



WWF

MONGOLIA

NATIONWIDE SNOW LEOPARD POPULATION ASSESSMENT OF MONGOLIA

KEY FINDINGS

Assessment duration:
May 2017 – October 2020

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Report by WWF-Mongolia
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CONTRIBUTOR



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FOREWARD

MINISTRY OF ENVIRONMENT AND TOURISM OF MONGOLIA

Mongolia is one of the few countries in the world supporting distribution ranges of snow leopards, the globally endangered and key representative species of high mountain ecosystem. Mongolia is home to the second largest population of snow leopards in the world, highlighting Mongolia's involvement in species survival. Therefore, Mongolia is contributing in implementation of the long-term Global Program for the Conservation of the Snow Leopard and its Ecosystem (GSLEP) initiated by the "Bishkek Declaration".

The Government of Mongolia adopted its National Programme for Very Rare and Rare Wildlife Conservation and National Programme for Biodiversity Conservation in 2011 and 2015, respectively. Under these strategic policy documents, a number of multi-faceted policy actions and initiatives are undertaken. One of these actions is to protect, preserve, and restore populations and ranges of endangered (very rare and rare) wildlife species in the country through scientific approaches and practices.

The effort recently undertaken nationwide is the snow leopard population and distribution range inventory that has been conducted by WWF-Mongolia, Snow Leopard Conservation Foundation, GSLEP and the national research and academic institutions and researchers.

The detailed snow leopard population and habitat assessment results have become an important key reference for prevention from snow leopard population decline and habitat loss through designation of its suitable habitat in the national Protected Area network and improvement of the species conservation management in order to ensure preservation of the healthy high mountain ecosystem, the snow leopard habitat.

Amongst the 12 snow leopard range countries in the world, Mongolia has initiated and undertaken the detailed studies and assessment of snow leopards in the country according to the Population Assessment of the World's Snow Leopards Guidelines with comprehensive scientific research methods and techniques through multi-parties' engagement within an entire potential species habitat. In that capacity, these studies and assessments may be a model for the rest of the range countries in the world, according to our considerations.

These assessment became an important driver for advancing endangered (very rare and rare) wildlife population research against the current development and for conservation needs through advanced scientific technological applications and innovative and informative approaches.

Taking this advantage, I would like to express my sincere gratitude to WWF-Mongolia that managed and all other scientific institutions and individuals that greatly contributed and supported these comprehensive studies and assessment.

Batbayar Tserendorj
Vice Minister of Environment and Tourism of Mongolia

WWF-MONGOLIA

It is our pleasure to present to you the results of the nationwide Snow Leopard population assessment of Mongolia, initiated by WWF-Mongolia three years ago. Although scientific research is one of the many parts in conservation, it is perhaps the most integral as it allows us to enhance our understanding of the underlying causes and issues, as well as help us determine and implement conservation management actions based on scientific analysis.

Over 500 contributors including researchers, students, wildlife rangers and local people have gathered vast amounts of material and data from the field by working in rugged mountainous areas and often facing extreme weather conditions during the past 3 years. Subsequently, researchers worked on collected data for many months and years to organize, analyze and obtain final results.

Even when the importance of the research work itself is clear, the question “why should we protect snow leopards, what is the value of snow leopards?” is often raised. The snow leopard is the apex predator of its habitat, in other words, we can consider all species in the snow leopard habitat as “subjects” that create an ideal condition for their “lord”, the snow leopard. The prey species, such as Siberian ibex, argali sheep, marmot and pika should be plentiful in numbers, and in its turn the pasture and water sources should be abundant for these prey species, for the sake of the lord.

It should be recognized if the lord is thriving on its range, having plenty of food and rearing offspring is a sign of the healthy and balanced ecosystem in the High Mountain. That is why it is important to protect snow leopards and by doing so protecting the entire High Mountain ecosystem.

It is certain that the assessment results presented herein will become a source for further research in the future. Therefore, the value of this assessment is not only measured by its current contribution to conservation, but also measured by future opportunities created by this assessment.

I personally salute all participants involved, who have given their support in completing this work.

May the fruits of research support and be the basis for conservation efforts.

*Batbold Dorjgurkhem,
WWF-Mongolia, Country Director*

SLCF MONGOLIA

Snow leopard conservation is emblematic for the protection of biodiversity and mountain ecosystems at large. Mongolia holds the second largest snow leopard population in the world and plays an important role in global conservation efforts. Under the Global Snow Leopard Ecosystem Protection Program (GSLEP), the Ministry of Environment and Tourism has identified three priority landscapes in Mongolia. Throughout these landscapes, we have carried out an ambitious effort to contribute to the Population Assessment of World Snow leopards (PAWS) initiative by GSLEP with the collaboration of many partners.

Snow Leopard Conservation Foundation (SLCF) leads the work particularly in the South Gobi landscape, covering an estimated 82,000 km² which is one of the three snow leopard landscapes. Over the last 15 years SLCF has spearheaded a long-term ecological study on snow leopards in the area. Through the PAWS initiative, we conducted the 2018 range wide occupancy survey in partnership with WWF-Mongolia and assessed the distribution of snow leopards over a 67,000 km² area of the South Gobi. We also continue to conduct a long-term monitoring of snow leopard abundance across 17 mountain ranges, including three protected areas and two low density snow leopard habitat areas, covering approximately 27,000 km².

The report represents the fruit of joint effort by National Park specialists, rangers, NGOs, Environmental Agencies of South Gobi and Bayankhongor Provinces, Academic institutions and international partnerships, including GSLEP and the Snow Leopard Trust. We especially thank our partners in the Gobi Gurvansaikhan National Park, Small Gobi Strictly Protected Area, Ikh Bogd National Park, Great Gobi Strictly Protected Area, Tost Tosonbumba Nature Reserve and their specialists, rangers, community volunteer rangers, herders and students of the National University of Mongolia for contributing to this work.

SLCF is pleased to contribute to this collaborative effort which provides critical information for the conservation of snow leopards in Mongolia and throughout Asia. We recognize that the findings of this report are preliminary and look forward to the future collaboration with partners in order to finalize the snow leopard distribution and abundance estimates at the national scale.

This assessment was made possible through the collaboration of many stakeholders working to safeguard the elusive snow leopard and we assure that it will be useful information to strengthen our conservation efforts in Mongolia and the World.

*Bayarjargal Agvaantseren
Director
SLCF Mongolia*

GSLEP The Bishkek Declaration 2017, endorsed by the governments of all snow leopard range countries urged the scientific community to develop and implement a replicable and reliable protocol to estimate snow leopard abundance within landscapes, countries, regions and the species' entire distribution range. An ambitious initiative, called PAWS (Population Assessment of the World's Snow Leopards) was launched by the Global Snow Leopard Environmental Protection (GSLEP) program, aimed to produce a scientifically robust population estimate of snow leopards. The initiative is guided by a 11 member scientific advisory panel that includes some of the world's recognized population ecologists and snow leopard ecologists. The advisory panel came up with generalized guidelines and procedural details to achieve this herculean task.

It is heartening to witness the leadership shown by Mongolia, home to the second largest population of snow leopards in the world, in becoming one of the first few countries to have initiated the implementation of a country-wide snow leopard distribution and population assessment using methods compliant to the PAWS guidelines. In an unprecedented effort, nearly half a million square kilometres were surveyed to develop a sophisticated distribution map of snow leopards across the species' potential range. These surveys were conducted in such a way that they addressed the possibility that snow leopards can at times be present in an area but still remain undetected. In the second phase, more than two dozen sites were sampled with nearly 1,500 camera traps that generated more than 1,300 encounters of wild snow leopards. As any statistician can confirm, using an adequate sampling design is essential in order to obtain reliable estimates, no matter what the sampling effort. These sites were sampled using the state-of-the-art sampling guidance developed by the PAWS team to ensure adequate representation of the entire country's snow leopard distribution. We believe that this effort would not have been achieved without the collaborative spirit of the national teams and experts.

While the results presented here show promise, we would also like to clarify that these are only preliminary estimates and one must wait for the final 2017-2020 estimates, to be calculated after the national team has obtained data from the remaining five trapping sessions, explored spatial heterogeneity in snow leopard density, and addressed the issue of possible misidentification of certain individuals that may lead to overestimation. Note also that without a design or model designed specifically to obtain estimates at fine spatial scales, estimates from larger-scale surveys will in general give biased estimates for smaller "pockets" within the surveyed region. We hope that this report helps illustrate the PAWS guidelines in practice and helps other range country teams and PAWS effort in the near future.

The GSLEP PAWS team is thrilled to be part of this collaborative effort. It was a pleasure to be involved in the planning, analysis and interpretation of this preliminary assessment. The work done is among the first of its kind at this scale, and represents the leadership and commitment of Mongolia towards achieving the goals of Bishkek Declaration 2017. We congratulate the Ministry of Environment and Tourism of Mongolia, WWF-Mongolia, Snow Leopard Conservation Foundation, the Institute of Biology of the Mongolian Academy of Sciences, the National University of Mongolia, State Protected Area Administrations comprising the national PAWS team in Mongolia for their hard work and commitment. We wish them our best and look forward to continuing supporting the country team in analysing and interpreting the final results once the final datasets are collated from the field.

David Borchers, PhD
PAWS Technical Advisory Panel Chair

Justine Shanti Alexander, PhD
PAWS Coordinator

Koustubh Sharma, PhD
International Coordinator
Global Snow Leopard and Ecosystem Protection Program

TABLE OF ACRONYMS

IUCN:	International Union for Conservation of Nature
MaxEnt:	Maximum Entropy method
GSLEP:	Global Program for the Conservation of the Snow Leopard and its Ecosystem
PAWS:	Population Assessment of the World's Snow Leopards
SLIMS:	Snow Leopard Information Management System
GPS:	Global Positioning System
DNA:	Deoxyribonucleic acid
SLCF:	Snow Leopard Conservation Foundation
SLT:	Snow Leopard Trust
IMC:	Irbis Mongolian Centre
METM:	the Ministry of Environment and Tourism of Mongolia
SCR:	Spatial capture-recapture
NDVI:	Normalized Differential Vegetation Index
AIC:	Akaike Information Criteria

INTRODUCTION

The threatened snow leopard (*Panthera uncia*) is the least studied big cat. Snow leopards have a vast global range across the Asian major and lesser high mountains of Himalaya to Kharakorum, Hindu Kush, Pamir, Tian Shan, Quilian, Kunlun, Altun, Khangai, Altai and Soyon Mountain ranges (Ghoshal et al., 2019). The species is an important cultural, ecological, and economic symbol for Asia's mountain ecosystems. Protecting snow leopard populations supports safeguarding the headwater of Asia's mighty rivers to whom billions of people depend on. This is especially true for Mongolia, where people and livestock depend on rivers and groundwater sources that are fed from the western mountain.

