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A granular view of a snow leopard population using camera traps in Central China

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ABSTRACT

Successful conservation of the endangered snow leopard (*Panthera uncia*) relies on the effectiveness of monitoring programmes. We present the results of a 19-month camera trap survey effort, conducted as part of a long-term study of the snow leopard population in Qilianshan National Nature Reserve of Gansu Province, China. We assessed the minimum number of individual snow leopards and population density across different sampling periods using spatial capture–recapture methods. Between 2013–2014, we deployed 34 camera traps across an area of 375 km^2, investing a total of 7133 trap-days effort. We identified a total number of 17–19 unique individuals from photographs (10–12 adults, five sub-adults and two cubs). The total number of individuals identified and estimated density varied across sampling periods, between 10–15 individuals and 1.46–3.29 snow leopards per 100 km^2 respectively. We demonstrate that snow leopard surveys of limited scale and conducted over short sampling periods only present partial views of a dynamic and transient system. We also underline the challenges in achieving a sufficient sample size of captures and recaptures to assess trends in snow leopard population size and/or density for policy and conservation decision-making.

1. Introduction

China is custodian of the largest proportion of the world's snow leopard population and is therefore vital to the conservation of the species (Riordan and Shi, 2010). There has been growing recognition of the importance of monitoring programs for long-term conservation efforts, especially those that engage and build capacities of nature reserves (Alexander et al., 2015; Sharma et al., 2014). Monitoring provides critical information on the status of local populations and the impact of conservation investments (Snow Leopard Network, 2014). Snow leopards are particularly difficult to monitor in a robust and reliable way (Alexander et al., 2015; Janečka et al., 2008). Snow leopards have highly variable home range areas, often being extremely large, presenting a direct challenge to local logistical and monitoring capacities (Alexander et al., 2015; McCarthy et al., 2008, 2005). Current methods mainly rely on snapshots with limited seasonal timeframes, conducted within subsets of their likely larger home range (Alexander et al., 2015; Jackson et al., 2006; McCarthy et al., 2008; Sharma et al., 2014). Additional studies are required to complement and deepen these assessments and provide more detailed information on spatial and population dynamics (Duangchantrasiri et al., 2015; Sharma et al., 2014).

GPS collaring is a valuable technique providing detailed information on spatial dynamics of individuals (McCarthy et al., 2005). However GPS technologies are expensive, logistically challenging and usually only allow collection of data for a few snow leopard individuals. Their use is frequently restricted in national border and other politically sensitive areas, which correspond to an important proportion of snow leopard range areas. Non-invasive techniques including camera trapping represent a feasible and cost-effective alternative. They can be used across years building up a comprehensive understanding of snow leopard survivorship and probabilities of temporary emigration and immigration (Sharma et al., 2014). Camera traps are also more suitable for local teams, including protected area staff, so that they can carry out these surveys independently and sustainably over the long term (Alexander et al., 2015).

As part of a long-term study of the snow leopard population in Qilianshan National Nature Reserve (QNNR) of Gansu Province, we present the results of a 19-month camera trap survey effort within a 375 km^2 area of northern Qilianshan National Nature Reserve. This study took advantage of a study area that could be accessed throughout the year in order to document the minimum number of individual snow and population density continuously during the 19-month study period. We also aimed to examine spatial and temporal patterns in these parameters and explore their implications for monitoring programs.

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2. Method

2.1. Data collection

Fieldwork was conducted in QNNR located in the south-central part of Gansu Province (39°14′ N, 100°51′ E). We collected camera trap data using a total of 34 camera trap stations, which we left active for varying periods between January 2013–July 2014.

As our target species was the snow leopard, the locations of camera trap stations were chosen based on the presence of natural pathways (such as ridges and valleys) that individual snow leopards were likely to use and on the high density of snow leopard signs. In addition all camera traps were initially placed in a site that we expected could be accessed all year round. The position of one camera trap was moved 400 m down river after 10 months given that it was no longer accessible during the summer months. Camera trap stations were set up at elevations between 2240 and 3840 m, each consisting of a single camera trap unit placed so as to maximise the likelihood of photographing snow leopard faces or tails for individual identification (Alexander et al., 2015). Each camera unit was separated by a horizontal buffer of at least 1 km from neighbouring cameras, except for three cameras, which were separated by 821, 955 and 961 m for reasons of accessibility. The batteries and SD cards of all camera traps were changed every three to 4 months, resulting in six sampling periods over the study period.

