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POTENTIAL HABITAT OF SNOW LEOPARD (*PANTHERA UNCIA*, FELINAE) IN SOUTH SIBERIA AND ADJACENT TERRITORIES BASED ON THE MAXIMUM ENTROPY DISTRIBUTION MODEL

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The snow leopard is an endangered large felid inhabiting highlands of 12 Asian countries. It is distributed across vast territories and adequate modern methods are required for mapping its potential habitats. The goal of the present study is to create a model of snow leopard potential habitat within the northern part of its range in Russia (and adjacent territories of Mongolia, China and Kazakhstan). More than 5 years of observations (total number of presence points = 449), environmental variables and the maximum entropy distribution method (Maxent) are used. The resulting map demonstrates that a suitable habitat (probability of the animal's presence between 0.5 and 1) of the northern population of snow leopard in Russia occupies 16 500 km^2 with a buffer of transient territories (probability between 0.25 and 0.49) covering 32 800 km^2. Most of a suitable habitat within the study area is associated with the Altai Mountains, Western Sayan Mountains, Sangilen Plateau, Tsagan-Shibetu and Shapshal. One third of the suitable habitat lies within areas of a varying protection status. The results of modeling are of importance both for scientists and conservation managers, as they allow for leopard occurrence to be predicted, supporting research on and the conservation of the species.

Keywords: Snow leopard, irbis, *Panthera uncia*, Maxent, habitat model, potential habitat

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The snow leopard, or irbis (*Panthera uncia*, previously *Uncia uncia*) is a large felid of the alpine and subalpine zones of Central Asia (Jackson, Hunter, 1996). Its highly fragmented habitats are scattered across an area of more than 1.6 million km^2 in 12 different countries (Fox, 1994; Jackson, Hunter, 1996) and mainly include steep, rocky rugged terrain with slopes exceeding 30–40 degrees (McCarthy, Chapron, 2003) with arid and semi-arid shrubland, grassland, steppe vegetation or, more rarely, sparse forests (Nowell, Jackson, 1996). Snow leopard is usually found at altitudes of 3.000–4.500 m (extremes are 5.500 m in the Himalayas and 600–1.500 m in the Sayan Mountains in Russia) (Nowell, Jackson, 1996), favoring slopes with 130°–200° expositions (Jackson, Ahlborn, 1984). Abundant snowfalls and permanent snowfields are unsuitable for snow leopard, rendering certain areas physically inaccessible for it either permanently or during the wintertime (Hunter, Jackson, 1997; Poyarkov et al., 2002a). Low winter temperatures and flat terrain also have been noted as factors limiting the distribution at the eastern limit of the species' range (Poyarkov et al., 2002a).

A number of publications (Fox, 1994; Jackson, 2012; Jackson, Fox, 1997; Jackson, Hunter, 1996; McCarthy, Chapron, 2003; Nowell, Jackson, 1996; Poyarkov et al., 2002) mention numerous persistent threats to snow leopard populations. The main are poaching (both hunting and trapping) of snow leopards and their prey; killing in snow leopard-livestock conflicts; habitat degradation and fragmentation due to livestock grazing and associated disturbance; an inadequate network of existing protected areas (PA); habitat loss due to the growth of polymetal–mining industry and other factors.

Presently, the snow leopard is classified as vulnerable C1 by the IUCN (International Union for Conservation of Nature) (http://www.iucnredlist.org) and included into Appendix I of CITES (1975). It is hard to assess precisely the total snow leopard population size due to its cryptic nature and remote habitats it uses (Nowell, Jackson, 1996). Estimates range greatly between 4510 and 7350 individuals (Fox, 1994), only 110–150 of them inhabiting Russia over an area of 58.000 km^2 (Poyarkov et al., 2002b).