The snow leopard, however, faces a number of threats across its range including retaliation killing, poaching, illegal trade, prey species depletion and unregulated infrastructure development. It is estimated that 221-450 snow leopards poached annually between 2008 and 2016 (Nowell et al., 2016), which may account for up to 13 percent of world population if using a global estimate of 2170- 3386 mature individuals on International Union for Conservation of Nature (IUCN) official website (<https://www.iucnredlist.org> by McCarthy & David Mallon, 2016).

In 2019 it was estimated that only 0.3-0.9% of the snow leopard range had peer reviewed abundance population estimates (Suryawanshi et al., 2019). In terms of assessing the snow leopard distribution only a small number of surveys have accounted for imperfect detection (Alexander et al., 2016; Ghoshal et al., 2019; Taubmann et al., 2016). The majority of previous distribution efforts have relied on either expert opinion (Alexander et al., 2016; Aryal et al., 2016; Kalashnikova et al., 2019; McCarthy & Chapron, 2003; Riordan et al., 2015), or on the modelling of presence-only data (e.g., with Maximum Entropy method (MaxEnt); (Aryal et al., 2016; Bai et al., 2018; Hameed et al., 2020; Holt et al., 2018; Kalashnikova et al., 2019; Li et al., 2016). Protecting the snow leopard and its vast habitat requires a good understanding of the species' status, distribution and population trends (McCarthy & Chapron, 2003).

The vital function of the snow leopard in their ecosystem and need to conserve the species was recognized by all 12 snow leopard range countries in the Global Snow Leopard and Ecosystem Protection Program (GSLEP) Bishkek Declaration 2017. Governments of all 12 snow leopard range countries have emphasized the need for more robust and expansive monitoring of snow leopard populations, as reflected in the Bishkek Declaration 2017 and the Kathmandu Resolution 2017. Subsequently, the Population Assessment of the World's Snow Leopards (PAWS) initiative started and a technical oversight panel was constituted by the GSLEP Steering Committee. The aim of PAWS is to achieve robust global snow leopard population estimates by 2022. There are several challenges in achieving reliable snow leopard population estimates. The species' secretive nature, generally low density, and remote terrain result in low detection and small sample sizes which limits capture recapture analysis and extrapolations. Density estimates risk being positively biased if high density regions are primarily sampled (Sharma et al., 2019). Recent studies suggest that the previous studies may have estimated snow leopard densities considerably higher than it might be in reality (Chetri et al., 2019; DoFPS, 2016).

In recent years, improved technology and analytical techniques (e.g. camera trapping, GPS collaring, fecal DNA analysis, and occupancy estimates) are beginning to address some of these population estimates challenges.

In Mongolia, population estimates of specific sites or regions have been derived from field sign encounter rates using Snow Leopard Information Management System (SLIMS) method, such as the number of tracks, feces or scrapes found, or based on 'expert opinion' or general intuition. In general, experts stated that the snow leopard population is 700 (Bold & Dorjzundui, 1976), ranges from 557-1127 (McCarthy & David Mallon, 2016), about 1000 (Munkhtsog et al., 2016) and 1500-1700 (Schaller et al., 1994) with a snow leopard range of 130,000 km² (Mallon, 1984), 103,000 km² (McCarthy, 2000) and 225,000 km² as Snow Leopard Conservation Units (McCarthy & David Mallon, 2016). Furthermore, existing national distribution maps of snow leopard are limited to large scale resolutions that often restrict proper planning of the conservation action on site.

Until now, there has been no attempt to estimate Mongolia's national snow leopard population size using systematic and robust scientific methods. In this assessment we apply the PAWS methods and aim to:

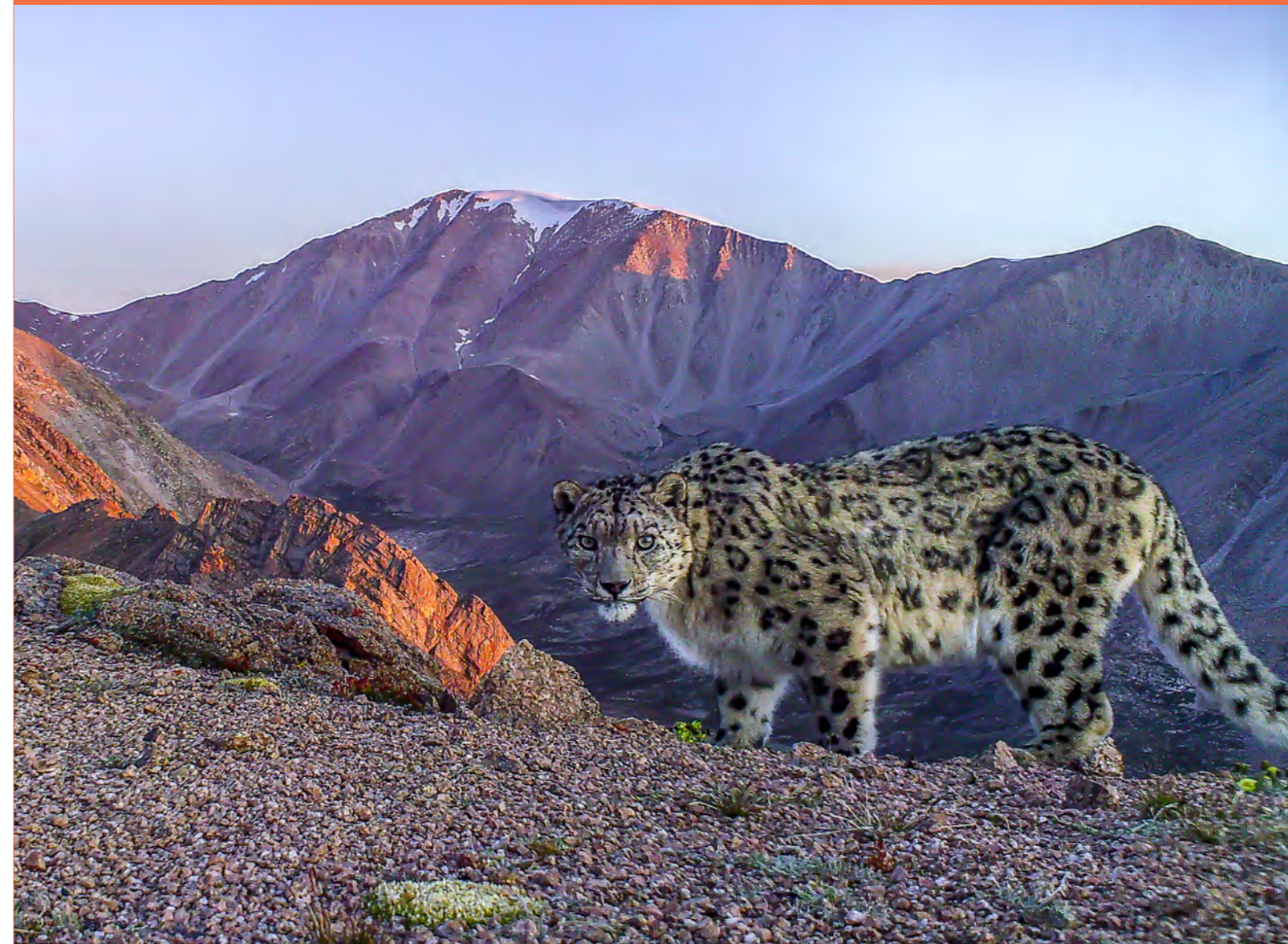
1. Assess the national snow leopard distribution incorporating both presence and absence data, and accounting for imperfect detection and variable survey effort using occupancy modelling approaches (MacKenzie et al. 2002, 2018; Mackenzie et al. 2003).
2. We then used the distribution assessment to inform the sampling of more intensive population assessments by camera trap across high, medium and low snow leopard occupancy areas.
3. Finally, we aim to provide a preliminary snow leopard population estimate for Mongolia.

This report represents an important first step towards obtaining the final robust snow leopard national estimate for Mongolia (2017-2020). We hope that readers will recognize the findings as preliminary. This means that further work is still required including incorporating data from 5 additional survey sites and exploring further a number of analytical issues. Addressing spatial heterogeneity of snow leopard density and addressing issues of mis-identification of individuals are envisaged as the next steps in the process. These first steps presented in this report represent a strong basis for the way forward.

WWF-Mongolia initiated a comprehensive study, Mongolia's Nationwide Population Assessment of snow leopard in 2017, and completed it along with partner organizations, including the Snow Leopard Conservation Foundation (SLCF), GSLEP, the Snow Leopard Trust (SLT), the Institute of Biology of the Mongolian Academy of Sciences, National University of Mongolia, University of St Andrews, Irbis Mongolian Centre (IMC) and Ministry of Environment and Tourism of Mongolia (METM).

The Nationwide Population Assessment of Mongolia's snow leopard has provided a valuable contribution to development of the PAWS Program in successfully achieving its target of robust and reliable population assessment of the World's snow leopards.

METHODS



PLANNING PROCESS

The aim of the assessment is to estimate the snow leopard population in Mongolia. The entire country was therefore considered as an area of interest and surveyed according to the PAWS Guidelines (<https://globalsnowleopard.org/wp-content/uploads/2020/08/PAWS-guidelines-2020.pdf>) (Sharma et al., 2019).

The PAWS guidelines recommend design-based inferences when assessing snow leopard populations at the country scale. Mongolian territory is over 1.56 mln km² large and has a wide range of habitats where explanatory variables (covariates) may have different effects and relevance, essentially limiting our ability to use these relationships in order to estimate snow leopard density at the national level. Design-based inferences are flexible to accommodate site or region specific explanatory variables that dictates the snow leopard density and distribution (Sharma et al., 2019).

