Snow Leopard Monitoring Methodology Field Report

June 6th, 2005

Base Camp-

Hello from Koilu Valley of the Tien Shan Mountains in Kyrgyzstan. I am excited to inform you that our research team has arrived intact along with all necessary field equipment in the Sary Chat Ertash Zapovednick (protected area). We have made camp at approximately 10,000 feet and are well acclimated for our daily climbs to 12,000 feet and above. Our river valley is nestled within rugged snow capped mountains. It is perfect snow leopard habitat.

The Team-

We are fortunate to have two Kyrgyz Graduate students working with us throughout the field season. Kubanych and Vassily are excellent biologists whose interest and knowledge in the flora and fauna of their native country is immeasurable. Dr. Tom McCarthy of the International Snow Leopard Trust (ISLT) and Dr. Alexander Vereshagin of Issyk Kul University in Karakol have kindly joined us for eleven days in the field, bringing with them a wealth of knowledge and expertise. Several Park Rangers have aided in transporting equipment to our study site, showing amazing stamina and horsemanship over an 8 hour ride from the nearest road. One ranger, Bakit has stayed with us to help in the camera placement. The camp manager and cook, Indira, continues to provide excellent food and warm firesides. Finally my wife, Jenni, and I, graduate students of the University of Massachusetts Amherst round out our team.

Progress-

We have successfully placed 22 pairs of cameras throughout our study area. Camera sites range in elevation from 10,000 to 12,000 feet. Several camera pairs are placed in areas heavily marked by snow leopards. All cameras are in locations of suspected snow leopard travel. The camera sites cover more than 100 square kilometers of the Sary Chat Ertash Zapovednick, not including the buffer zone for snow leopards on the fringe. Efforts are now being

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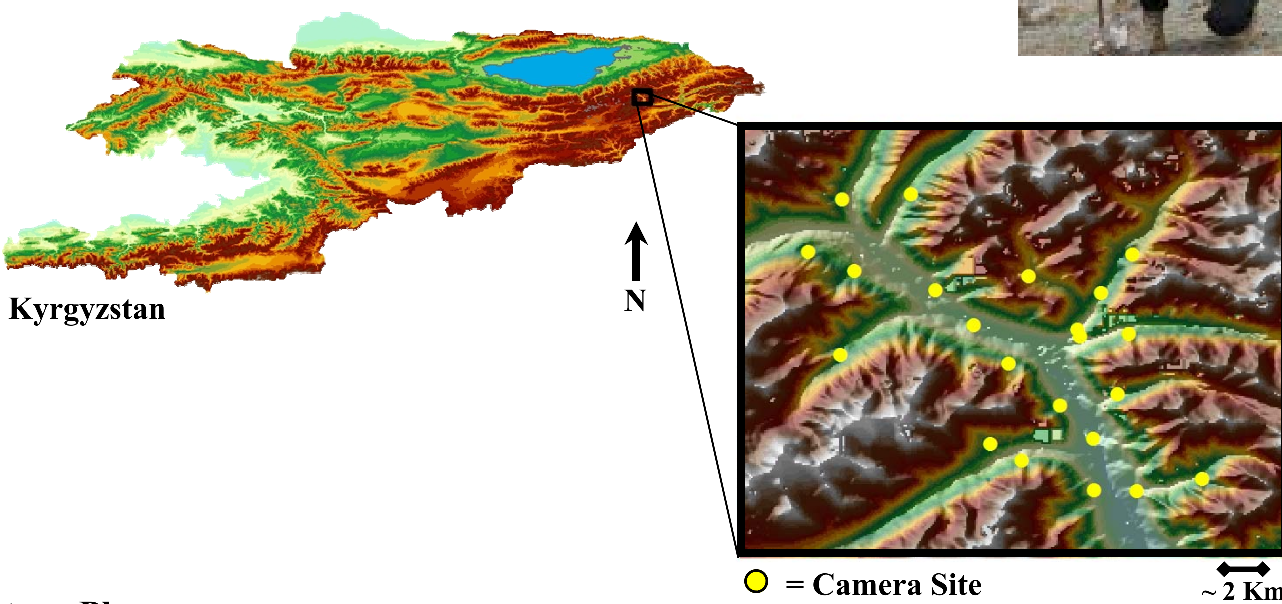
June 6th, 2005

Progress (continued)-
focused on snow leopard sign transects and ungulate surveys. Over the last two days Dr. McCarthy and Dr. Vereshagin have trained our team in the methodology for sign transects and ungulate surveys as used across all snow leopard range.



Future Plans-
Dr. McCarthy and Dr. Vereshagin leave camp tomorrow, (carrying this report with them.) We will leave the cameras in position for another six weeks. In those weeks we will intensively survey the area for snow leopard sign and ungulate numbers. During that time Dr. Raghu Chundawat, ISLT's regional science and conservation director, will visit our camp. He will observe our methods for use across the border in the Chinese Tien Shan. At the end of six weeks time we will pull all camera pairs and move to our second site in the Jangart Hunting Reserve. I will attempt to send another field report during a short break between study sites.

Special Thanks-
I would like to thank to the Wildlife Conservation Society (and their private donor), the International Snow Leopard Trust, and the Kumtor Operating Company for the funding support which has made this project possible. Also cheers to the University of Massachusetts Amherst and Dr. Todd Fuller for advice and support in project design and methodology.

Sincerely,
Kyle McCarthy
Project Leader

Snow Leopard Monitoring Methodology Field Report

July 24th, 2005

Salamatzizby (Hello in Kyrgyz)

Greetings from 14,000 feet at the Kumtor Gold Mine in the Tien Shan Mountains of Kyrgyzstan. We are between study sites and enjoying the great food, hot showers and laundry facilities provided by the Kumtor Operating Company. After touring the facility we are impressed with the care and consideration expressed towards the local communities and their surrounding environment. Oh, and did I mention the hot showers?

Our Progress-

Dr. Raghu Chundawat joined us in our study area for 4 days. His knowledge of snow leopard biology and experience in using camera traps for tiger research helped fine tune our methodology. It also gave Dr. Chundawat a chance to see what will be needed for his portion of the project across the border in China. One result of Raghu's visit is that we have now collected wolf feces in addition to snow leopard feces to allow for a comparison of food habits between species. Following Dr. Chundwats departure we began to intensively survey our study site. We were able to complete approximately one ungulate survey and one SLIMS sign survey for every 8 square kilometers. We have also counted marmot holes in 2 hectare plots as an index of relative marmot abundance between sites. In our ungulate surveys we saw several large herds (60+) of argali and ibex. Our cameras took more than 200 pictures, but we must wait until we finish our next study site and return to Bishkek to get the film developed. One camera was knocked down and had several tooth marks on it, we suspect either snow leopard or wolf. The adjacent cameras photos will tell us the truth of the matter.