A number of researchers have assessed snow leopard potential distribution ranges both at the global (Fox, 1994; Green, 1987; Hunter, Jackson, 1997; Jackson, 2002; Williams, 2006) and local levels (Forrest et al., 2012; Jackson, Ahlborn, 1984; McCarthy et al., 2010; Poyarkov et al., 2002a), using increasingly complex methods, from GPS tracking and camera-trapping to DNA analysis. The general map of snow leopard potential range created by Hunter and Jackson (1997) was based on expert evaluations of environmental parameters. For Russia, the most recent map of snow leopard distribution was developed by a group of experts who assessed the habitat suitability using a range of different methods, e.g. landscape mapping, orographic schemes etc. (Lukarevskiy, Poyarkov, 2007; Paltsyn et al., 2012; Poyarkov et al., 2002a). All these methods have a number of limitations, such as inability to account for a variety of environmental parameters that influence snow leopard populations. Some modeling methods used were rather subjective (Poyarkov et al., 2002a; Lukarevskiy, Poyarkov, 2007).

This work is aimed at creating a precise map of potentially suitable and transient habitats for the snow leopard within the northern part of its range (Russia and the adjacent regions of Mongolia, China and Kazakhstan) and comparing the existing potential suitability map to the current PA network; determining the real and exact borders of snow leopard optimal habitats in various places of its western part across the territory of Russia; analyzing the correspondence of PA to the optimal habitat structure, contributing to an enhancement of snow leopard conservation efforts. We used 449 presence points collected during 5 years of field work, environmental data and employed a machine-learning method of species distribution modeling (Maxent (maximum entropy)) (Elith et al., 2006; Elith et al., 2011).

We used Maxent for the following reasons. The Maxent model requires only presence data while absences are pseudo-absences (sampled randomly), being less restrictive than for example in logistic regression modeling, where absence data should be real absences. Maxent predictions have proved to better discriminate suitable versus unsuitable areas for different species than more common presence-only modeling methods, such as Genetic Algorithm for Rule-Set Prediction (GARP) tested against real pres./abs. data (Elith et al., 2006). Maxent explores complex relationships with the environment (but does not retain ALL of the complex relationships). Maxent is a generative, but not discriminative model, thus being appropriate for small data sets.

In addition, we discuss the influence of environmental parameters on the species distribution and select the main variables that affect the distribution of the snow leopard.

MATERIALS AND METHODS

We obtained snow leopard occurrence data during several seasonal expeditions between 1998–2000 and 2010–2012. The total length of the routes covered was 3.113 km and all of them lie between 52° N and 84° E and 49° N and 99° E (southern Siberia). We collected data during animal tracking, camera-traps data (only the 2010–2012 period) and information provided by local observers (only in 2 cases for the 1997–2000 period). Coordinates of located tracks, scrapes, excrements and scent mark locations were grouped into a table. It also includes coordinates of the camera-traps that registered snow leopards. Coordinates were recorded using GPS devices (Garmin GPSMAP 60CSx, Garmin 12XL and eTrex) with 3–15 m accuracy. In order to minimize distortion and overlay the data with environmental variables during further analysis, we transformed the coordinates from datum WGS 1984 into Albers equal-area conic projection for Siberia. The total number of presence points is 449.

Ripley's K-function was used to estimate the pattern of spatial distribution (clustered or not) (Ripley, 1976) by comparing the density of observed points on different scales with a theoretical random distribution. The confidence interval for the expected theoretical distribution was calculated by running 100 Monte Carlo simulations. The results demonstrated that observed function values were much greater than the upper bound of the confidence interval, which meant that the observed sample was clustered.

We employed the fixed kernel smoothing method to correct the observation bias. This allowed us to calculate a utilization distribution, i.e. the allocation of an animal's position on the plane (Worton, 1989). This method transforms presence points into a continuous surface, where every point is assigned a value of probability density, the highest in the areas with the highest concentration of observations. A smoothing parameter was determined based on the method of least squares cross validation (LSCV), which minimizes the integrated least square error between the true and estimated distribution (Horne, Garton, 2006).

We considered a 95% confidence region of utilization distribution (removing "outliers", i.e. incidental animal relocations) to be habitat range (Worton, 1987). Ten isopleths obtained had an area between 129 and 1.203 km^2. Approximate calculations of individual leopard's home range made by McCarthy, Fuller and Munkhtsog (2005) gave the result of 14–1590 km^2 for habitat range size, which was estimated using minimum convex polygons with 75% core activity isopleths yielding 11–585 km^2. Thus, based on the conservative minimum range number, we automatically sampled one point every 6 km within the computed home range borders to confirm that we had obtained at least 3 points from each territory we visited, but had not exceeded the initial number of sampled points. The process produced 203 presence points in total.