The PAWS process (Sharma et al., 2019) recommends a two-step process. The first step includes occupancy based surveys (Mackenzie & Royle, 2005) conducted across large landscapes to develop reliable species distributions and a stratification surface with variable probability of use by snow leopards. The second step involves a standardized sampling process across various strata identified (i.e. low, medium and high density areas) in order to intensively survey the specific sampling frames. Abundance estimations using spatial capture-recapture methods, are carried out in each intensively surveyed site (Borchers & Efford, 2008; M. G. Efford et al., 2009). The two-step process was used in order to assess the snow leopard abundance at the national scale of Mongolia. The sampling approach was developed in collaboration with the PAWS technical advisory panel.

A four-day long PAWS planning workshop was organized in Ulaanbaatar in May, 2018. The workshop focused on planning the implementation of a nationwide snow leopard population assessment in a collaborative effort between WWF-Mongolia, Ministry of Environment and Tourism of Mongolia, SLCF, GSLEP, SLT, National University of Mongolia, the Institute of Biology of the Mongolian Academy of Sciences and Otgon-Bor khavtsal NGO.

The workshop also aimed to align the proposed project with PAWS and aimed to build an understanding of the basic sampling theory, methods of occupancy estimation and spatial capture recapture modelling. The workshop specifically focused on preparing participants from various organizations to lead teams and conduct sign based occupancy surveys across all of Mongolia's supposed snow leopard range.

MACRO LEVEL

It is challenging to collect individual capture and recapture data systematically to assess abundance at the national scale as it requires a substantial amount of resources. For example in the case of Mongolia we estimate that approximately 20,000 camera traps would be needed to cover the entire predicted snow leopard range at the density of 4 cameras per 100 km² area. The PAWS Guidelines recommend that the area of interest, in this case the entire Mongolian potential snow leopard range, should first be surveyed using an occupancy approach at macro level in order to assess how occupancy varies across the country. The distribution assessment provides the basis for our camera trap site level sampling approach- ensuring that camera trap surveys occur in each strata.

SIGN BASED OCCUPANCY SURVEY



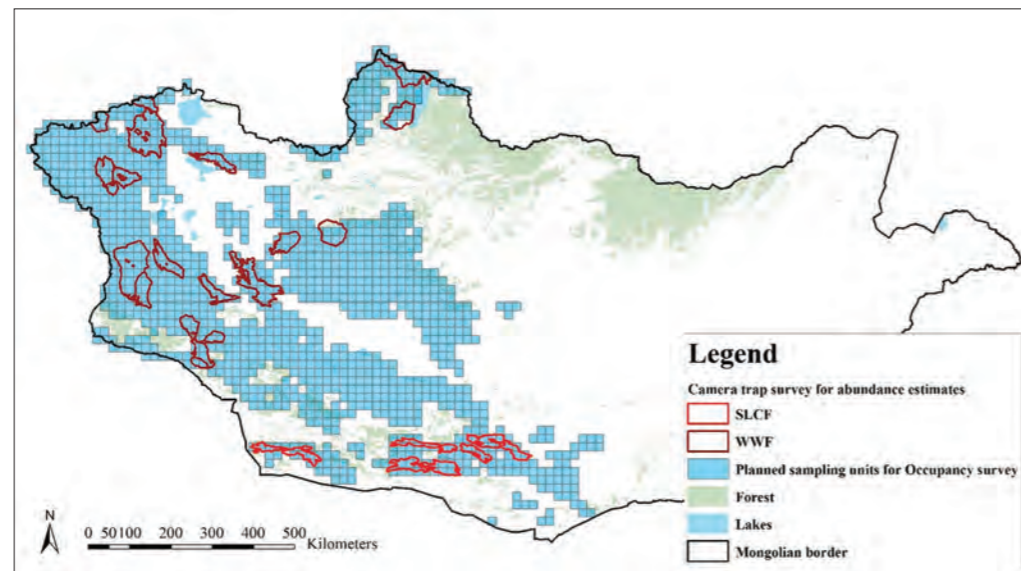
Following the workshop, we divided the entire country of Mongolia into grids of 20x20 km (400 km²). This consisted of 4,163 grid cells (1,665,200 km²) across the entire country. In Mongolia snow leopards are known to select rugged habitat and live almost exclusively in mountainous areas with marginal or no tree cover. The species is known to inhabit a wide range of altitude from 900 m to 3500 m a.s.l. across the country. They do however travel across or use steppe, depressions, sand dunes and frozen water bodies, which are considered as non-habitats for snow leopards. A MaxEnt habitat preference model based on 15 collared snow leopard individuals with 26000 locations in Mongolia was used to inform the occupancy planning stage and ensure that no areas that were predicted to be suitable for snow leopards were left out. A terrain ruggedness index (Riley et al. 1999) map was created for the entire country to demarcate areas of mountainous habitat (defined by slope > 5%) and non-habitats. We used the digital elevation model to create slope surface of Mongolia at ArcMap 10.7 software downloaded from Shuttle Radar Topography Mission, SRTM (<http://srtm.csi.cgiar.org/>) and excluded 400 km² grid cells that had less than 5% (20 km²) of the total area as mountainous. We also excluded grid cells that were predominantly forested (defined as more than 50% forests) or were separated from known snow leopard distribution range by 400 km (assuming these were only used for transit purposes). A remaining total of 1,200 grid cells (480,000 km² referred to as sampling units) fit the criteria (Map 1). More information is provided at Bayandonoj et al., (in review). Each sampling unit size was chosen to be 400 km² (20x20 km), which will comfortably accommodate a single snow leopard home range in Mongolian case study (336-617 km² by Kernel utility distributions, 327-615 km² by Minimum convex polygons, and 129-220 km² by Local convex hulls methods; from the Johansson et al., 2016).

A total of 12 teams (consisting of 60 researchers from Academic institutions

and National and International NGOs, 126 rangers from State protected areas and 31 drivers) were trained to survey the 480,000 km² in a coordinated effort between August 2018 and March 2019. Each survey team consisted of 7-8 members with at least two individuals who had experience in detecting and recognizing snow leopard signs. Transects were planned in such a way that they surveyed the rugged areas within the sampling units along the mountain ridgelines and valleys where snow leopard are likely to leave a sign. Observers recorded snow leopard sign detections on the edges of canyons, on ridgelines or under overhanging rocks and recorded the location of each scrape, scratch, spray, pugmark, scat or direct observation. More details can be found in Bayandonoi et al., (in review).

Map 1.

1,200 sampling units surveyed using occupancy based sign methods in Mongolia. 22 sites that were surveyed using camera traps by WWF-Mongolia and SLCF during 2017 and 2020.



OCCUPANCY DATA ANALYSIS



In May 2019 we organized a workshop by bringing together all survey team leaders, including in-country as well as international snow leopard experts. The participants identified key variable combinations that could potentially be tested in the model to improve inference on detecting snow leopard signs and estimating probability of site use.

The probability of detecting snow leopard signs was assumed to be affected by a range of factors. The team considered the following seven sampling covariates: transect segment length (on average of 1000 m), mean altitude of track on each segment (averaged values at each 100 m), average ruggedness on each segment, average slope of each segment, field team category, number of observers on segment, survey state (on foot or from a vehicle). The probability of snow leopard site use was also predicted to be affected by a range of factors. We considered five site covariates: average elevation, average ruggedness of sampling unit, average ruggedness of mountainous habitat within sampling unit, coverage of forest within sampling unit and mean NDVI within sampling unit.

The occupancy model extension of Hines et al. (2010) was used to allow for correlated detections between transect segments as they tended to follow travel paths such as ridges and valleys. A candidate model set for possible effects of covariates on detection and occupancy was defined and run in software PRESENCE (2.12.36 version) using standard approaches. Each model was ranked by Akaike's Information Criterion (AIC) to choose the best model balancing between likelihood (fit) and over parameterization (number of parameters). We ran a total of 27 models, each with different combinations of site and survey covariates (for more information see Bayandonoi et al., in review). We used AIC weights of models to define variable importance. We used the top model to predict the probability of sites being used in unsampled areas. To assess the effective coverage of our sampling, we plotted occupancy as a function of different covariates and marked the covariate values represented by sampling units to assess the sufficiency of the sampling effort.



MICRO LEVEL

MICRO LEVEL SITE SELECTION



The key assumption when extrapolating from the camera traps to the entire survey region is that the cells covered by camera traps are representative of cells throughout the whole region. We already know that this is not true, because cameras in Mongolia previously had been placed mostly in favourable habitats where snow leopard density is expected to be high (according to the country level occupancy results). The net effect of placing cameras in high-density areas and then acting as if these were representative of the whole country is that estimates of abundance and density will be higher than they are in reality.

We therefore aimed for camera traps to be placed across different strata (high, medium, low expected snow leopard density) with a degree of uncertainty below 30%. It is recommended to survey high and medium density strata more intensively with camera trap surveys to reduce the coefficient of variation for estimating the nationwide population size—ensuring negligible degree of uncertainty.

We first assessed where ongoing camera trap work was taking place. Most of these surveys were taking place in high probability of snow leopard site use based on national occupancy assessment. New survey sites were therefore planned in low snow leopard site use areas so that each strata was surveyed with a spatially balanced sampling approach. The Balanced Acceptance Sampling approach which utilizes Halton sequence was used to inform the selection of the low density strata survey sites (B. Robertson et al., 2018; B. L. Robertson et al., 2013). The sampling approach was developed in collaboration with the PAWS technical advisory panel to ensure that the final estimates represent unbiased status of snow leopards for the entire country.