Finally, after seven and a half weeks in Sarry Chat we pulled all of the cameras, packed our belongings and started on the 7 hour horse ride to the nearest road. From there a park jeep met us and we traveled to Barscoon and the park headquarters to meet with the park manager. We are pleased with our progress to date and anxious to begin research in the new study area where we expect to find even higher snow leopard densities.

Snow Leopard Monitoring Methodology Field Report

July 24th, 2005

The Next Step

In two days time we will pack our ponies and move to our new study site in the Jangart Hunting reserve. There we will again have the assistance of Dr. Alexander Vereshagin in camera placement. We will also have one biologist from the Kyrgyz government join our team to observe our work and smooth any political issues with the local hunting agencies. Cameras will remain in place for 7 weeks during which time we will complete more ungulate and SLIMS surveys. After Jangart I will send a final field report from Bishkek with results from the developed film.

Again, Thank You-

I would again like to thank to the Wildlife Conservation Society (and their private donor), the International Snow Leopard Trust, and the Kumtor Operating Company for the funding and project support. Also thanks to the University of Massachusetts Amherst and Dr. Todd Fuller.

Sincerely,
Kyle McCarthy
Project Leader

Evaluation of 3 methods for estimating snow leopard population size and trends under various environmental conditions

Report Summary-
Because of their cryptic nature, large home ranges, and low population densities, snow leopards are by nature extremely difficult to monitor or survey. To date, no methodology for confidently estimating population size, or even population trend, has been validated for the species. SLIMS (Snow Leopard Information System) is currently the standard tool used by snow leopard managers across their range. SLIMS uses the density of snow leopard sign, such as feces or scrapes, as an index of snow leopard density. The Snow Leopard Survival Strategy suggests that the ability of these sign transects to predict leopard abundance or trends urgently needs to be tested under a broad range of habitats, and that "a reliable, and preferably simple and inexpensive, method for monitoring population changes over time is much needed…" To address this need we are comparing 3 methods of estimating relative and absolute snow leopard population size in 3 study areas of varying management and environmental conditions, and thus snow leopard densities, in the Kyrgyz Republic and the bordering Xinjiang province of China. Using remote cameras we have captured 47 images of snow leopards and several pictures of other species including brown bear, wolf, ibex, argali, stone marten, red fox, snow cock, and more. SLIMS sign surveys and ungulate counts were also completed in each study area as two alternative methods to estimate snow leopard densities.

Snow leopard images captured during this study can now be individualized using each cat's unique spot pattern to create an independent population estimate. We will also use sign density, calculated using the SLIMS methodology, as an indicator of relative abundance. Ungulate counts will be used to estimate the available biomass of prey species, and the number of snow leopards that biomass can support. The sign density results and predator/prey ratio model will then be contrasted with the density estimates obtained from camera trapping.

The results of our study will provide a much needed evaluation of the standard SLIMS method and a newly developed method for measuring snow leopard density, camera trapping. Our study may also provide an additional method to the researcher's tool chest, that being prey-predator population modeling.

We are also pleased to report that the first ever picture of a snow leopard in the Sary Chat Ertash Zapovednik (protected area) was taken by one of our remote cameras and will be used in the new Kyrgyz Red Book listing of endangered species.

Summary Line-
Passive Infrared camera traps are being used to capture snow leopard images and thus provide snow leopard density estimates. These estimates are being used to critique SLIMS snow leopard sign surveys and to compare ratios of snow leopards and their prey across three study areas.

Project Leaders-
Kyle P. McCarthy

Other Staff-
Alexander Vereshagin, Jumabay uulu Kubanychbek, Nemchenko Vasily

Collaborators-
Wildlife Conservation Society
International Snow Leopard Trust
Bashat Community Business Forum
Kumtor Operating Company

Project Duration-
01, March, 2005 to 31 December, 2005

Approved Budget

Salaries		WCS	ISLT/KOC	Total
Local Biologist stipends	60 days @ $10		$ 600	$ 600
Field assistants and guides (2)	200 days @ $2		$ 400	$ 400
Interpreter	3 mo @ $250		$ 750	$ 750
Student stipend	4 mo @ $1500	$ 6,000		$ 6,000
Transport and Accommodations				
One RT Air Boston - Bishkek		$ 1,800		$ 1,800
Visas		$ 100		$ 100
Hotel Bishkek - 8 days			$ 320	$ 320
Meals Bishkek			$ 200	$ 200
Field Costs				
Vehicle mileage			$ 650	$ 650
Pack animals		$ 500		$ 500
Field hotels		$ 300		$ 300
Field food for team of 4	90 days @ $20	$ 1,800		$ 1,800
Field equipment – camp		$ 1,000		$ 1,000
Small scientific supplies			$ 400	$ 400
Trap Cameras	30 @ $450	$ 2,500	$ 11,000	$ 13,500
Trap Cameras on loan from ISLT	15		$ -	$ -
Trap Camera batteries			$ 400	$ 400
Film for trap cameras w/developing	150 @ $10	$ 500	$ 1,000	$ 1,500
Miscellaneous				
Office supplies/postage			$ 200	$ 200
Telephone/FAX			$ 130	$ 130
Contingency			$ 450	$ 450

Total estimated costs	$ 14,500	$ 16,500	$ 31,000
Sources of Funding			
WCS Research Grant Program			$ 14,500
ISLT Small Grants			$ 8,000
Kumtor Operating Company – Kyrgyzstan			$ 5,000
Total secured			$ 27,500

Activity/Progress-

In January 2005 we cold weather tested 4 camera models in snow leopard enclosures of both the Anchorage, AK and Seattle, WA zoos. Based on performance and cost we selected the Camtrakker Ranger over the Camtrakker Original, Camtrakker Digital, and Trailmaster units. We ordered 48 Camtrakker Ranger units and accessories for use in Kyrgyzstan and China.