All calculations were made in R software environment (version 3.0.1). Packages: spatstat (Baddeley, Turner, 2005), rgdal (Bivand et al., 2013), adehabitatHR (Calenge, 2006), maptools (Bivand, Lewin-Koh, 2013) and sp (Pebesma, Bivand, 2005).

For habitat modeling, we selected 15 environmental variables of three different types (Table 1). The first type are climatic variables (data were available for different periods): percentage snow cover for the period 2000–2011 (monthly average and maximum); type of cover, e.g. snow, water, ice or bare ground for the period 2006–2011 (monthly); mean monthly temperature and annual precipitation (~1950–2000). The second type included physiographic variables (time-constant): elevation, slope, aspect, topographic ruggedness index, distance to water sources, pattern of tree, shrub and bare ground distribution, and forest type. The third type comprised elements of infrastructure (also considered temporally constant): distance to roads and settlements.

All variables were obtained for the whole world or for Eurasia and stored in GRID format in Albers equal-area conic projection for Siberia. Prior to analysis in Maxent they were converted into ASC files with unified cell size and extent using Geospatial Data Abstraction Library (GDAL) run via python scripts. The pixel size in our study is 250 m.

Study area

Our model estimated a potential geographic distribution of snow leopard between 52° N and 84° E and 49° N and 100° E (~0.5 million km^2) or the western and central parts of the northern snow leopard range in Russia (Fox 1994) within the Altai, Sayan and Tannu-Ola mountains including: Southern Siberia (Altai krai, Kemerovskaya oblast, Krasnoyarsky krai, Altay Republic, Tuva Republic, Khakassia Republic), adjacent territories of China (partially Xinjiang Uyghur Autonomous Region), Mongolia (partially Bayan-Ölgii, Zavkhan, Khovd, Khövsgöl, Uvs aimags) and Kazakhstan (East Kazakhstan oblast). The analysis did not include the Eastern Sayan, since we did not collect data there.

The north-eastern part of the snow leopard range in Russia was not included in the present study, since data were collected neither in that area nor its vicinity. So Maxent did not have full information about the whole variability of leopard environmental preferences; this could have led to assigning much lower probabilities to habitats that were partially different (NE part), although several authors (Matyuchkin, 1984; Medvedev, 1990) indicate that territories lying east of our study area (Republic of Buryatia and Zabaykalsky Krai) are also inhabited by the snow leopard.

Climate of the area is arid and semi-arid with maximum precipitation (~165 mm) and temperature (+23°C) in July–August and minimum (less than 40 mm and –35°C) in January–February (Hijmans et al., 2005).

Vegetation varies from semi-deserts and steppe in the south to complex ecosystems associated with different altitudinal belts in the northern part of the study area with a mosaic of deciduous and evergreen coniferous forests, deciduous broadleaf forests, sedge and shrub alpine tundra and barren land culminating in glaciers on some mountain tops.

Though altitudes of the study area vary from 200 (north of the Altai Mountains) to 4506 m (Belukha Mountain), most of the territory elevated higher than 1400 m with prevailing altitudes of 2500–3500 m in combination with extremely rugged relief (Riley et al., 1999).

The territory encompassed 25 PAs (~17% of the study area) of different categories including UNESCO world heritage sites (Uvs Nuur Basin and Golden Mountains of Altai) and Biosphere Reserves (IUCN, UNEP, 2013).

Modeling

The method used for distribution modeling was maximum entropy distribution (Maxent), a machine learning algorithm that approximates the unknown true distribution of a species through probability distribution of maximum entropy, which is limited only by occurrence data, expressed as simple functions of the environmental variables called "features" (Phillips, Dudík, 2008). E.T. Jaynes gave a general answer to this question: "the best approach is to ensure that the approximation satisfies any constraints on the unknown distribution that we are aware of, and that subject to those constraints, the distribution should have maximum entropy" (Jaynes, 1957).