CAMERA TRAP SURVEY BY SPATIAL CAPTURE-RECAPTURE



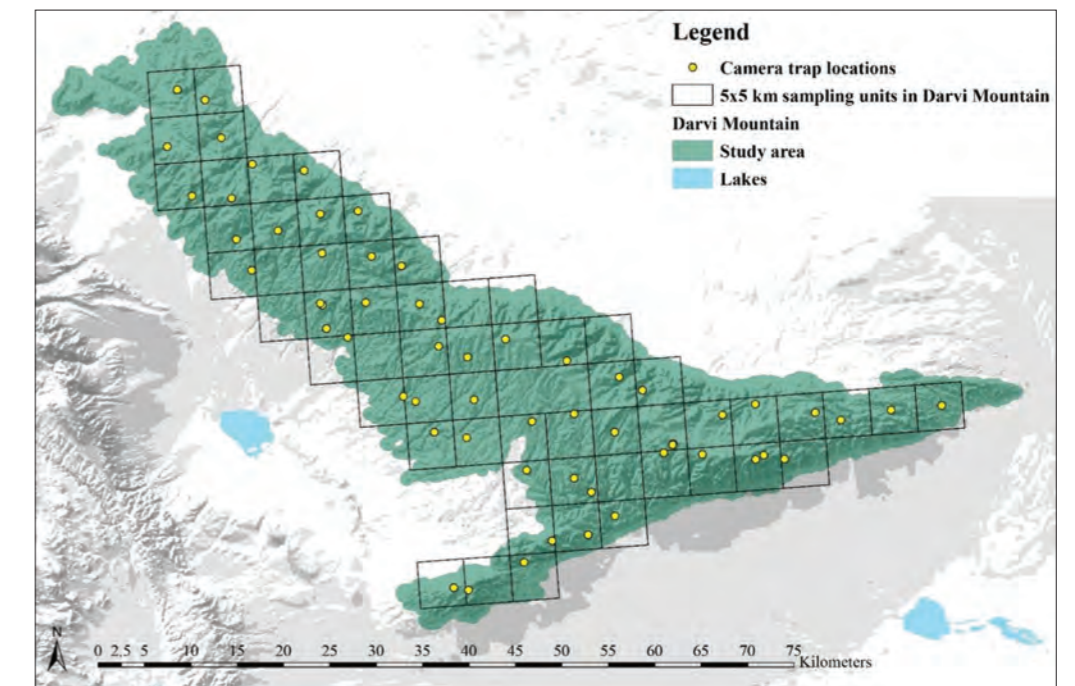
Spatial capture-recapture (SCR) is now recognized as a robust method to estimate the population size of elusive and cryptic species in relatively small areas (i.e. 500 to 10,000 km²). The approach depends on using capture and recapture data of individuals. The camera trap surveys aimed to meet the PAWS “Good practices for estimating snow leopard population abundance”:

- Camera arrays covered an area at least several times the size of a snow leopard home range, bigger than 400 km² area,
- Most cameras were spaced 2-5km (1-2 sigma) apart to allow particular individuals to be recorded more than one location by camera traps,
- Used a regular grid design,
- Cameras setup to sample across habitat gradients,

- Cameras placed near scrapes, marking sites, saddles, ridge paths, valley paths, etc to maximize the capture of snow leopards,
- Cameras operated up to 90 days with an assumption that the snow leopard population is to be closed, where there should not be/or negligible immigration or emigration of snow leopards in study sites.

The size of the study sites were at least 2 times bigger than the average home range of snow leopards ranging from 848-12,232 km², which satisfies the assumption of SCR method. Camera trap study area boundaries were defined by mountain edges next to flat terrain (defined as slope < 5 degree) and noticeable natural barriers such as big rivers, sand dunes and lakes. Cameras were positioned systematically so that at least one camera was to be deployed in a 5x5 km sampling units or placed 3-5 km apart from each other to cover the entire mountainous study area uniformly. This facilitated at least 5 camera traps to be positioned in snow leopard home range (Map 2) which ranges typically between 124 km² and 207 km² in size for female and male individuals respectively in Mongolia (Johansson et al., 2016; Poyarkov et al., 2019). Camera traps were placed as a single unit at each location and programmed to capture 3 to 8 burst photos and in some cameras continued by 20-40 seconds of short video footage.

Map 2.
Example of the camera trap placement design of 58 camera traps setup across 1,776 km² in Darvi Mountain in western Mongolia.



Camera traps are left for about 3 months in the field to facilitate the assumption of the closed population, and also providing enough encounters of the snow leopard for sufficient data collection for the SCR analysis. Cameras were installed in locations that maximized the capture rate of snow leopards, such as areas with snow leopard signs, wildlife tracks, along the ridgelines, saddles, and at the bottom of rock cliffs along the river basin in narrow valleys.

Box 1. Spatial capture-recapture

Spatial capture-recapture method is widely used to estimate animal abundance and density. Method is based on recognizable particular individual's records/captures at certain locations/areas repeatedly to determine the home range center and its size. It also assesses the effect of factors, such as topography, elevation, food source and so on, to species density and home range, thus allowing researchers to obtain spatially dependent more reliable density and abundance results.

**INDIVIDUAL
IDENTIFICATION
OF SNOW
LEOPARDS**

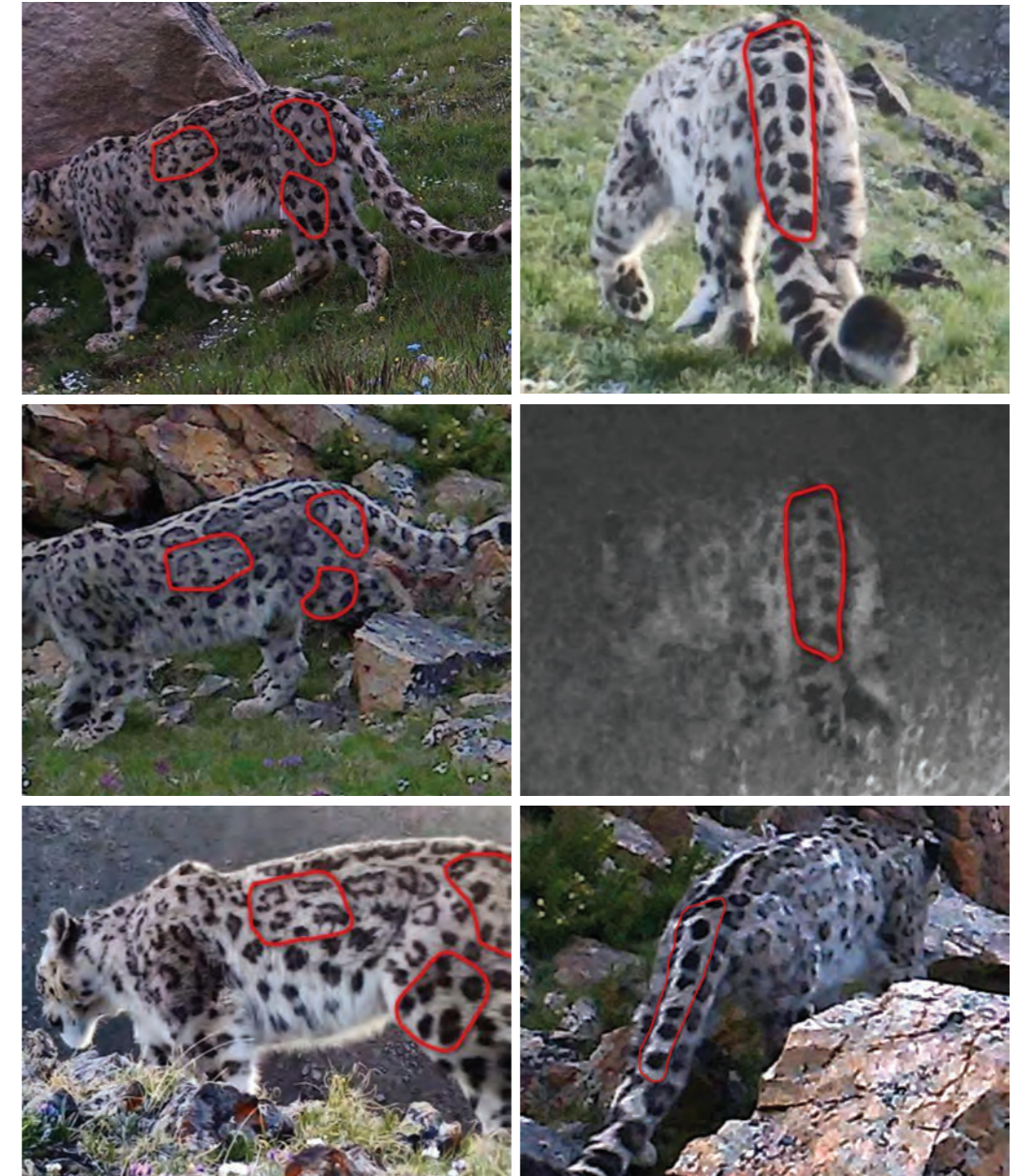


Images were downloaded from the camera traps at the end of each sampling period. In the case of video footage snapshot images were extracted from the short videos of snow leopards and used for the individual identification. Snow leopard identification was carried out according to the PAWS recommendation (<https://globalsnowleopard.org/wp-content/uploads/2020/10/Best-practices-for-Individual-ID.pdf>). Individual identification took place in two phases, the independent identification and the joint identification. Snow leopard photographs from each mountain (survey site) were compared by 2 to 3 experienced researchers independently to avoid a potential subjective bias by team identification. All observers were tested their risk of making errors using the PAWS online training tool (camtraining.globalsnowleopard.org) and evaluated their skills in identifying snow leopards. 12 observers identified snow leopards with a success rate ranging from 89% to 100% with a mean of 95% according to the training tool. After the completion of the independent identification, the teams performed joint identification by comparing each other's results together to spot errors and discuss uncertainties to obtain final identification of the snow leopard individuals that are used for the SCR analysis. Snow leopard individuals were compared to neighboring mountain's individuals to identify double-counts of snow leopards as well.

Individuals were compared using specific groups of identifiable spot patterns on the flanks, legs, along back and tail (Figure 1). Burst photos and video footages helped maximize captures of snow leopards in different angles and body parts. When a snow leopard spent time at a scrape, spray or waterhole site the number of captures increased. Encounters that consisted of only a single flank and could not be compared with the other individuals were considered as "unidentifiable". Encounters with blurry images, individuals far away, only a fraction of the body parts captured in images, or where the spot patterns could not be confidently recognizable were also considered as "unidentifiable", thus not included in SCR analysis.

Snow leopard individual capture histories were collated for each camera trap location. These consisted of camera trap ID, individual IDs, number of days the camera trap was active (effort) and camera trap GPS locations were prepared as a matrix for the SCR analysis.

Figure 1.
Example of the individual comparison using a specific spot patterns at flank, legs (left column) and tail (right column).