2.2. Data analysis

First, we collated all photographic captures of snow leopards (n = 251), noting the time and location of each capture. Capture events were reviewed independently by two separate observers to identify individual snow leopards, using the snow leopard's coat patterns as unique identifiers. Each observer compared each capture event using a ‘capture matrix’, resulting in 31,375 comparisons, and noted whether captures were the “same”, “not the same” or were not suitable for comparison (“low quality photo” or “unsuitable angle” for comparison). The photos obtained were of uneven quality, and did not all allow the unambiguous identification of individual snow leopards, especially in the case of captures taken at night or of fast-moving individuals. A third observer then reviewed the capture matrix, and jointly with the first two observers, considered all discrepancies in identification and sought a final agreement on capture events for each identified individual. Each individual snow leopard was given a unique identification number and their capture histories noted for the six sampling periods. ID cards were created for each individual to describe their unique phenotypical characteristics. The sex of individuals was not ascertained given the difficulty of distinguishing sex from photo captures, with the exception of individual adults accompanied by sub-adults or cubs, which were presumed to be female.

For the density estimates we combined two consecutive sampling periods, as initial runs of the model in SPACECAP indicated the need to increase the sample size of snow leopard captures and recaptures. The population density of snow leopards (including adult and sub-adults) was therefore estimated for three sampling periods independently using a Bayesian spatially explicit capture–recapture (SERC) model (Royle et al., 2009). We also estimated density for the entire 19-month period. Recent simulation studies suggest that estimators of density using SERC models are robust even in case of potential transient or dispersing individuals (Royle et al., 2015). SERC models were implemented in the R package, SPACECAP (Gopalaswamy et al., 2012)(version 1.1.0) (Gopalaswamy et al., 2014) running in R (version 3.1.1) (R Core Team, 2014). Data were prepared for SPACECAP analysis as described in Alexander et al. (2015). In particular, each day was considered a unique sampling occasion and the state-space was set as 1.96 km^2 and generated for an area within 24 km buffer distance surrounding the sampled area. SPACECAP was run using a half normal model, data augmentation increased to 200, with 60,000 iterations, a burn-in of 10,000, and a thinning rate of 1. Our model across the entire 19 months was run in SPACECAP with 60,000 iterations, a burn-in of 25,000. We used the Geweke statistic reported by program SPACECAP to check for convergence of the MCMC chains (Gopalaswamy et al., 2014).

3. Results

3.1. Capture success

The total trapping duration across all camera stations was 7133 full days. Due to logistical constraints to all-year access to certain camera trap locations, the trapping effort varied across the six sampling periods (Table 1). Within this period individual camera units were active for between 23–504 full days (mean = 209).

A total of 25 camera traps (74%) captured snow leopards. In total, 251 snow leopard captures were recorded over the 7133 trap-days, representing an average capture success of 3.52 captures per 100 trap-days. The number of captures varied between camera trap stations (range = 0–42). One camera trap in particular recorded a high number of snow leopard captures (n = 42), as well as the highest capture rate (19.91 captures per 100 days over an active period of 211 days). Camera trap success was highly dependent on location. Success rates were greatest in areas of broken terrain and ridgelines (with 100% success for cameras located in areas of broken terrain and 91% success for cameras located along ridgelines). We were less successful with camera traps located along steeply rolling slopes (43% capture success). Captures took place primarily during the night between 18:00 and 6:00 (69% of captures).

Of all captures, 174 (69%) were of sufficient quality to allow individual identification. Among these, 45 (26%) included the snow leopard's head and 79 (45%) its tail (Fig. 1). We identified 17–19 individual snow leopards. The precise total was uncertain as the frontal features only were captured for two adults and the rear features only for another three adults. We could not therefore be sure that the two individuals captured from the front were different from the three captured from the rear. Our minimum estimated number of adult was therefore 10 and the maximum was 12. In addition, we identified five sub-adults and two cubs. We constructed capture histories for the maximum estimate of 19 individuals (Table 2). On most occasions, we captured individuals on their own, but we also captured three family groups. Two of these family groups comprised a presumed female adult with two sub-adults. The third family group comprised of a presumed female adult with one sub-adult in early 2013. The same female adult was captured with two cubs in late 2013 (QN-18 and QN-19). The mean number of captures for the 19 individuals was 9.16 (Range 1–24).