In March 2005 ISLT's Conservation Director, Tom McCarthy, met with Kyrgyz associates in Bishkek and finalized study area selections and travel plans. We then selected two Kyrgyz Ph.D. students, Jumabay uulu Kubanychbek and Nemchenko Vasiliy, to assist in the research. Kubanychbek is a part time employee of the International Snow Leopard Trust and their Kyrgyz counter-part NGO, Bashat Community Business Forum. Vasiliy works for the Sary Chat Ertash Zapovednik as the park ornithologist.

In May 2005 Kyle McCarthy (project leader) arrived in Bishkek with cameras and other field equipment. Two days were spent obtaining necessary permits and supplies then the field team departed for the Sary Chat Ertash Zapovednik, our first study site. Horses were purchased from nearby villages and park rangers enlisted to help transport the equipment on a 10 hour horse journey into the center of the National Park. On May 23rd the first cameras were placed in Kyrgyz snow leopard habitat. Over the following week cameras were deployed across approximately 120 km^2 in the center of the national park. Cameras were placed in snow leopard pathways marked by sign and scrapes.

Between June 1st and July 19th Kyle, Kubanychbek, Vasiliy, and Jennifer McCarthy surveyed for ungulates and conducted SLIMS sign transects across the study area and maintained camera film and batteries. In the National Park a total of 14 sign surveys and 16 ungulate surveys were conducted. Only one snow leopard photo was taken over the 49 day trapping period. One brown bear, 34 ibex, 53 argali, and several small birds and mammals were also captured on film. After 49 days of deployment the cameras were removed from the field and two days were spent in the small village of Uch Koshkon recharging batteries.

We then moved into our second study site near the confluence of the Sary Jaz, Ak Shirak, and Jangart rivers. This study area included portions of the Jangart hunting reserve. We again deployed our cameras in snow leopard traffic areas and completed 12 sign and 9 ungulate surveys. A total of 14 snow leopard, 25 ibex, 1 argali, and several small animal photos were taken in our second study site between August 3rd and September 21st.

In October the Cameras were sent to China where Raghu Chundawat (ISLT's Regional Science and Conservation Director), Kubanychbek and several Chinese associates completed complementary research in the Tien Shan of Xinjiang province. The study area was the Muzat Valley on the eastern edge of the Tomur Nature Reserve. The reserve itself lies on the border with Kyrgyzstan. It was selected as the third site for our camera work since it is known to have a large snow leopard and ungulate population. Thirty-two pictures of snow leopards were taken in China over a 59 day study period. Nineteen SLIMS sign surveys and 11 ungulate surveys were conducted by the China team.

Currently we are analyzing data and interpreting the results. Snow leopard photos are being individually identified for mark-recapture population estimates. Feces collected from sign surveys are being sieved for hair and bone content to determine diet. Portions of fecal samples have also been sent out for individual identification via genetic analysis. All data is being pooled and evaluated for statistical and ecological significance.

In addition to the MS thesis that will stem from this work (expected 9/2006, University of Massachusetts-Amherst), we intend to publish three articles from our gathered data. The first will discuss the relation between camera capture data, SLIMS sign surveys, and ungulate survey results. The second will explain and compare snow leopard and wolf food habits in the Sary Chat Ertash Zapovednik. The third will be based on individual identification using DNA analysis of collected snow leopard feces.

WCS will receive copies of the thesis and all journal publications. WCS's role as a primary funder of the work in its entirety will also be acknowledged in all publications.

Exploratory Activities-
N/A

Problems and Constraints-
Our second study site was initially planned to be within the Jangart hunting reserve completely. The chief of the hunting agency asked the military to not allow us past a mandatory check station. We had permission from the government, but there are multiple agencies with authority in the matter and the hunting agency had agreements with them as well. We eventually compromised and were allowed to travel through the hunting area and complete our research on the outer boundary of the reserve.

Goals/Activities for the next year-
It is important over the next year to determine what further research and conservation activities are needed in the Tien Shan Mountains of Kyrgyzstan. Several topics will be discussed and evaluated for practicality and conservation value.

Conservation Accomplishments & Evaluation-
Kyrgyzstan is a country whose government is still trying to find stability. In some ways this makes Kyrgyzstan a land of opportunity. With the right help they may avoid many of the errors that other developed countries have made in managing their natural resources. Our preliminary data suggests that there are important areas to conserve outside the boundaries of the current national parks. Working with Bashat CBF we hope to convince the government to incorporate

the Jangart hunting reserve into the Sary Chat Ertash Zapovednik. This area and others would be excellent additions to the current 2% of snow leopard habitat that is protected in this country.

On a regional scale we have raised some important questions into the methods used for monitoring snow leopard populations. These critical questions will be fully explored in the months to come and will be presented in refereed publication. We will discuss camera trapping techniques and reliability of data from small populations, validity of sign surveys, and legitimacy of predator/prey ratios.

Overall the project was successful in gathering the required data to meet our original goal. *To provide a well-tested method to estimate snow leopard population size which can be easily applied across a broad range of habitats, thus allowing populations to be monitored and efficacy of conservation efforts to be evaluated.* Fewer photographs were obtained than originally hoped which, in itself, is important to our evaluation of these methods. As with all research our findings highlight the need for additional work, but the first step has been taken towards a better understanding of snow leopard population monitoring.

List of publications during past 6 months- (see attached)
Field Report 1
Field Report 2

Assessing Estimators of Snow Leopard Abundance

KYLE P. MCCARTHY,[1] *Department of Natural Resources Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA*

TODD K. FULLER, *Department of Natural Resources Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA*

MA MING, *Xinjiang Conservation Fund, Baicaoyuan Xiaoqu, Building 2, Unit 6, Room 501, Xin Yi Road, Urumqi, 830003, P. R. China*

THOMAS M. MCCARTHY, *International Snow Leopard Trust, 4649 Sunnyside Avenue N, Suite 325, Seattle, WA 98103, USA*

LISETTE WAITS, *Center for Research on Invasive Species and Small Populations, Laboratory for Conservation and Ecological Genetics, University of Idaho, P.O. Box 441136, Moscow, ID 83844-1136, USA*

KUBANYCH JUMABAEV, *Bashat Community Business Forum, per. Pozharskogo d. 1 Bishkek, 720035, Kyrgyzstan*