ABUNDANCE ESTIMATION



Abundance estimate refers to adult snow leopards. Cubs up to 2 years old who are captured travelling with their mother were not included in any SCR analysis.

The snow leopard abundance for Mongolia was estimated through stratified random sampling approach using the macro design toolkit developed by PAWS core team (see Sharma et al., 2019 for details). The data on abundance was analysed using spatial capture recapture framework (Borchers & Efford, 2008).

The country's potential snow leopard habitat was stratified using the probability of site use estimated from a country-wide occupancy survey (Mackenzie et al 2018) during 2018-2019 based on 20x20 km sampling units. The occupancy surface representing sampling units was smoothed using a focal statistics tool (ArcMap 10.8) by creating a moving average window across the entire potential distribution range at 5x5 km resolution to generate a more ecologically meaningful surface for snow leopard habitat use across the country. The smoothed surface was reclassified into three strata, viz. low, medium and high by defining cut-offs at 0.33 and 0.66. Different strata were sampled in such a way that the low, medium and high strata were represented by 0.3, 1.27 and 2.61 camera traps per 100 km² each. A total of 22 camera trapping sessions represented the three strata with 71 (5%), 676 (47%) and 698 (48%) traps in low, medium and high strata respectively. Data from 22 sessions were pooled for countrywide SCR models. The integration space for each session was defined at a resolution of 1000m, covering the three strata but excluding non-habitats. The smoothed stratification surface was treated as a categorical covariate, to test if the snow leopard density varied across the three strata. We compiled all camera traps and capture data from the entire country so each encounter corresponded to a specific trap and session, and each trap had a unique location.

In this preliminary analysis, we ran density models using the package "secr" (Murray G Efford, 2020) in programming environment R. We modelled the encounter rate at the activity center (λ_0) to be depend on the camera trap type. It was hypothesized that the camera traps might have an effect on the probability of detecting snow leopards (represented by λ_0). We also allowed density to vary between each of the three strata, but to be constant within each stratum. In this preliminary analysis, we make no attempt to model variation in density within stata and rely on the design to give us unbiased spatial capture-recapture estimates of abundance in each stratum. We used AIC to compare the models (without covariates and with various combinations of covariates). AIC weights indicate that the snow leopard density depends on stratum, and the coefficients of the three strata conformed to our hypothesis that low, medium and high strata represent lowest to highest density of snow leopards across the country. Models that tested the effect of camera type on detection probability (denoted by

λ_0 , encounter rate at activity center) ranked lower than the models that assumed no effect.

We estimated the proportion of each of the three strata across Mongolia's entire potential snow leopard distribution by clipping the occupancy classes for the shapefile that denote its habitat and excludes land-forms that are clearly non-habitats (steppe, water-bodies and settlements). Snow leopard distribution is spread from the North-West to South-East for over 1500 km and spans through substantially different landscapes which affects the snow leopard density. Therefore, we first tested the potential effect of three geographically distinct landscapes, namely Altai, South Gobi and Central-Northern Mongolia by running separate SCR analysis. It turned out that these distinct landscapes show no considerable difference in snow leopard density, allowing us to run country-wide estimates with data from 22 spatial sessions. Each camera trapping session was first modelled to have independent density estimates, but the ranging and encounter rate parameters are assumed to be the same between sessions. This approach allowed a relatively more rigorous and reliable estimation of ranging and encounter rate parameters especially for those sessions that did not have a high number of encounters. We then modelled density to be a function of the three strata, and also tested the effect of different types of camera traps on detection probability. Based on its minimum AIC, we chose the model assuming density as a function of strata and estimated total abundance of snow leopards from the entire country by projecting the stratified density estimates across the integration space representing the entire country's snow leopard habitat. Different types of camera traps had little effect on detection probability of snow leopards. We also used the density coefficients of the three strata to estimate snow leopard abundance from each stratum.

CORRIDOR ANALYSIS



Corridors for potential dispersal of snow leopard between isolated territories were identified using a least cost path analysis in ArcMap 10.7. For the least cost analysis, altitude, slope, ruggedness, Human disturbance index (Heiner et al, 2017), snow leopard occupancy estimates, snow leopard distribution map, snow leopard sign locations, snow leopard habitat modelling results were used to produce the least cost path.

SNOW LEOPARD DENSITY MAP

Based on a predicted stratified distribution results from occupancy estimates a more detailed prediction on potential snow leopard density stratification was drafted using below criteria. The intent of this map is to support conservation planning on the ground more effectively. The criteria included:

- The value of occupancy estimates at each 20x20 km sampling units were smoothed using a focal statistics at ArcMap 10.7 down to 5x5km grids to obtain relatively more ecologically meaningful surface for snow leopard site use,
- The snow leopard distribution was classified using the mean density value for the 3 strata from occupancy survey into 3 classes: Low density area, Medium density territory and High density territory,
- 1329 signs of snow leopard (the signs used for marking territory: scrapes, scratches and sprays) detected during occupancy survey was used to verify the strata classification for territorial habitats,
- 281 locations of the camera traps that captured snow leopard between 2017 and 2020 was used to verify the strata classification for territorial habitats,
- 224 territorial signs of snow leopard recorded during a camera trap field work was used to verify the strata classification for territorial habitats,

The range map boundary was illustrated based on natural topographic barriers below:

- Major rivers along the outskirts of entire sampling units were used as defining lines for the snow leopard range boundary, assuming that Snow leopard unlikely have a territory at both sides of such major rivers
- Lakes and sand dunes were excluded, considered non-habitat for the snow leopard,
- In general, densely forested continuous areas (small forest patches were not excluded) and forested part of the sampling units above 50% coverage of forest were excluded from the snow leopard distribution map, assuming snow leopard avoid such contiguous forested areas,
- Less than 5 degree sloped steppe and valleys between mountains (high altitude Mountain steppes are not excluded) were excluded, deemed such areas are not used by snow leopards as territory, instead used occasionally for the corridor for long distance movements between potential habitats,
- In the mountainous area with no specific barriers, roughly a 20 km buffer from snow leopard signs was added to accommodate possible SL habitat and boundary was drawn taking into account topographic edges such as ridge and valley.

RESULTS



SNOW LEOPARD DISTRIBUTION

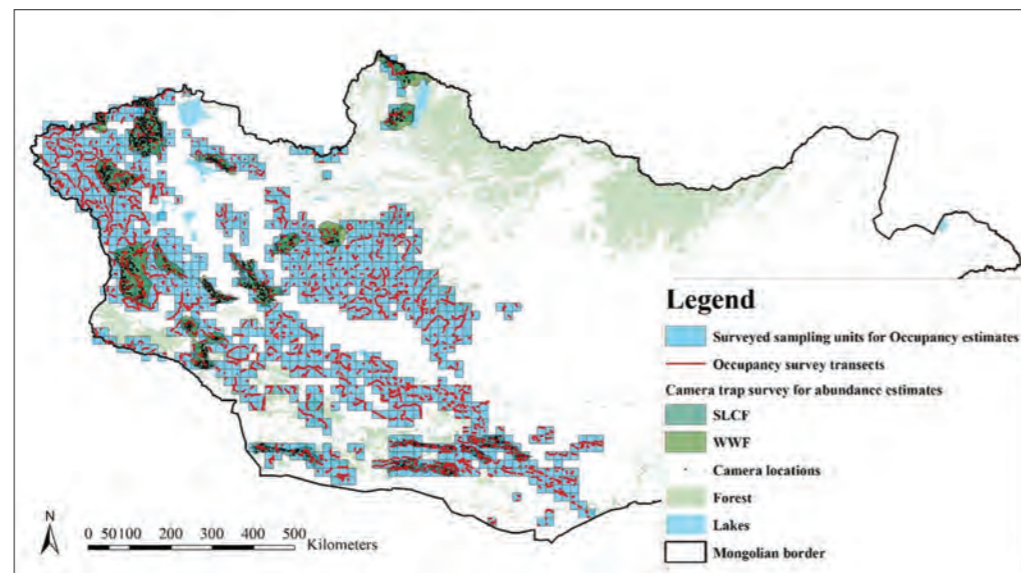
The nationwide snow leopard population assessment is the first ever comprehensive survey in Mongolia and was conducted between 2017 and 2020. The survey covered around 406,800 km² area of potential snow leopard habitats in Altai and Gobi Altai Mountain ranges from western Mongolia to southern Mongolia, Soyon Mountain range in Northern Mongolia, Khangai Mountain range in Central Mongolia and trans-Altai in south west of Mongolia (Map 3).

OCCUPANCY SURVEY EFFORT



Between August 2018 and March 2019 the 12 teams surveyed a total of 1017 sampling units (406,800 km²) out of the original 1200 sampling units that were identified as those representing potential snow leopard habitat. Potential snow leopard habitats were surveyed in the Altai Mountain range from western Mongolia to southern Mongolia, Soyon Mountain range in Northern Mongolia, Khangai Mountain range in Central Mongolia and trans-Altai in south west of Mongolia. The remaining 183 units could not be surveyed due to inaccessibility. 1017 of the 1200 sampling units were surveyed for snow leopard signs by traversing on average 19 km long transects on foot, on horse or in vehicles. In total, our teams covered 19,924 km (Map 4) in transects (13,129 km on vehicles, 6,794 km on foot).

Map 3. Field surveyed 1017 sampling units for occupancy estimates (in blue), surveyed tracks (in red) and camera trap survey Mountains (in green) with camera trap locations (in black dots).