3.2. Temporal and spatial patterns

The total number of individuals captured across each sampling period varied. Only six individual snow leopards (four adults and two sub-adults) were captured continuously across all sampling periods (Table 2). Four individuals were caught only in early 2013 (three adults

Table 1
Sampling effort (number of active camera trap-days) expended during different time periods from 2013 to 2014 in Qilianshan National Nature Reserve, Gansu.

Sampling periods	Period start	Period end	Active camera trap − days
1	January 9, 2013	April 8, 2013	1381
2	April 9, 2013	July 7, 2013	1285
3	July 8, 2013	October 5, 2013	1117
4	October 6, 2013	January 3, 2014	1424
5	January 4, 2014	April 3, 2014	1159
6	April 4, 2014	July 9, 2014	767
		Total	7133

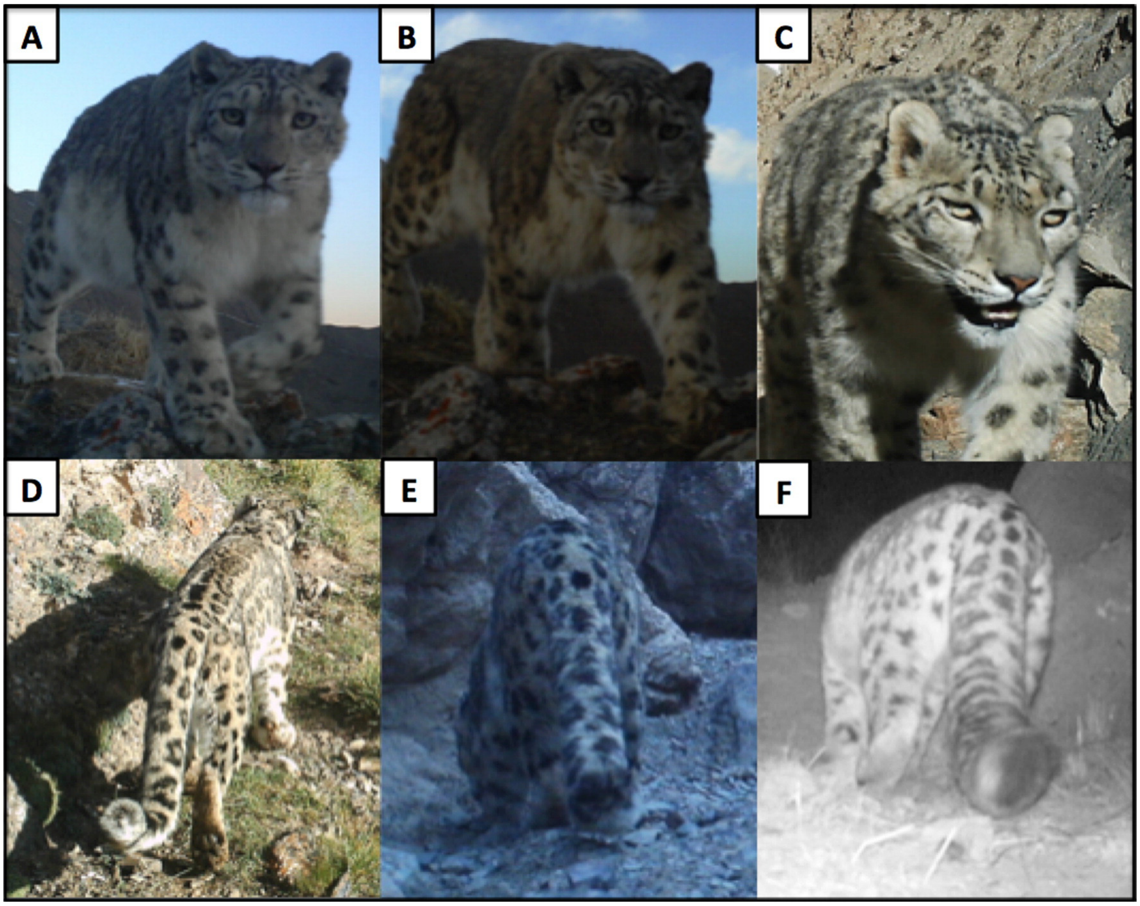

Fig. 1. Snow leopard individual identification. A and B are photos of the same individual from different capture events. D and E are photos of the same individual from different capture events. Identification is based on distinct spot patterns on the face and tail.

and one sub-adult) and no longer observed during the rest of the trapping period. The average time period between subsequent captures varied between individuals (mean = 47 days; range = 16–109 days).

Posterior density estimates from fitting the model with the half-normal detection function also varied between 1.46 (SD 0.44) and 3.29 (SD 1.10) snow leopards per 100 km^2 across each sampling period (Table 3). The density estimate for the entire 19-month period was estimated at 1.40 (SD 0.36).

Captures of snow leopard individuals tended to be clustered in the south-western part of the study area (Fig. 2), within close proximity to high mountains (peaks reaching 5400 m) and further from the north-western border of QNNR where there is greater presence of

Table 2