ABSTRACT The secretive nature of snow leopards (*Uncia uncia*) makes them difficult to monitor, yet conservation efforts require accurate and precise methods to estimate abundance. We assessed accuracy of Snow Leopard Information Management System (SLIMS) sign surveys by comparing them with 4 methods for estimating snow leopard abundance: predator:prey biomass ratios, capture–recapture density estimation, photo-capture rate, and individual identification through genetic analysis. We recorded snow leopard sign during standardized surveys in the SaryChat Zapovednik, the Jangart hunting reserve, and the Tomur Strictly Protected Area, in the Tien Shan Mountains of Kyrgyzstan and China. During June–December 2005, adjusted sign averaged 46.3 (SaryChat), 94.6 (Jangart), and 150.8 (Tomur) occurrences/km. We used counts of ibex (*Capra ibex*) and argali (*Ovis ammon*) to estimate available prey biomass and subsequent potential snow leopard densities of 8.7 (SaryChat), 1.0 (Jangart), and 1.1 (Tomur) snow leopards/100 km^2. Photo capture–recapture density estimates were 0.15 ($n = 1$ identified individual/1 photo), 0.87 ($n = 4/13$), and 0.74 ($n = 5/6$) individuals/100 km^2 in SaryChat, Jangart, and Tomur, respectively. Photo-capture rates (photos/100 trap-nights) were 0.09 (SaryChat), 0.93 (Jangart), and 2.37 (Tomur). Genetic analysis of snow leopard fecal samples provided minimum population sizes of 3 (SaryChat), 5 (Jangart), and 9 (Tomur) snow leopards. These results suggest SLIMS sign surveys may be affected by observer bias and environmental variance. However, when such bias and variation are accounted for, sign surveys indicate relative abundances similar to photo rates and genetic individual identification results. Density or abundance estimates based on capture–recapture or ungulate biomass did not agree with other indices of abundance. Confidence in estimated densities, or even detection of significant changes in abundance of snow leopard, will require more effort and better documentation. (JOURNAL OF WILDLIFE MANAGEMENT 72(8):1826–1833; 2008)

DOI: 10.2193/2008-040

KEY WORDS camera, capture–recapture, density, index, predator:prey ratios, techniques, Tien Shan, *Uncia.*

The snow leopard (*Uncia uncia*) has been described as having an almost legendary secretiveness and camouflage, a characteristic that makes monitoring snow leopard populations difficult (Jackson and Hunter 1996). The first photograph of a wild snow leopard was not published until 1980 (Schaller 1980), and with live-capture rates as low as 3/1,000 trap-nights (McCarthy et al. 2005), conventional capture–recapture methods are logistically difficult. To monitor snow leopard populations efficiently, managers developed the Snow Leopard Information Management System (SLIMS; Jackson and Hunter 1996). For the last decade, SLIMS has been used range-wide to monitor status and distribution of snow leopards and their prey. The SLIMS assesses relative snow leopard abundance through repetitive standardized sign surveys (Jackson and Hunter 1996). As suggested by Anderson (2001), indices as a measure of abundance can be fraught with potential error and bias. The developers of SLIMS acknowledge this and suggest using a general procedure for estimating snow leopard numbers (Jackson and Hunter 1996). Unfortunately, due to lack of a more direct, affordable method, these and other potentially erroneous estimates are the basis for range-wide snow leopard population estimates (McCarthy and Chapron 2003).

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In 2002, the Snow Leopard Survival Strategy was developed, which recommended that the use of sign transects to predict leopard abundance be tested (McCarthy and Chapron 2003). In short, to formulate and achieve conservation objectives, planners required tested methodologies for accurately estimating numbers and population trends. We assessed usefulness of sign surveys for estimating or predicting snow leopard population size or abundance by comparing them with 4 estimators of actual, potential, or relative snow leopard density: predator:prey biomass ratios, capture–recapture density estimation, photo-capture rate, and individual identification through genetic analysis.

STUDY AREA

Our research occurred from June to December 2005 and included 2 study areas in the Tien Shan Mountains of Kyrgyzstan, the SaryChat Ertash Zapovednik and the Jangart Hunting Reserve, and a third study site in the adjacent Tomur Nature Reserve in the Tien Shan Mountains of China (Fig. 1). The 3 sites represent areas of varying prey density (Vereshagin et al. 2004; T. M. McCarthy, International Snow Leopard Trust, unpublished data) and, thus, we suspected variation in snow leopard density. We expected human-caused snow leopard mortality to be similar in each area, a necessary component of predator–prey modeling. Each area is characterized by

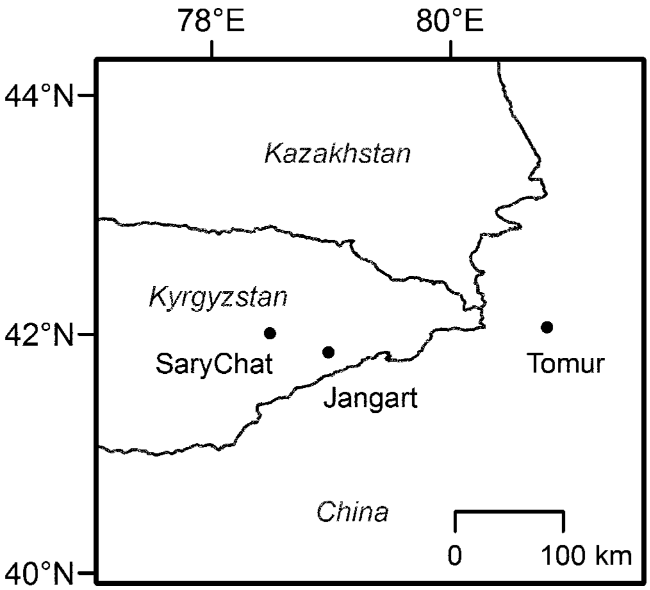

Figure 1. Study area diagram depicting 3 snow leopard camera capture–recapture study sites, SaryChat, Jangart, and Tomur, in the Tien Shan Mountains of Kyrgyzstan and China, 2005.

central river valleys with steep, rugged terrain rising to mountain peaks at >4,000 m. Vegetation was variable but similar in each area with predominant xerophytic grass species and barren rock. Based on geographical distance, average snow leopard home range, and separation by large rivers, we assumed each area to support independent snow leopard populations.

The SaryChat Ertash Zapovednik (SaryChat) was a 720-km^2 protected area in the Issyk Kul oblast of Kyrgyzstan and was a key component of the Issyk Kul Biosphere Reserve. The Jangart area was situated about 80 km southeast of SaryChat and was very near the Kyrgyz–China border. For decades Jangart served as a quasi-protected area owing to highly restricted access in the sensitive border zone. Jangart was recently designated as a hunting reserve. There was no permanent human habitation; however, hunting camps were used by local guides and their clients. The Chinese study site was within the Tomur, a protected area immediately across the China–Kyrgyz border and about 125 km east of Jangart. Hunting was forbidden and direct human impacts on snow leopard were minimal.

