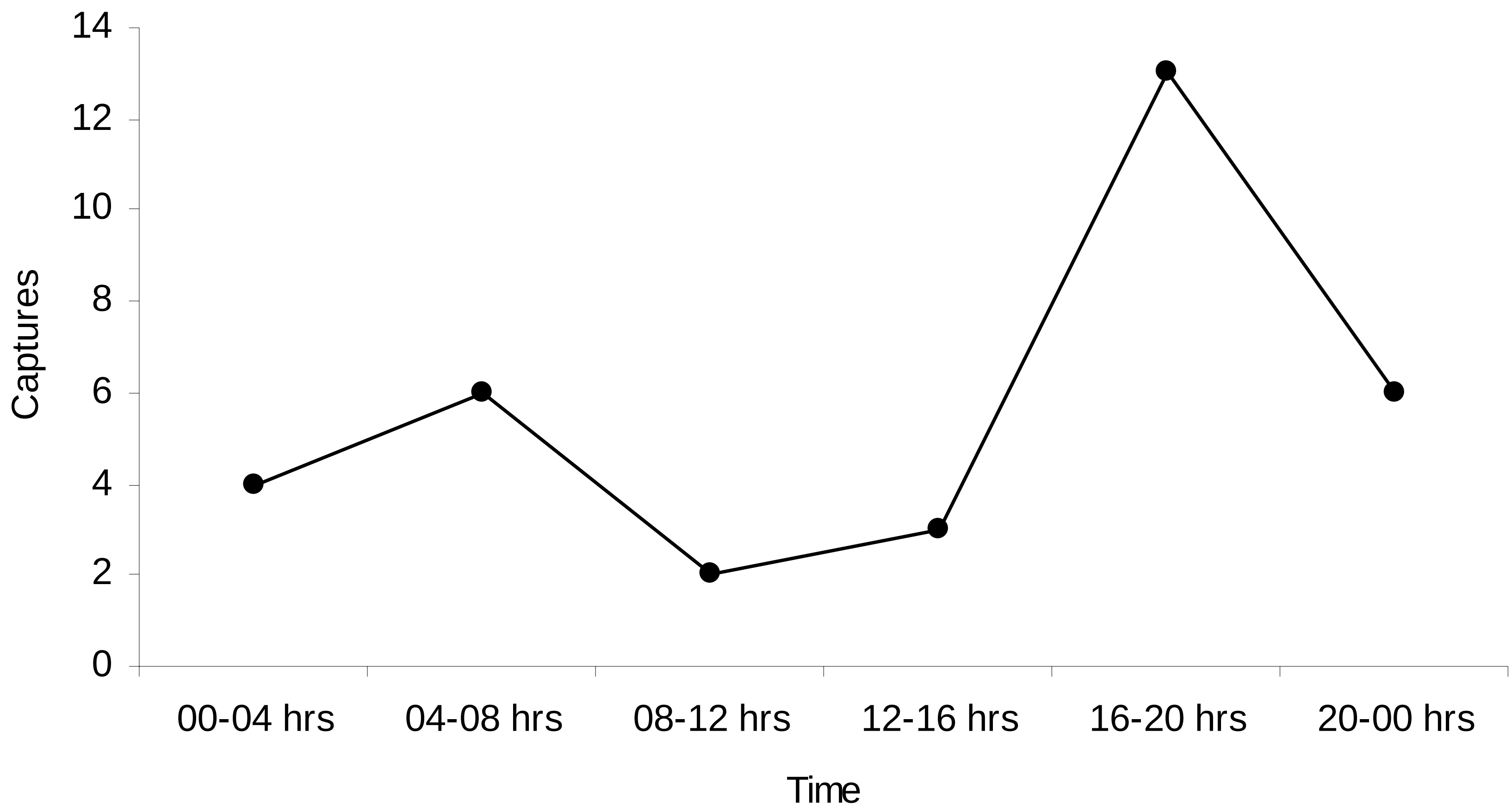

Figure 5. Activity patterns of snow leopards. Snow leopards show a bimodal activity peak and were found to be most active in the evening and morning hours.

Red fox (Rishi Kumar Sharma)

Horse kill (Rishi Kumar Sharma)

Ibex (Rishi Kumar Sharma)

Landscape (Rishi Kumar Sharma)

Camera trap survey (Rishi Kumar Sharma)

Landscape (Rishi Kumar Sharma)

Spiti women in traditional attire (Rishi Kumar Sharma)

Pea fields (Rishi Kumar Sharma)

Ibex from camera trap
(Nature Conservation Foundation-Snow Leopard Trust)

Camera trap (Rishi Kumar Sharma)

Volunteers learning to identify snow leopard signs
(Rishi Kumar Sharma)

Famous Chumurti horse (Rishi Kumar Sharma)

Snow leopard from camera trap
(Nature Conservation Foundation-Snow Leopard Trust)

Two snow leopards from camera trap
(Nature Conservation Foundation-Snow Leopard Trust)

Snow leopard from camera trap
(Nature Conservation Foundation-Snow Leopard Trust)

Snow leopard from camera trap
(Nature Conservation Foundation-Snow Leopard Trust)