Freely distributed Maxent 3.3.3k software was used for calculations (http://www.cs.princeton.edu/~schapire/maxent/). It allowed control of input feature types and a number of other model settings ("regularization parameters"), preventing matching the input data too closely – "overfitting". In particular, to avoid overfitting, which can occur due to use of complex feature classes and thus requiring more regularization, use of features was restricted to hinge (similar to a continuous variable, but constant below a certain threshold, e.g. below sample values), threshold features (binary "feature" with 1 assigned to values above threshold) and category indicators (categorical variables with each category converted into separate binary feature) (Phillips, Dudík, 2008).

10000 background points (Maxent default) or "pseudo-absences" were sampled across the analyzed

Table 1. Environmental data used for the snow leopard potential distribution modeling

No.	Variable	Producer/Product	Source
1	Aspect, degrees	Aspect (Spatial Analyst tool in ArcGIS[a] 10.1) based on SRTM[b]	Jarvis et al., 2008
2	Bare land, per cent	MODIS[c] VCF[d]	Hansen et al., 2003
3	Elevation, meters	SRTM	Jarvis et al., 2008
4	Forest type, contains 29 categories	GLC 2000[e]	Bartalev et al., 2003
5	Mean annual temperature, °C × 10	Global Climate Data	Hijmans et al., 2005
6	Precipitation, mm	(WorldClim): current conditions	Hijmans et al., 2005
7	Roads proximity, km	Global Climate Data (WorldClim): current conditions	OSM[f]
8	Settlements proximity, km	Euclidean distance (Spatial Analyst tools in ArcMap 10.1): road layer buffer for main roads (5 km), secondary roads (2 km) and other roads (1 km)	OSM
9	Shrub cover, per cent	MODIS VCF	Hansen et al., 2003
10	Slope, degrees	Slope (Spatial Analyst in ArcMap 10.1) based on SRTM	Jarvis et al., 2008
11	Snow cover, categories: snow, ice, water, ground	IMS[g] at 4 km Resolution Mode chosen using Cell Statistics (Spatial Analyst in ArcMap 10.1)	National Ice Center, 2008
12	Snow cover, per cent of pixel covered	Based on MODIS/Terra Snow Cover Monthly, 0.05 degree resolution, Version 5. Averaged using Cell Statistics (Spatial Analyst in ArcMap 10.1)	Hall et al., 2006
13	Topographic Ruggedness Index (TRI), m	Raster Calculator (Spatial Analyst in ArcMap 10.1) based on SRTM Equation used: SquareRoot(Square(max3 * 3) – Square(min3 * 3)), where max3 * 3 and min3 * 3 were calculated in Focal Statistics for 3 * 3 nearest neighbors as maximum and minimum respectively	Riley et al., 1999
14	Tree cover, per cent	MODIS VCF	Hansen et al., 2003
15	Water bodies proximity, m	Euclidean distance (Spatial Analyst tools ArcMap 10.1) based on HydroSHED[h] for Asia at the scale of 15 seconds	Lehner et al., 2008

[a] A software. for working with maps and geographic information.
[b] Shuttle Radar Topography Mission that obtained digital elevation model on a global scale.
[c] Moderate-resolution Imaging Spectroradiometer onboard of the TERRA Satellite.
[d] Vegetation Continuous Fields.
[e] Global Land Cover.
[f] OpenStreetMap project aiming to create a free editable maps.
[g] Daily Northern Hemisphere Snow and Ice Analysis.
[h] Hydrological data and maps based on Shuttle elevation derivatives.

area automatically. They provide a sample of conditions available to the species within the study region (Phillips et al., 2009). A number of 5.000 iterations of the algorithm were chosen in order to give the model time to converge (Young et al., 2011).

Predictive performance of the distribution model obtained was estimated using cross-validation. Data were separated into 15 equal folds of training (14 folds) and test points (1 random fold), creating semi-independent data sets, different for each of 15 independent runs. Thus, during replicate runs it uses all the sample data present to test prediction reliability and gives an opportunity to measure the amount of variability in the model (Young et al., 2011). The rest of Maxent software settings were kept as default, pre-tuned and validated over a wide range of datasets (Phillips, Dudík, 2008). Algorithm default output format is logistic. It gives an estimate of the species probability presence across the whole area analyzed ranging from 0 (lowest probability) to 1 (highest probability). Within these extremes the areas with 0.5 and higher probability of presence were considered suitable or core animal habitat, where the animal may be found with 50% chance or higher, while the areas with probability of occurrence between 0.49–0.25 – transient, e.g. encountering an animal there is possible but not very plausible.