METHODS

The SLIMS sign surveys in all areas followed adaptations of Jackson and Hunter (1996) and focused on counting snow leopard feces, scrapes, claw rakes, scent marks, and pug marks. We selected survey sites throughout the study area based on topography and defined by watershed boundaries. Although it introduced bias into the sampling design, it was necessary to focus survey sites in areas likely to have snow leopard sign in terrain where even short transects can be exhaustive. Typically, search sites consisted of well-broken and rocky terrain, sharply defined ridgelines, cliff bases, river gorges, and entrances to well-defined valleys.

In each site we walked a survey line along the most likely place to find snow leopard sign. In most cases, we placed survey lines along ridgelines (Jackson and Ahlborn 1989). Cliff bases, ridgelines, prominent features, and river confluences were also possible survey routes. As we walked transects we recorded length (based on paces) and number and type of sign. Numbers of scrapes and feces are correlated, as are total number of sign sites and total sign, suggesting that total average sign is valid as a comparative measure among study areas (McCarthy 2007).

We initially planned to conduct sign surveys in Kyrgyzstan and China consecutively within a 3-month time span to limit seasonal variation. Unfortunately, due to logistical constraints, we conducted the Tomur surveys in November and December, rather than August, and thus after snowfall, causing any accumulated sign to be snow-covered and unobservable. Therefore we partitioned the sign data to use the only 2 surveys completed there before snowfall, one ridgeline and one cliff-base survey. In addition, we conducted only ridgeline surveys in Jangart. Therefore we further partitioned the data to look only at ridgeline surveys in each study area. To preserve the only 2 presnow survey points in Tomur, we adjusted the cliff-base survey by the ratio of cliff-base sign to ridgeline sign found in SaryChat.

We adapted camera-trapping methods from Henschel and Ray (2003). Karanth et al. (2002) and Henschel and Ray (2003) provided detailed methods for using camera-traps in tiger and leopard (*Panthera pardus*) density estimation, respectively. Camera-trapping of snow leopards, although in its infancy, has had initial success as well. In Zanskar Valley, Ladakh India, Spearing (2002) captured 10 snow leopard images in just 64 camera-trap–nights, and in Hemis National Park, Ladakh, India, researchers captured 194 images, and 12 uniquely identifiable snow leopards, in 1,612 camera-trap–nights (Jackson et al. 2006).

We first identified suspected snow leopard trails and marking sites from past sign surveys or likely terrain features. Across each study area, in consecutive time periods, we set camera sites in these snow leopard trail or sign-site areas approximately 2 km apart in a roughly circular pattern. At each camera location we placed 2 CamTrakker™ Ranger cameras (CamTrakker, Wattkinsville, GA), approximately 3 m apart across the trail or sign site. We placed cameras in rock piles or on metal stakes at approximately 45–50 cm from the ground and generally faced north or south. We programmed each camera with a 90-second delay between photographs, limiting images taken when ibex (*Capra ibex*) or argali (*Ovis ammon*) would pass by or stay in front of the camera. Trapping periods lasted 7–8 weeks.

Using spot pattern as a unique identifier, we created photo-capture histories based on the time of individual capture, with each day considered a unique trapping event. We excluded unidentifiable individuals from analyses. Where we captured >1 photo or animal, we used Program CAPTURE to compute *N* based on a jackknife model of heterogeneity (M[h]; Otis et al. 1978). Following Karanth and Nichols' (1998) discussion on capture–recapture models, we believe the M(h) most accurately represents true snow

Table 1. Snow leopard home-range estimates (km^2) and related ungulate density (no./km^2) from published studies, India, 1990, Mongolia 1992, 2005, Nepal 1994, 1996, 1997.

Location	No. animals monitored	No. days monitored	Mean home-range size	Ungulate density	References
India	1	70	19	3–3.5	Chundawat 1990
Mongolia	1	41	12	1.7–2.3	Schaller at al. 1992
Nepal	3	Winter	19	6.6–10.2	Oli 1994, 1997
Nepal	5	120–450	19.4	4–8	Jackson et al. 1989
Mongolia	4	207	451	0.9	McCarthy et al. 2005

leopard behavior; that is, we expected each individual snow leopard to behave in a heterogeneous manner due to varying environmental factors and species interactions experienced by such a dispersed population.

Several different methods have been used in prior research on large felids to estimate the effective study area, or the sampling area to which the enumeration of individuals can be applied to estimate density (O'Brien et al. 2003, Wallace et al. 2003, Karanth et al. 2004). Each method is meant to spatially buffer potential capture locations to obtain a sampling area. The mean-maximum-distance-between-recaptures method is based on theoretical constructs for capture–recapture of small mammal populations, and some suggest it is less reliable as trap rate decreases and home range size increases (Wilson and Anderson 1985). A second method is maximum distance between recaptures (O'Brien et al. 2003), but it is not well-supported in the literature and is likely open to the same criticisms as the previous method. A third method is to use either the average minimum reported or average home-range size of the species of interest (Otis et al. 1978). For snow leopards, however, home range sizes vary greatly, likely in response to the available food biomass; also, there were no available snow leopard home-range data for the Tien Shan Mountains. To estimate home range size we first took an average of all available published snow leopard home-range data to create a buffer. Because home range size of carnivores is often inversely correlated with prey biomass (Fuller and Sievert 2001), we also took these snow leopard home-range data and associated ungulate densities (see below and Table 1), fit simple linear regression to them, and extracted expected snow leopard home-range size in each of our study areas. The regression analysis was limited by the paucity of data on snow leopard home range. However, extracted home-range estimates were similar to ranges estimated from one satellite and one Global Positioning System-collared cat from similar barren, low prey density areas in Mongolia and Pakistan (McCarthy et al. 2005; T. M. McCarthy, unpublished data).

To estimate snow leopard density, we calculated the effective study area size by each of the methods described above: greatest distance moved between recaptures, half the mean maximum distance moved in recaptured animals, radius of the average minimum home range or average home range, and radius of the estimated home range from ungulate densities (McCarthy 2007). We then used the resultant total coverage of the camera sites and buffer circles as the effective study area for density calculations.