Capture histories of individual snow leopards photographed in Qilianshan National Nature Reserve (QNNR), Gansu Province, China, on 6 sampling periods during January 2013–July 2014.

Individual-ID	Age category	Description	Sampling periods						Total captures	Mean time period between captures (days)
			1	2	3	4	5	6		
QN-01	Adult	Alone	1	1	1	1	1	1	24	21
QN-02	Adult	Alone	1	1	1	1	1	0	14	28
QN-03	Adult	Alone	1	1	0	0	0	0	2	67
QN-04	Adult	Alone	1	0	0	0	0	0	1	-
QN-05	Adult	Alone	1	0	0	0	0	0	1	-
QN-06	Adult	Alone	1	0	1	1	1	1	13	37
QN-07	Adult	Alone	0	0	1	1	0	0	4	42
QN-08	Adult	Alone	0	0	0	1	1	1	13	16
QN-09	Adult	Alone	0	0	0	1	1	0	6	24
QN-10	Adult	Family 1	1	1	1	1	1	1	15	36
QN-11	Subadult	Family 1	1	1	1	1	1	1	18	28
QN-12	Subadult	Family 1	1	1	0	1	1	0	7	58
QN-13	Adult	Family 2	1	1	1	1	1	1	7	68
QN-14	Subadult	Family 2	1	1	1	1	1	1	18	25
QN-15	Subadult	Family 2	1	1	1	1	0	1	8	58
QN-16	Adult	Family 3a&b	1	1	1	1	1	1	16	33
QN-17	Subadult	Family 3a	1	0	0	0	0	0	1	-
QN-18	Cub	Family 3b	0	0	0	1	1	1	3	109
QN-19	Cub	Family 3b	0	0	0	1	1	1	3	109
Total number of individuals captured			14	10	10	15	13	11		

Table 3
Trends in estimated density of snow leopards (including adults and sub-adults) in Qilianshan mountains, Gansu Province, China, across three sampling periods between January 2013 and July 2014. Population density estimates were estimated independently over 3 sampling periods using a Bayesian spatially explicit capture–recapture model.

Sampling periods	Density (SE)	95% Confidence interval	
		LCL	UCL
1 & 2	1.46 (0.44)	0.64	2.27
3 & 4	2.62 (0.77)	1.18	4.11
5 & 6	3.29 (1.10)	1.24	5.44
All periods	1.40 (0.36)	0.76	2.01

human disturbances, such as agricultural fields, paved roads and villages. We observed overlapping movement patterns in the south-western area with one camera trap capturing up to five different adult snow leopard individuals. Fewer snow leopard individuals were captured in the north-eastern area.