RESULTS

The resulting model of potential habitat showed suitable territories occupying 16500 km^2 (3.3% of the study area) with transient territories covering 32800 km^2 (6.6%) and in most cases forming ~10 km buffer around the core habitat (see Fig. 1).

Most of the suitable habitat modeled for the study area is found within Russian territory: Altai Republic, Tuva Republic and, occasionally, in Krasnoyarskiy kray (Altai Mountains, the Western Sayan Mountains, Sangilen Plateau, Tsagan-Shibetu, Shapshal). Several clusters are shown in the boundary zone of Mongolia – Bayan-Olgii and Uvs aimag. At the same time, boundary zones of Xinjiang-Uyghur Autonomous Region in China and East Kazakhstan oblast in Kazakhstan have much smaller areas occupied by such habitats (Figure 1). This general pattern is also correct for transient habitat with an exception of several small patches that form, in some cases, corridors between core areas in Tuva Republic and Altai Republic in Russia (the Alashskoe Highlands, the Tannu-Ola Mountains, the South-Western Sayan Mountains).

Roughly 7.000 km^2 (40%) of the area found suitable by our analysis was previously marked as current snow leopard habitat by other researchers (Lukarevskiy, Poyarkov, 2007). Most of these territories (~6.600 km^2) overlapped with the habitats of Argut, Kuray, Shapshal and Sangilen snow leopard sub-populations in the Altai and Tuva, while the patch in the Western Sayan Mountains, predicted by our model, has very limited similarity (overlap of ~100 km^2) with the territory of West-Sayan grouping indicated in previous researches (Lukarevskiy, Poyarkov, 2007). Likewise, ~9.000 km^2 of transient habitat was enclosed by Argut, Kuray, Shapshal and Sangilen groupings habitat, but with considerable areas falling within West-Sayan and Tannu-Ola groupings areas (500 km^2 each).

The overall suitable habitat encompassed by the protected areas comprises 5.100 km^2 (31%): ~3.400 km^2 (21%) within high-ranking IUCN categories (I and II) and ~1.700 km^2 (10%) within other protected areas. Namely, those high-rank PA are: Altai Tavan Bogd and Uvs Nuur Basin (Turgen and Tsagan-Shuvuut clusters) in Mongolia; and Ubsunurskaya Kotlovina (Mongun-Taiga cluster), Zona pokoya Ukok, Sayano-Shushensky Zapovednik and Saylugem National Park in Russia. However, three large protected areas with high protection status (Altaisky and Khakassky Zapovedinks along with Pozarym Federal Nature Refuge) hardly overlap with predicted potential habitat. At the same time only ~9.000 km^2 (28%) of the transient habitat is enclosed by the borders of PAs of all types with approximately 50/50 distribution among the areas of different status.

The average test AUC for 15 replicate runs was 0.93 with the standard deviation of 0.02, which indicated that the model predictions were significantly better than random, e.g. 0.5 (Phillips et al., 2006). The drop in AUC (normalized to percentages) as a result of permutation of values of individual variables was used as a variable importance indicator. The analysis showed that the resulting model was not critically influenced by any of the stand-alone variables. Among those environmental variables which had provoked a certain change in model, when considered together, were winter (30%) and spring (14%) precipitation. The other marginally influential variables were elevation (7%), average snow cover in March (5%), relief ruggedness (4%) and temperature in January (4%). The impact of the remaining variables on the model was almost negligible.