We used photo rates (e.g., photos/100 trap-nights) as an index of abundance (Carbone et al. 2001). We calculated photo rates for each of our sites as number of individual photo events divided by total number of trap-nights. We defined a photo event as any photo (or set of photos at a given photo-trap site) of a snow leopard, even if it was unidentifiable as an individual, taken on a given day (we considered days independent). One photo showed 2 snow leopards walking together; however, in general, unless a mother is with cubs, the snow leopard is a solitary animal. Photo rate as an index of abundance is simple, and, although it does not provide specific numbers, it may be more reliable for rare species and small sample sizes where traditional capture–recapture methods have less power (Wilson and Anderson 1985, Carbone et al. 2001).

We used ungulate surveys to estimate ungulate biomass and the potential density of snow leopards supportable by that biomass (Fuller and Sievert 2001, Carbone and Gittleman 2002). Here, ibex and argali surveys followed SLIMS methodology in Jackson and Hunter (1996). We identified search sites to provide coverage throughout each study area using 1:100,000 topographical maps. We then traveled to each site and located a vantage point where a high proportion of the survey block was visible, while maintaining enough distance so as not to disturb any ungulates present. We recorded on the topographic map the boundaries of the visible area and subsequently calculated its area. We used binoculars (10×) and spotting scopes (15–45×) to locate and determine group size, sex and age of individual ibex, and number of argali. We conducted surveys in the early morning and late afternoon when animals are likely feeding and sun position makes them most visible. We surveyed no blocks more than once. We calculated size of the effective area for these data as the total area surveyed, as defined on the topographical map. We did not calculate detection probabilities due to the difficulty of accurately measuring distances to sighted animals. However, similar terrain in each study site likely leads to equivalent detection probabilities and total ungulate counts can be used as a relative index between sites.

To calculate ungulate biomass we first applied proportions of identified age and sex classes of ibex to unidentified animals, assuming that age and sex class proportions of identified animals and unidentified animals were similar (McCarthy 2007). In this manner, we could include all individuals in biomass calculations. We then calculated total biomass for each study area based on average Siberian ibex weights and average argali weights as reported by Fedosenko

Table 2. Capture–recapture results of snow leopards photographed in Kyrgyzstan and China, 2005.

Area	No. of capture events[a]	Trap rate[b]	No. of individuals identified	No. of individuals recaptured	Method	Estimated N	SE	95% CI
SaryChat	1	0.085	1	0	Min[c]	1	0.47	1–1
Jangart	6	0.557	5	1	M(h)[d]	7	3.62	6–25
Tomu	13	1.102	4	3	M(h)	6	5.35	5–38

[a] Capture events where we captured an individually identifiable snow leopard in a given day; we counted multiple captures in the same day of one individual as one capture event.
[b] Captures/100 trap-nights.
[c] With only one capture event, mark–recapture modeling is not possible. We substituted $N \geq 1$ for an estimated N.
[d] M(h) represents the use of the model for heterogeneity in Program CAPTURE.

and Blank (2001). We next computed ungulate biomass/100 km^2 using Carbone and Gittleman's (2002) conversion factor of 10,000 kg prey for 90 kg of predator and extrapolated to potential snow leopard numbers using the average snow leopard weight of approximately 50 kg.

These calculations assumed that the survey sites as a whole encompass the total of each respective study area and that capture probabilities were similar in each area. We recognized that snow leopard density estimates might be high or low, however, because these calculations also assume that snow leopards are the only carnivore reliant on the ungulate biomass present, even though other predators such as brown bear (*Ursus arctos*) and wolf (*Canis lupus*) are also present in unknown numbers, and that these snow leopard density calculations do not account for small animals consumed by snow leopards such as marmots (*Marmota baibacina*) and hares (*Lepus tolai*). For further analyses we assumed that variation caused by other predators or food resources was similar across sites and that our rough estimates are at least comparable in a relative, if not absolute, sense.

We collected samples of suspected snow leopard feces along SLIMS transect lines throughout each study area. To minimize collection of erroneous samples, we preferentially selected based on their size, shape, location, and surrounding sign. For example, we collected feces found along a ridgeline, near or in a suspected snow leopard scrape, but we did not collect feces found alone on a survey with no corroborative sign or in an unlikely position. This sampling method does not lend itself to unbiased population estimates; however, with a limited budget it was necessary to maximize likelihood of collecting true snow leopard feces. To avoid contamination, we collected fecal samples of approximately 1 mL using latex gloves and plastic spoons. We then stored samples in individual 5-mL transport tubes containing 4 mL of 90% ethanol. We performed DNA extraction and polymerase chain reaction (PCR) set up in a facility dedicated to low-quantity DNA samples. We conducted DNA extraction with the Qiagen stool kit (Qiagen Inc., Valencia, CA) using standard manufacturer protocols and including negative controls to monitor for contamination. We identified the species depositing each fecal sample by PCR and sequencing of an approximately 160–base-pair section of the cytochrome B gene of the mitochondrial DNA control region using established primers and previously published methods (Farrell et al. 2000, Onorato et al. 2006). We attempted individual identification for all snow leopards using 10 polymporphic microsatellite loci as outlined in Waits et al. (2007). Probability of observing matching genotypes for unrelated individuals (2.1×10^{-11}) and siblings (7.5×10^{-5}) is extremely low using these loci (Waits et al. 2007), so we could easily discriminate individuals. We replicated genotypes 2–8 times/locus/sample and accepted them for use only after they met 95% reliability criteria using Reliotype (Miller et al. 2002).

RESULTS

We conducted surveys and trapping for 49 days in SaryChat (28 May–15 Jul 2005), 49 days in Jangart (3 Aug–20 Sep 2005), and 59 days in Tomur (23 Oct–20 Dec 2005). We completed SLIMS sign surveys in SaryChat ($N = 16$ surveys; total transect length = 8.2 km), Jangart ($N = 13$; 8.6 km), and the Tomur ($N = 20$; 15.0 km) study sites.