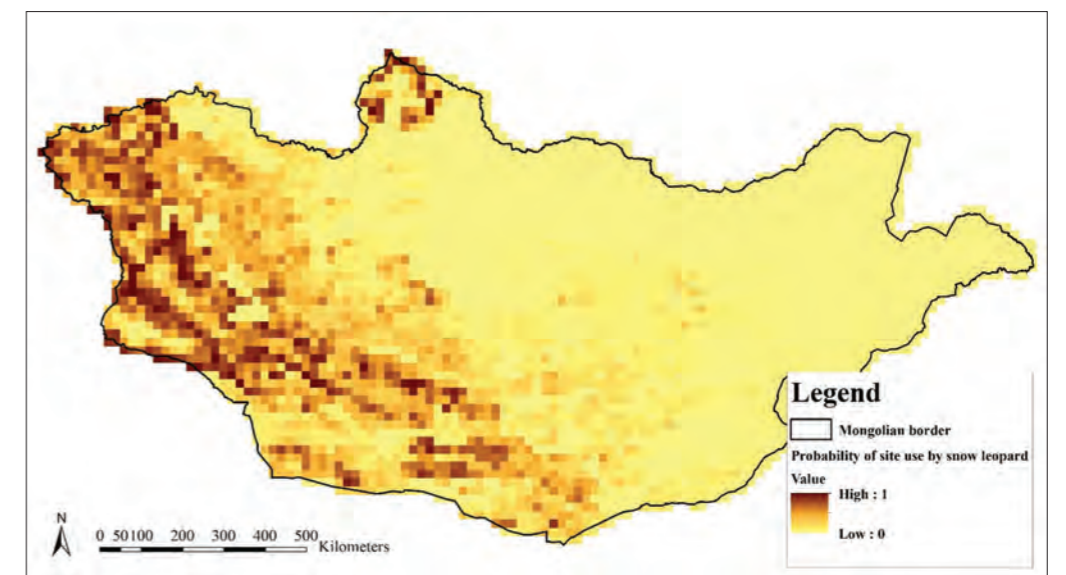
A total of 1508 snow leopard signs were recorded by field teams, of which 1236 scrapes, 92 pugmarks, 74 scratches, 19 sprays and 87 scats were recorded in 238 sampling units. Scats were not used in any analysis due to potential species identification uncertainty. The remaining 1421 snow leopard signs from 235 sampling units were used for the occupancy analysis, which provided a naïve occupancy estimate of 0.22.

OCCUPANCY ESTIMATES



The top model from 27 occupancy models had an AIC weight of 56% and together with next two models had a AIC weight of 99%. We used the summed AIC weights of the top 3 models to determine the relative importance of covariates in explaining the variation in data of probability of site use and detection of snow leopards. The 3 models suggest that mean ruggedness of mountainous habitat, mean NDVI and quadric relationship of elevation contributes most for probability of site use by snow leopards, though most variables have some effect on probability of site use. In general, snow leopards use more rugged areas with less vegetation and tree covers and inhabits relatively medium elevation, rather than low or high elevation in Mongolia (for more information see Bayandonoi et al., in review). In addition, probability of detecting snow leopard signs was influenced by average ruggedness on each segment, mode of survey and the interaction of these two covariates. Value of the covariates from the top models were used to predict the probability of site use by snow leopards across Mongolia (Map 4).

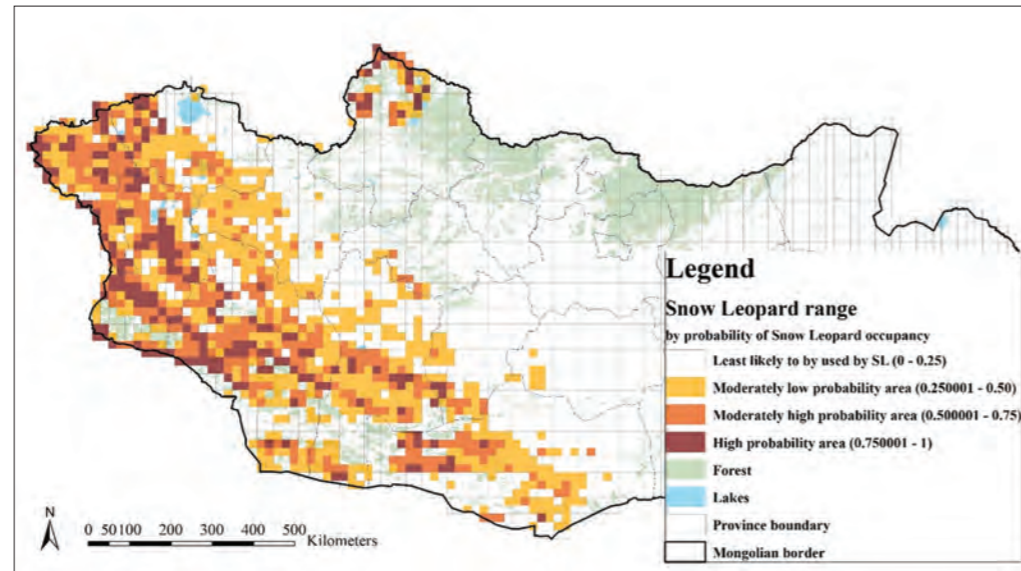
Map 4. Predicted distribution of snow leopard across Mongolia estimated from the occupancy model with the minimum AIC developed from the 1017 sampled units. The probability of site use by snow leopards ranges from 0 to 0.99.



CLASSIFIED SNOW LEOPARD OCCUPANCY

The occupancy survey results provided an opportunity to upgrade a snow leopard range in Mongolia. The snow leopard range in Mongolian spans along Mongolian's Altai and Gobi Altai Mountain ranges, Trans-Altai Mountains, Khangai Mountain range including Khan Khukhii and Tarvagatai Mountain ranges, and Ikh Soyon range, Khoridol Saridag Mountain in Northern Mongolia (Map 5).

Map 5. Predicted distribution of snow leopard across Mongolia classified according to 4 criteria (High, moderately high, moderately low and least likely probability area used by snow leopards).



Snow leopard range was categorized into 4 classes based on probability of site use by snow leopards.

- High probability area: where the value of the probability of site use by snow leopards are within a range of 0.75 – 1 accounts for 78,000 km² (5% of Mongolian landmass).
- Moderately high probability area: where the value of the probability of site use by snow leopards are within a range of 0.5 – 0.75 accounts for 135,200 km² (8% of Mongolian landmass).
- Moderately low probability area: where the value of the probability of site use by snow leopards are within a range of 0.25 – 0.5 accounts for 230,400 km² (14% of Mongolian landmass).
- Least likely to be used by snow leopards: where the value of the probability of site use by snow leopards are within a range of 0 – 0.25 accounts for the rest of the Mongolian territory.

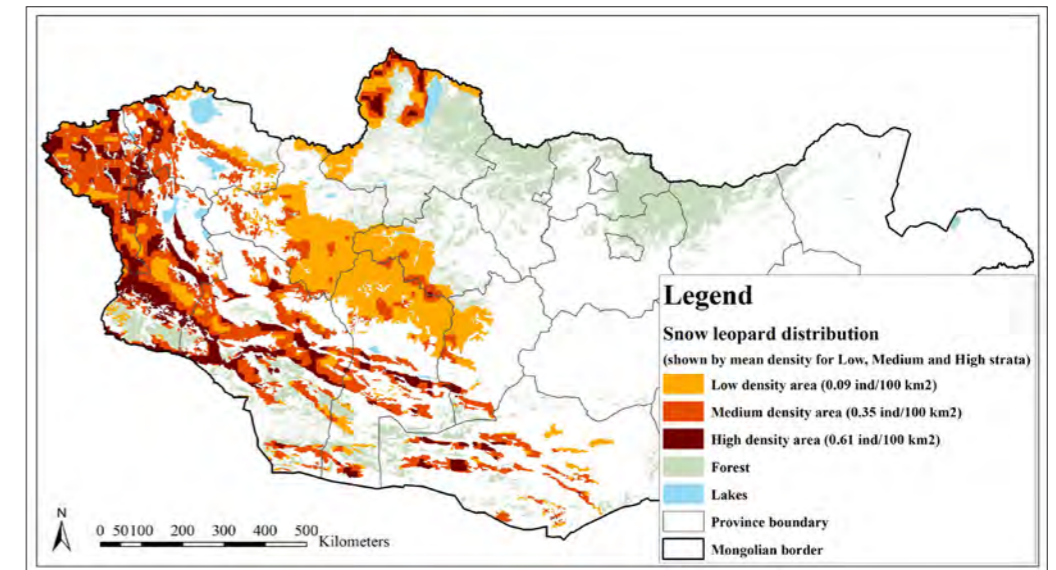
SNOW LEOPARD STRATIFICATION MAP



The probability of snow leopard site use was used to create a stratification of snow leopard density. The stratification of the snow leopard distribution map is based on mean density value estimated from SCR analysis for high, medium and low probability of site use by snow leopard strata and validated by snow leopard signs (Map 6). The three strata were defined by their estimated occupancy, as described above. They comprise:

- **High density area**, which has an estimated mean density of 0.61 individual per 100 km². We consider this area as where we expect a high density snow leopard population.
- **Medium density area**, which has an estimated mean density of 0.35 individual per 100 km² with signs of snow leopard and largely the surrounding area of the High density area. Snow leopard populations are likely to inhabit habitats in this category.
- **Low density area**, which has an estimated mean density of 0.09 individual per 100 km². This habitat is assumed to have a low density snow leopards. This may accommodate snow leopards and likely to be important for the dispersal.

Map 6. Snow leopard distribution map stratification based on the predicted density of snow leopard obtained by SCR analysis for each occupancy strata in Mongolia.



Using above stratification, snow leopards are estimated to cover a total area of 326,617 km², where the high density territory size is 48,290 km², the medium density territory size is 153,840 km² and the low density area size is 124,487 km². All 3 strata of snow leopard density accounts for 21% of Mongolian territory. The snow leopard distribution map from this research is roughly 3 times bigger than a distribution map by McCarthy (2000). The snow leopard distribution in Khangai Mountain range is much larger than on the map depicted by McCarthy, however according to this assessment the density of snow leopards in this area is extremely low with only several pockets of confirmed areas. Moreover, Khoridol saridag and Ulaan Taiga Mountains in Soyon Mountain range, south of the Mongol Altai and Gobi Altai mountain ranges, such as Mountains surrounding Dzungarian gobi, including Takhiin Shar Mountain, Khavtaga Mountain, and south of Gichgene and Edrene Mountains, Shar Khulst Mountain, Jinst Mountain, Ikh Bayan Mountain and Darvi Mountain were identified as snow leopard distribution in this assessment as well.

COUNTRY-WIDE ABUNDANCE OF SNOW LEOPARD

According to our preliminary results, the country-wide snow leopard population was estimated to be 953 (95% confidence interval: 806-1,127) adult snow leopards across the entire snow leopard habitat of 326,617 km² (Table 1). The 95% confidence intervals indicate that the population could be between 806 and 1,127 adult individuals.

Table 1. Preliminary snow leopard population size and density by three strata and country-wide.