DISCUSSION

Snow leopard potential range is one of the key parameters of the species ecology and the importance of its adequate and detailed evaluation for scientific research and protection endeavors is hard to underestimate. In previous years, attempts to estimate the potential habitat of the snow leopard in Russia on the basis of landscape maps (Poyarkov et al., 2002a) and orographic schemes (Lukarevskiy, Poyarkov, 2007) have already been made. The main parameters considered were ruggedness, elevation, vegetation and soil types, while such parameters as snow depth or precipitation were omitted. Taking into account the limitations of both the methods used in the past and the data

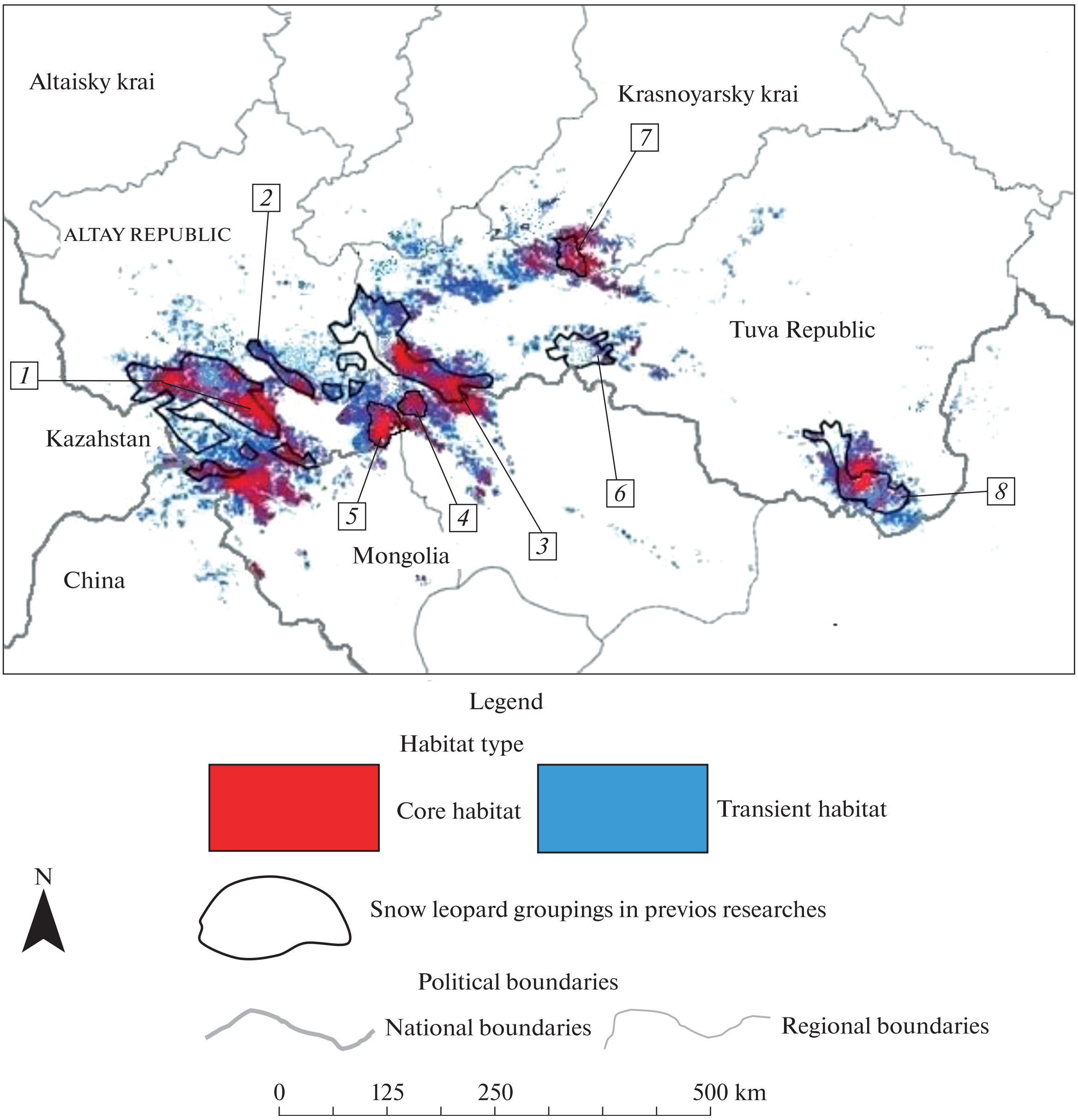

Fig. 1. Map of snow leopard potential habitat nuclei overlapped with previously indicated existing groupings (marked by numbers) according Poyarkov et al., 2002 with same changing. The numbers of groupings: *1* – Argut river and Uzhno-Chuyskiy ridge, *2* – Kurayskiy ridge, *3* – Shapshal and Tsagaan-Shibetu mounting, *4* – Big Mongun-Tayga mounting, *5* – Chihacheva ridge, *6* – Tannu-Ola ridge, *7* – West Sayan ridge (Sayano-Shuchenskiy zapovednik), *8* – Sangylen mounting.