Overall, without any corrections, average sign/km was 16.4 (SE = 7.4), 40.7 (SE = 11.0), and 94.6 (SE = 16.9) in SaryChat, Jangart, and Tomur, respectively, with between-group variation ($F_{2,46} = 11.85$, $P \leq 0.001$). Data partitions and proportional adjustments provided us with revised average sign numbers for presnow, ridgeline-only surveys. For these adjusted counts, sign density was 46.3/km (SE = 13.0, SaryChat), 94.6/km (SE = 16.9, Jangart), and 150.9/km (SE =18.1, Tomur), with between-group variation ($F_{2,24} = 4.28$, $P = 0.026$). By using snow-free counts we limited bias associated with sign visibility and other weather-related variations, and were able to make clearer comparisons among sites. However, this left us with only 2 survey points in Tomur, one of them adjusted, limiting our overall confidence in inferences from these results.

We deployed cameras over a period of 7 months in the 3 study areas at 20–24 stations (Table 2). Intervals between study periods were required for transferring equipment between sites. Number of trap-nights in each area ranged between 1,078 and 1,180 and was a function of the number of camera stations and number of days they remained operable.

Capture rates (no. of different, identifiable individuals captured/100 trap-nights) were lower than expected, ranging from <0.1 to 1.1 (Table 2). At SaryChat, our first study site, we captured only one snow leopard image, which limited our results to a minimum population of one. For the Jangart and Tomur sites, we obtained 10 and 28 snow leopard photos (i.e., photo events), but due to several individuals being unidentifiable, or having multiple pictures of the same animal in the same capture period, we were only able to record 6 and 13 capture events, respectively. We photographically recaptured 1 of 5 individuals at Jangart and 3 of 4 individuals at Tomur. Estimated population sizes in these 2 areas were 7 (SE = 3.62) and 6 (SE = 5.35), with large confidence limits of 6–25 and 5–38 animals, respectively.

We placed buffers of 7.67 km, 11.78 km, and 11.47 km, equal to the estimated radius of a snow leopard home range based on available ungulate biomass (our best estimate of an appropriate, area-specific buffer; McCarthy 2007), around the SaryChat, Jangart, and Tomur camera-trapping sites, respectively. We used the area within buffered camera sites, measured at 655 km^2, 808 km^2, and 813 km^2, as our effective study area for SaryChat, Jangart, and Tomur, respectively. Given these effective areas, estimated snow leopard density from capture–recapture calculations was 0.15 individuals/100 km^2 in SaryChat, 0.87/100km^2 in Jangart, and 0.74/100km^2 in Tomur. We obtained photo rates (no. snow leopard photos/100 trap-nights) of 0.09 in SaryChat, 0.93 in Jangart, and 2.37 in Tomur from camera capture data.

Ungulate surveys covered 141 km^2 in SaryChat, 86 km^2 in Jangart, and 250 km^2 in Tomur, with 228, 11, and 264 ibex counted, and 397, 0, and 29 argali counted, respectively. Total estimated ibex biomass ranged from 659 kg to 13,191 kg, and ranged from 767 kg ibex/100 km^2 to 9,197 kg ibex/100 km^2 (Table 3). Total estimated argali biomass ranged from 3,552 kg to 48,632 kg and ranged from 4,130 kg argali/100 km^2 to 34,491 kg argali/100 km^2. Overall, total ungulate biomass ranged from 4,897 kg/100 km^2 to 43,688 kg/100 km^2. Potential snow leopard densities, based on Carbone and Gittleman's (2002) formula, were 8.7, 1.0, and 1.1 individuals/100 km^2 in SaryChat, Jangart, and Tomur, respectively.

Genotyping of feces generated a higher number of known individuals than visual discrimination of photographs and provided minimum population estimates for SaryChat, Jangart, and Tomur of 3, 5, and 9 individuals, respectively, based on 9, 9, and 17 successful genotypes, respectively. However, we also found that in our fecal collection we collected several other species than snow leopard, and, in fact, our collection error (non–snow leopard species) averaged 41%. The most commonly collected feces other than snow leopard were red fox (*Vulpes vulpes*; 27%). Other erroneous collections include stone marten (*Martes foina*; 6%), wolf (4%), Chinese desert cat (*Felis bieti;* 3%), and wild boar (*Sus scrofa*; 1%). To assess how this may have affected SLIMS surveys we looked at the average number of sites in each survey where there was both a feces and a scrape present, increasing our confidence that it was true snow leopard sign. These data showed a strong correlation with average total sign/km, ($r_{47} = 0.89$, $P \leq 0.001$), suggesting that error in sign collection is likely consistent across sites and that relative amount of snow leopard sign is not influenced by species identification error.

Table 3. Total ibex biomass (kg), categorized by age class, and total argali biomass (age class data unavailable) in 3 study sites of Kyrgyzstan and China, 2005.

	Study area		
	SaryChat	**Jangart**	**Tomur**
Total Ibex	228	11	264
Kids	502	32	1,124
Yearlings	264	0	619
Subad M	903	0	847
Ad M	7,473	450	7,128
Subad F	652	0	118
Ad F	3,173	177	3,355
Total ibex biomass	12,967	659	13,191
Total argali biomass	48,632	3,552	0

DISCUSSION

We identified several key issues in efficacy of SLIMS sign surveys. First, sign surveys are subject to observer bias. Members of our field crew with similar training and experience often disagreed over what constituted a snow leopard scrape when conducting transects together; though we attempted to come to an agreement on what constituted a snow leopard scrape, we likely continued to make some different identifications. Perhaps more importantly, 2 different field crews, both SLIMS-trained, erroneously collected non–snow leopard fecal samples for DNA analysis and, thus, likely misidentified such sign in the field while conducting SLIMS surveys. Our limited dataset suggests that erroneous fecal collection rates may be equal across sites and that the overall magnitude may be unaffected. However, this equality may not be true across snow leopard range where sign identifiers differ and where there are differing species in different abundances whose sign could be confused with that of snow leopards. This bias could artificially inflate sign numbers unequally, making its value as a relative index questionable.

Second, environmental conditions such as snowfall and site differences likely also affect amount of snow leopard sign detected. Limiting our sign survey results to account for environmental variability (snow cover) and site selection bias (ridgeline) may have provided more comparable relative indices of snow leopard abundance between sites. Although sign transects are valuable for presence–absence surveys, standard SLIMS sign surveys that do not account for variation in sampling design may be unreliable.