4. Discussion

We present a multi-seasonal study of a snow leopard population using camera traps in China's north-eastern snow leopard range. Within the relatively small size of the study area, a large number of snow leopard individuals were captured across the six sampling periods. The total captured population (including sub-adults and cubs) varied between estimates of 10–15 individuals over the 19-month sampling period. Such fluctuations are likely arising from demographic changes related to adult/cub survival, as well as sub-adult dispersal and movement of individuals in and out of the study area (Duangchantrasiri et al., 2015; Goodrich et al., 2008). We did not identify any distinct pattern in the number of individual snow leopards in relation to seasons. Seven adults were not observed continuously throughout the whole study period, but only for 1–3 sampling periods, suggesting that the study area forms only part of much larger home ranges. The individuals that were present at least five out of six sampling periods included three females with sub-adults or cubs. This supports previous hypotheses that females tend to remain within more restricted geographic areas, and remain in close vicinity to their mother's range after dispersal (Sharma et al., 2014). The snow leopard population in this area appeared to be reproducing actively as one of the females was observed with sub-adults in the 2014 winter and with two new cubs in the following summer.

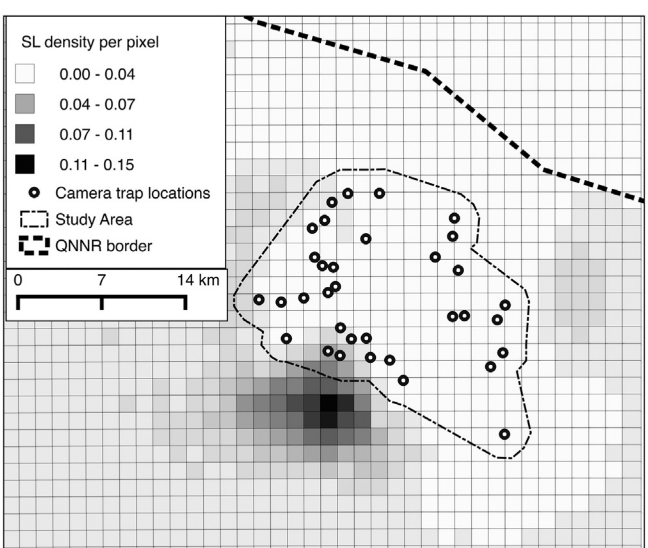

Fig. 2. The map of the spatial distribution of snow leopard density estimates surrounding the study area. A pixelated density map for the entire 19-month sampling period produced in SPACECAP showing estimated snow leopard densities per pixel of size 1.96 km^2.

Density estimates also varied across sampling periods between 1.46 to 3.29 per 100 km^2, with fairly large posterior standard deviations associated with our estimates. Observed changes in parameter estimates were likely the product of two main factors. First, variation in the number of captured individuals, possibly reflecting demographic changes and movements in and out of the study area as discussed above. Second, the imprecision of estimates, largely due to constraints in reaching an adequate sample size of individuals captured and recaptured for SERC analysis (Alexander et al., 2015). The fact that individuals were captured on average once every 50 days reasserts the difficulty of achieving adequate sample sizes for closed capture–recapture analysis. This 19-month study usefully complements our earlier study, in which we estimated a population of 20 individual snow leopards and a density of 3.31 per 100 km^2 (CI = 1.43–5.32), on the basis of a single-season camera trap survey in an overlapping, but larger and more remote part of QNNR.

Finally, it is interesting to note that most of the adult snow leopard individual captures were clustered in a relatively small area (50 km^2) within the south-western part of the study area, furthest away from human habitation and the Nature Reserve border. This supports previous observations of home range overlap between individuals (McCarthy et al., 2005).

Our study enabled a fine-grained observation of a snow leopard population, highlighting their transience and propensity to share a small geographic area. Snow leopard surveys of limited scale and conducted over short sampling periods may only present partial views of a dynamic system. In the context of limited resources, the challenge remains to achieve a sufficient sample size of captures and recaptures to assess trends in snow leopard population size and/or density. More research is required to determine survey designs that meet sample size requirements, while taking into account snow leopard population dynamics and behaviour patterns (Alexander et al., 2015). In most circumstances, larger scale and more camera trap intensive surveys will be needed. Strategic investments are urgently needed to develop and test smarter and more robust monitoring approaches to inform policy and conservation decision-making across the snow leopard range.

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