Occupancy strata	Density (ind/100km ²)	Total Area (km ²)	Abundance				
			Mean	SE	LCL	HCL	CV
Low	0.09	124,487	116	63.7	42	317	55.1%
Medium	0.35	153,840	544	58.3	442	671	10.7%
High	0.61	48,290	295	28.5	244	356	9.7%
Overall population	0.31	326,617	953	82	806	1127	25%

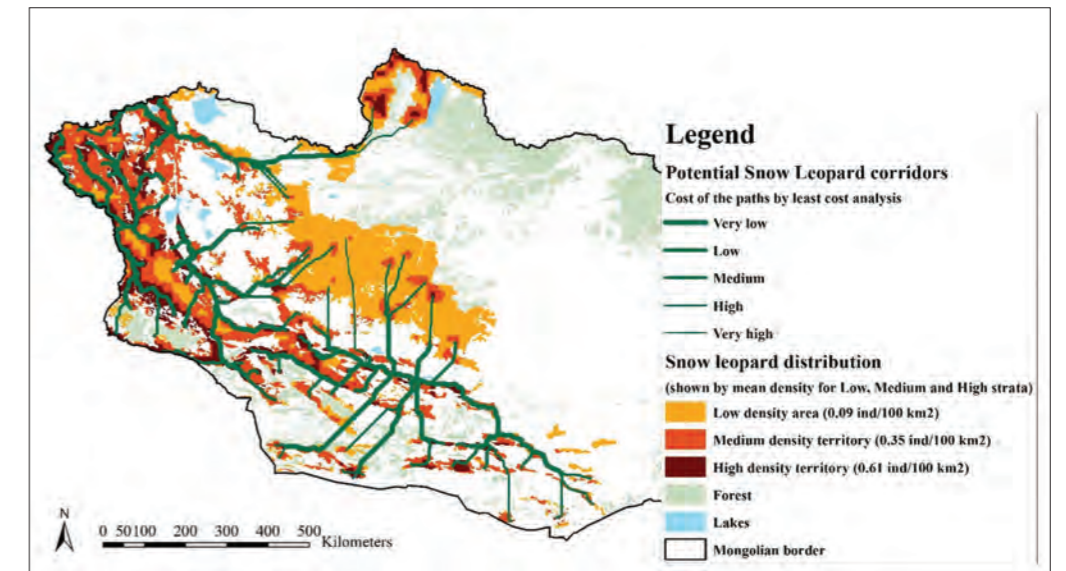
High and medium strata have relatively narrow confidence intervals. These two strata accommodate up to 88% of estimated snow leopard abundance in Mongolia. Higher CV and wider confidence interval in the Low stratum was likely a result of lower number of cameras per 100 km² or much more variable spatial distribution of animals in the low stratum. Nevertheless, although the CV was much higher in the low stratum, this stratum contributes only about 12% to the total abundance estimates.

These results represent the initial analysis based on the models developed from the joint effort between WWF-Mongolia, SLCF and PAWS team (represented by GSLEP, St Andrews University & SLT). The data used for this analysis does not include information from 5 camera trapping sessions from which data is yet to be retrieved. These additional trapping sessions will contribute information from 244 camera trap stations, thus improving our understanding further, especially at low strata. We would also like to clarify that these results must not be used to estimate snow leopard abundance from smaller pockets within the country as that information requires careful modelling of snow leopard density as a function of additional spatial covariates. Given the probability of misidentifying certain individuals which can lead to possible overestimation of abundance, we plan to run additional models that test the use of parameterization that estimates the probability of detecting a snow leopard at least twice, thus minimizing (if not completely eliminating) the possibility of inclusion of ghost individuals in the analysis.

POTENTIAL CORRIDORS FOR THE SNOW LEOPARDS

Corridor for potential dispersal of snow leopards was identified by least cost path analysis. The result identified several potential corridors from Altai Mountain range to Khangai Mountain range with a relatively high cost of crossing the depressions in between two Mountain ranges (Map 7). Distribution of the snow leopard in the south-east part of Altai Mountain range is more fragmented than west-northern part of the Altai Mountain range due to gradual topographic change from high mountainous area to relatively low and isolated mountains to south-east. The potential corridors between such isolated mountains in Southern Mongolia and pockets in Khangai Mountain range was identified.

Map 7. Potential corridors identified by least cost path analysis from the snow leopard distribution map. Most cost effective and less energy required paths are shown in bold green paths, the high cost and energy required paths are shown in thin green paths.



Box 2. Camera trap survey

In total of 85,081 km² area, ranging from 848-12,232 km², were surveyed by 1445 camera traps within the PAW's Guidelines during 2017 and 2020 across the country (Map 1). Over 2 million photographs and short videos were collected using 1445 camera traps over 98,421 camera trap days. A total of which 1401 were of snow leopards. The average period of operation per camera was 68.1±1.46 (SE) days. Average encounters of each individual was 5.85±0.54 (SE) and average camera trap units for each individual recorded was 3.12±0.21 (SE). A total of 240 individuals of adult snow leopard and 89 cubs (up to 2 year old individuals accompanying their mother) were identified in 22 mountains (see Appendix 1). Cubs account for 27% of the individuals detected in the 22 mountains.

INFORMATIONAL VALUE FOR CONSERVATION

The national scale Population Assessment of snow leopards in Mongolia is the largest comprehensive assessment of this elusive species based on reliable scientific data worldwide for the species. The results of the assessment will foster informed decisions on the conservation of the species, notably through the following aspects:

- detailed overview on the current snow leopard population size and distribution in Mongolia,
- establishment of a baseline for future snow leopard population dynamic and changes over time,
- provide decision makers in the area of conservation with information for effective conservation management of snow leopards,
- contribute valuable data to the World Snow Leopard Population Assessment.

We are looking forward to the final set of camera trap data to be gathered from the field and incorporated into this assessment. We also look forward to exploring spatial heterogeneity in snow leopard density, and also address the issue of possible misidentification of certain individuals. We recognize that not taking these issues into account can potentially lead to over-estimation of abundance. This report is the first output of the Mongolia PAWS assessment process. We will continue to refine and work towards a final robust snow leopard national estimate for the 2017-2020 period.

Mongolia is essential to the species survival as it harbors what might be the second largest population of snow leopard in the world, especially in case of proposed subspecies of *P.u. irbis* suggested by Janecka et al., (2017), and may serve as a source population to sustain an isolated and smaller populations in Russia via gene flow of migratory individuals.

Thus, maintaining a healthy transboundary population of the snow leopard along Mongolia and Russian border area, especially in Ikh Soyon Mountain range, Siilkhem, Altai Tavan Bogd and Tsagaan Shuvuut Mountains at the border area is a necessary step. This assessment will contribute to the coordinated management plans of the Transboundary State Protected Areas from each country, thus also supporting the long term viability of snow leopard populations in Russia. The two countries signed a transboundary snow leopard population monitoring programme in January 2021 reiterating the need of obtaining such critical data from the Nationwide Population Assessment of snow leopard of Mongolia and Russia, respectively.

The snow leopard distribution appears to be more fragmented in Southern Mongolia (Gobi region) as it is restricted to isolated mountains and in Khangai Mountain range to only small pockets.

It should however be noted that many mountain areas in the South Gobi are predicted to have a high snow leopard density. Such meta-population geographical and distribution characteristics require snow leopards to migrate between isolated mountains. The identification of the potential corridors between isolated sub-populations is therefore crucial for planning the conservation of the species and maintaining free movement between these populations in Southern and Central Mongolia.

The Nationwide Population Assessment of snow leopards in Mongolia has provided valuable contribution to the development and implementation of PAWS Guidelines. It paves the way for the worldwide Population Assessment of snow leopards by demonstrating best practices and protocols for data collection and for the management of such an assessment. The largest of the 3 landscapes out of 20 that GSLEP is committed to secure are in Mongolia, further highlighting the importance of Mongolian involvement in the conservation of the World's snow leopard population.

The efficient conservation actions demand regular monitoring of this endangered species. Thus it is recommended to repeat the Nationwide Population Assessment of snow leopards on a regular basis, preferably at least once in a snow leopard's average lifespan of 8-10 year. Regular assessments will help conservationists to identify the local and regional extinction and colonization, population health at specific habitats. This will enable conservationists to evaluate ongoing conservation activities, conservation managements, and upgrading current and future conservation strategies.



LITERATURE CITED

Alexander, J. S., Shi, K., Tallents, L. A., & Riordan, P. (2016). On the high trail: Examining determinants of site use by the Endangered snow leopard *Panthera uncia* in Qilianshan, China. *Oryx*, 50(2), 231–238. <https://doi.org/10.1017/S0030605315001027>

Aryal, A., Shrestha, U. B., Ji, W., Ale, S. B., Shrestha, S., Ingty, T., Maraseni, T., Cockfield, G., & Raubenheimer, D. (2016). Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalaya. *Ecology and Evolution*, 6(12), 4065–4075. <https://doi.org/10.1002/ece3.2196>

Bai, D. F., Chen, P. J., Atzeni, L., Cering, L., Li, Q., & Shi, K. (2018). Assessment of habitat suitability of the snow leopard (*Panthera uncia*) in Qomolangma National Nature Reserve based on MaxEnt modeling. *Zoological Research*, 39(6), 373–386. <https://doi.org/10.24272/j.issn.2095-8137.2018.057>

Bold, A., & Dorjzundui, S. (1976). Snow leopards (*Uncia uncia*. Schreber) in southern Gobi-Altai Mountain range. Institute of Biology, Mongolian Academy of Sciences, 11.

Borchers, D. L., & Efford, M. G. (2008). Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics*, 64(2), 377–385. <https://doi.org/10.1111/j.1541-0420.2007.00927.x>

Chetri, M., Odden, M., Sharma, K., Flagstad, Ø., & Wegge, P. (2019). Estimating snow leopard density using fecal DNA in a large landscape in north-central Nepal. *Global Ecology and Conservation*, 17, e00548. <https://doi.org/10.1016/j.gecco.2019.e00548>

DoFPS. (2016). National Snow Leopard Survey of Bhutan 2014 – 2016 (Phase II): Camera Trap Survey for Population Estimation (Vol. 2016, Issue August).