The camera capture–recapture method has been identified as a viable way to estimate densities of individually recognizable animals with large home ranges and low densities (e.g., Silver et al. 2004). For snow leopard, however, extremely low capture rates and associated high standard errors suggest that under some circumstances this method may be vulnerable to logistical constraints. Recent camera capture–recapture surveys in the Hemis National Park of India have proven successful in providing snow

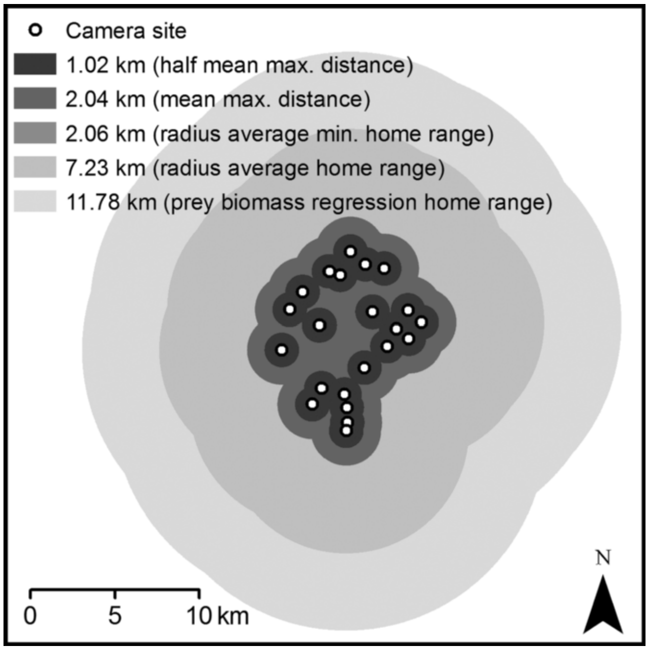

Figure 2. Effective snow leopard study-area buffers around camera-trap sites in the Jangart hunting reserve, Kyrgyzstan, 2005, based on differing methods from the literature.

leopard density estimates with lower standard errors, but that study was in an established long-term research area with high snow leopard densities (4–8/100 km^2) where capture rates were high (5.6–8.9 vs. <0.1–1.1/100 trap-nights in our areas; Jackson et al. 2006).

Snow leopard densities and home range areas likely vary greatly over their range as a function of varying environmental and resource conditions. In areas with low snow leopard densities and little prior knowledge of snow leopard behavior, it may prove impossible to attain an adequate capture rate for viable capture–recapture modeling within the 7-week suggested time frame to maintain population closure (Karanth et al. 2002). This is consistent with the suggestions of Jackson et al. (2006) that camera capture–recapture may only work when snow leopard densities are high enough to provide ample capture–recapture data.

Another constraint of density estimation using capture–recapture models is the method for determining the effective area surveyed. It is important to buffer the study area to account for animals that traverse outside the range of camera sites. Several methods have been used in prior research on large felids including buffers equal to the radius of the average minimum home range, half the mean maximum distance moved in recaptured animals, and the greatest distance moved between recaptures (O'Brien et al. 2003, Wallace et al. 2003, Karanth et al. 2004). Each of these methods seemed suspect for our data and, hence, we chose to use a buffer width equal to the radius of the average snow leopard home range as estimated from local ungulate abundance. However, due to variation between estimated ungulate densities and snow leopard densities, this method is also suspect. By selecting a different method, density estimates can be altered dramatically (see Fig. 2), which suggests that with low capture rates and variable home-range sizes, camera capture–recapture density estimates (as opposed to simple photo rates) of snow leopards may be unreliable. However, photo-rates do appear to be a legitimate index of leopard abundance in our study areas based on similarity with genetic individual identification. Photo-rate as a relative index may be suitable when true densities are not needed but where an accurate index to population size is sufficient.

We expect that with an increase in prey biomass there should be an increase in predator biomass (Fuller and Sievert 2001, Carbone and Gittleman 2002). However, given our small sample sizes overall it is understandable that ungulate biomass did not provide snow leopard population estimates similar to other methods. It is possible that the lack of correlation is driven by previous loss of snow leopards from the area due to poaching or disease, though we have no evidence for this. This previous loss of snow leopards could allow ungulate populations in SaryChat to expand while snow leopard populations were low, a likely scenario for SaryChat (A. Vereshagin, Bashat Community Business Forum [Bashat CBF], personal communication). Another factor affecting the predator:prey ratio could be competition with wolves. Varying environmental conditions could increase niche overlap and create higher competition for food resources. Finally, and perhaps most likely, ungulate surveys are suspect due to methodology. Although ungulate surveys covered each of our study areas, survey areas were only a small proportion of the total area used by our photo-captured snow leopards. Also we did not repeat surveys, and in retrospect, they seem fairly cursory; thus, estimates from our surveys may be far from representative of true ungulate densities in an area, especially given the lack of known detection probabilities. So, regardless of whether ungulate counts are accurate, or whether snow leopard populations are affected by unknown factors such as poaching, disease, or competition, the use of prey biomass:snow leopard ratios may be unsupported.

Genetic analysis of fecal DNA showed promising potential as an index of snow leopard abundance. A more structured format for scat collection, such as repetitive transects distributed over several months, would allow for insight into marking behavior and territoriality and even provide a framework for density estimation (Gese 2001). Scent pads to collect hair samples from cheek rubbing (Weaver et al. 2005) could also be used to create a more rigorous sampling design. In addition to the advantage of reliable identification not subject to observer bias, genetic data can provide valuable and unique information about genetic relationships (including source of dispersers) that is not obtainable with the other methods. However, the biggest limitation in either case is cost (currently approx. US$50–225/sample) and logistics of transporting fecal matter between countries. By using in-country labs to obtain genetic data, costs could be minimized and transportation issues eliminated. However, specialized equipment and training would be needed.

MANAGEMENT IMPLICATIONS

Previous SLIMS sign surveys are important as an index to abundance, and all surveys should be subjected to similar correction factors to account for differences in weather and transect location. Future SLIMS surveys can be improved by implementing more rigorous training of observers and designing sampling schemes range-wide to limit the effect of random placement of survey transects and environmental variation. However, further research into accuracy of sign discrimination is warranted before any value is placed on sign survey data. Ungulate surveys as conducted currently by SLIMS researchers range-wide may be best used as presence–absence indicators. Photo capture–recapture density estimation may be of little value when population numbers are extremely low and individuals are elusive and highly dispersed; elsewhere, this technique may provide useful insights (Jackson et al. 2006). In many circumstances, however, photo capture rates may provide more reliable results than capture–recapture density estimation as an index to relative abundance. The most promising method for future monitoring of snow leopard populations may be fecal DNA analysis especially given lower costs and a more rigorous standardized study design.

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