Efford, M. G., Borchers, D. L., & Byrom, A. E. (2009). Density estimation by spatially explicit capture-recapture: likelihood-based methods. In D. L. Thomson (Ed.), *Environmental and Ecological Statistics* (pp. 255–269). Springer Science+Business Media, LLC.

Efford, Murray G. (2020). secr: Spatially explicit capture-recapture models. R Package Version 4.3.1. <https://cran.r-project.org/web/packages/secr/index.html>

Ghoshal, A., Bhatnagar, Y. V., Pandav, B., Sharma, K., Mishra, C., Raghunath, R., & Suryawanshi, K. R. (2019). Assessing changes in distribution of the Endangered snow leopard *Panthera uncia* and its wild prey over 2 decades in the Indian Himalaya through interview-based occupancy surveys. *Oryx*, 53(4), 620–632. <https://doi.org/10.1017/S0030605317001107>

Hameed, S., Ali, H., Kabir, M., Younas, M., Bischof, R., Nawaz, M. A., Trust, S. L., Lumpur, K., Management, N. R., & Nawaz, M. A. (2020). Identifying Priority Landscapes for Conservation of Snow Leopards in. *BioRxiv*, 1–34. <https://doi.org/10.1101/2020.01.27.920975>

Heiner, M. et al. (2017). Identifying Conservation Priorities in the Face of Future Development, Applying Development by Design in the Western Mongolia: Mongol Altai Mountains, Great Lakes Depression and Lakes Valley.

Holt, C. D. S., Nevin, O. T., Smith, D., & Convery, I. (2018). Environmental niche overlap between snow leopard and four prey species in Kazakhstan. *Ecological Informatics*, 48(March), 97–103. <https://doi.org/10.1016/j.ecoinf.2018.09.005>

Johansson, Ö., Rauset, G. R., Samelius, G., McCarthy, T., Andrén, H., Tumursukh, L., & Mishra, C. (2016). Land sharing is essential for snow leopard conservation. *Biological Conservation*, 203, 1–7. <https://doi.org/10.1016/j.biocon.2016.08.034>

Kalashnikova, Y. A., Karnaukhov, A. S., Dubinin, M. Y., Poyarkov, A. D., & Rozhnov, V. V. (2019). Potential habitat of snow leopard (*Panthera uncia*, Felinae) in South Siberia and adjacent territories based on the maximum entropy distribution model. *Zoologicheskii Zhurnal*, 98(3), 332–342. <https://doi.org/10.1134/S0044513419030061>

Li, J., McCarthy, T. M., Wang, H., Weckworth, B. V., Schaller, G. B., Mishra, C., Lu, Z., & Beissinger, S. R. (2016). Climate refugia of snow leopards in High Asia. *Biological Conservation*, 203, 188–196. <https://doi.org/10.1016/j.biocon.2016.09.026>

Mackenzie, D. I., & Royle, J. A. (2005). Designing occupancy studies: General advice and allocating survey effort. *Journal of Applied Ecology*, 42(6), 1105–1114. <https://doi.org/10.1111/j.1365-2664.2005.01098.x>

Mallon, D. (1984). The snow leopard, *Panthera uncia*, in Mongolia. In *International Pedigree Book of Snow Leopards* (Volume 4, pp. 3–10). Helsinki Zoo, Finland.

McCarthy, T. M. (2000). *Ecology and Conservation of Snow Leopards, Gobi Brown Bears, and Wild Bactrian Camels in Mongolia*. University of Massachusetts.

McCarthy, T. M., & Chapron, G. (2003). *Snow Leopard Survival Strategy*. ISLT and SLN.

McCarthy, T. M., & David Mallon. (2016). *Snow Leopards* (Philip Nyhus J., T. M. McCarthy, & D. P. Mallon (eds.); 1st ed., p. 644). Academic Press. <https://doi.org/https://doi.org/10.1016/B978-0-12-802213-9.00068-7>.

Munkhtsog, B., Purevjav, L., McCarthy, T. M., & Bayrakcismith, R. (2016). Northern Range: Mongolia. In N. J. Philip, T. M. McCarthy, & D. P. Mallon

(Eds.), *Snow Leopards: Biodiversity of the world: Conservation from genes to landscapes* (pp. 493–500). Elsevier.

Nowell, K., Li, J., Paltsyn, M., & Sharma, R. (2016). An Ounce of Prevention: Snow Leopard Crime Revisited (Issue October).

Poyarkov, A. D., Munkhtsog, B., Korablev, M. P., Kuksin, A. N., Alexandrov, D. U., Chistopolova, M. D., Hernandez-Blanco, J., Munkhtogtokh, O., Karnaukhov, A. S., Lkhamsuren, N., Bayaraa, M., Jackson, R. M., Maheshwari, A., & Rozhnov, V. V. (2019). Assurance of the existence of a trans-boundary population of the snow leopard (*Panthera uncia* Schreber, 1776) at Tsagaanshuvuut – Tsagan-Shibetu SPA at the Mongolia-Russia border. *Integrative Zoology*, 1–18. <https://doi.org/10.1111/1749-4877.12420>

Riordan, P., Cushman, S. A., Mallon, D., Shi, K., & Hughes, J. (2015). Predicting global population connectivity and targeting conservation action for snow leopard across its range. *Ecography*, 38, 001–008.

Robertson, B. L., Brown, J. A., McDonald, T., & Jaksons, P. (2013). BAS: Balanced Acceptance Sampling of Natural Resources. *Biometrics*, 69(3), 776–784. <https://doi.org/10.1111/biom.12059>

Robertson, B., McDonald, T., Price, C., & Brown, J. (2018). Halton iterative partitioning: spatially balanced sampling via partitioning. *Environmental and Ecological Statistics*, 25(3), 305–323. <https://doi.org/10.1007/s10651-018-0406-6>

Schaller, G. B., Tserendeleg, J., & Amarsanaa, G. (1994). Observations on snow leopards in Mongolia. *Seventh International Snow Leopard Symposium*, 7:33-42.

Sharma, K., Borchers, D., Mackenzie, D., Durbach, I., Sutherland, C., Nichols, J. D., Lovari, S., Zhi, L., Khan, A., Modaqiq, W., McCarthy, T., Alexander, J. S., & Mishra, C. (2019). Guidelines for estimating snow leopard abundance and distribution using a combination of spatial capture-recapture and occupancy models. In Submitted to the Steering Committee of the Global Snow Leopard and Ecosystem Protection Program. *Global Snow Leopard and Ecosystem Protection Program*. <https://doi.org/10.1017/CBO9781107415324.004>

Suryawanshi, K. R., Khanyari, M., Sharma, K., Lkhagvajav, P., & Mishra, C. (2019). Sampling bias in snow leopard population estimation studies. *Population Ecology*, 61(3), 268–276. <https://doi.org/10.1002/1438-390X.1027>

Taubmann, J., Sharma, K., Uulu, K. Z., Hines, J. E., & Mishra, C. (2016). Status assessment of the Endangered snow leopard *Panthera uncia* and other large mammals in the Kyrgyz Alay, using community knowledge corrected for imperfect detection. *Oryx*, 50(2), 220–230. <https://doi.org/10.1017/S0030605315000502>

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APPENDIX

Appendix 1. Mountains surveyed by camera traps according to the PAWS Guidelines. Data from these mountains used for the nationwide snow leopard population assessment of Mongolia. *cubs are up to 2 years old who are travelling with their mother.

Mountain (site)	Survey Area Size (km ²)	Date surveyed	Number camera traps	Number of snow leopard captures	% captures successfully identified	Number of individuals identified from the photos		Organization
						Adult snow leopards	Cubs*	
Munkh Khairkhan	7,599	May 2017 - Sep 2017	102	54	92%	19	4	WWF-Mongolia
Uyench	3,325	Oct 2017 - May 2018	29	94	100%	10	0	WWF-Mongolia
Tsagaan Shuvuut	2,515	May 2018 - Sep 2018	62	53	97%	6	2	WWF-Mongolia
Siilkhem B	4,535	May 2018 - Sep 2018	22	43	96%	10	2	WWF-Mongolia
Khoridol Saridag	3,003	Feb 2019- Jun 2019	43	3	100%	1	0	WWF-Mongolia
Kharkhira-Turgen	6,809	June 2019- Sept 2019	230	67	100%	12	8	WWF-Mongolia
Sair-Khatuu	2,658	June 2019- Sept 2019	82	44	100%	7	2	WWF-Mongolia
Darvi	1,776	June 2019- Sept 2019	59	18	96%	6	1	WWF-Mongolia
Khasagt Khairkhan	4,754	June 2019- Sept 2019	114	87	98%	15	7	WWF-Mongolia
Khuvch	5,862	July 2020 - Oct 2020	73	43	95%	13	6	WWF-Mongolia
Khan Khukhii	3,144	July 2020 - Oct 2020	34	1	100%	1	0	WWF-Mongolia
IkhSoyon	12,232	June 2020 - Sep 2020	138	18	100%	2	0	WWF-Mongolia
Baatar Khairkhan	2,333	Sep 2016 - May 2017	68	94	89%	17	5	WWF-Mongolia
Baruun Shiluustei	4,882	June 2020 - Sep 2020	32	11	100%	2	3	WWF-Mongolia
Tarvagatai	5,691	June 2020 - Sep 2020	31	0	-	0	0	WWF-Mongolia
Jargalant Khairkhan	848	Sep 2014 - May 2015	40	163	94%	15	10	WWF-Mongolia
Tsambagarav	2,325	Oct 2017 - May 2018	45	35	92%	7	1	WWF-Mongolia
Altan/Nemegt/Gilbent/Siverej	1,738	May 2018- Aug 2018	40	118	99%	18	9	SLCF/SLT
Noyon	1,440	Nov 2017- Feb 2018	41	78	94%	17	4	SLCF/SLT
Tost	2,185	Sep 2019- Jan 2020	40	190	96%	22	18	SLCF/SLT
Zuulun	1,225	Jun 2019- Sep 2019	20	45	82%	13	6	SLCF/SLT
Gurvansaikhan	2,500	Mar 2019- May 2019	55	141	84%	26	1	SLCF/SLT
Great Gobi Strictly Protected Area	1,702	Mar 2020- May 2020	45	1	100%	1	0	SLCF/SLT
Total	85,081		1,445	1,401	96%	240	89	

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