available, we tried to improve the analysis by adopting a different modeling technique and using broader set of variables (Table 1). Additionally, we added new snow leopard occurrence data, collected between 2010 and 2012, approximately within the same territories as the data from 1998–2000 (used for the previous habitat estimations), excluding Sayano-Shushensky Zapovednik, which was incorporated in our survey for the first time.

According to our analysis, potentially suitable (core) habitat for snow leopard in Russia comprises 12 500 km^2. This number appears to be much smaller than the 28 500–60 000 km^2 previously estimated by Poyarkov et al. (2002a) and Lukarevskiy and Poyarkov (2007), but is twice as large as the 6.000 km^2 shown by Paltsyn and colleagues (2012) (if Eastern groupings in Okin and Tunkin Ridges are excluded). In this context our model can be considered rather conservative, though it is important to note that our results, in addition to core habitats, also highlight 33 000 km^2 of possible transient areas – supposedly suitable for the leopard short-term occupation. These territories mostly surround suitable habitats as buffers or form "transitional corridors" (e.g. Tannu-Ola and Western Sayan mountain ranges) between them, which animals can use for relocation.

Suitable areas in the adjacent regions of the neighboring territories were found to be smaller than expected. The core habitat in Eastern Kazakhstan comprises 131 km^2 and falls completely within the borders of Katon-Karagaisk Nation Park. This area, as we believe, is part of territory that belongs to the snow leopard population nucleus in the Central Altai Mountains. Small isolated groupings (211 km^2 in total) within the study area were also found in the north of Xinjiang (China), mostly in highlands, together with the South Altai and Mongolian Altai Mountains. In Mongolia, suitable habitat encompassed within the study area is also found in the Mongolian Altai Mountains and to the south-east from Saylyugem Mountain Range (with some other – smaller – areas, its size adds up to 3.688 km^2). It is important that the core area within Uvs Nuur Basin Strict Protected Area (Tsagan-Shuvuut cluster) is closely connected with the sub-population in Russia (in Tsagan-Shibetu Mountain Range), which is one of the main population "contributors" for Tuva, with a high density of snow leopards (Munkhtsog et al., 2014). Snow leopards from this sub-population enter Russian territory frequently, thus placing this area into focus of trans-boundary protection. Chichacheva Mountain Range is another suitable trans boundary area for the leopard which also remains unprotected.

The pattern of suitable leopard habitat which falls within our study area was also corrected. According to our estimations, suitable and transient habitat in Russia overlap, in general, with the previously produced range maps, but show a number of mismatches in previous works. In particular, core areas in the West-Sayan Mountains, such as upper reaches of Maliy Abakan river, Sailyg-Khem-Taiga Ridge, north-west of Kantegirskiy Mountain Ranges, are not suitable for snow leopard, as we previously believed, but serve only as transit areas.

The influence of such environmental parameters as elevation, ruggedness, land-cover and distance to water, despite being noted as major factors of leopard potential distribution in other Maxent models (Li et al., 2014; Mondal et al., 2013), in the present study were not so important as cumulative precipitation in winter and spring. Such impact of precipitation in February and March might be explained by the fact that during that period snow leopard comes into estrus and actively moves around its territory and beyond (Geptner, Sludskiy, 1972). Consequently, abundant snowfalls in late winter – beginning of spring may become an obstacle for relocation. Such important variable as May precipitation may determine the fact that in May cubs are born, and depending on other parameters (such as temperature or elevation), precipitation can play both negative and positive roles (as general productivity of ecosystem in late spring and summer grows). At the same time, possible influence of December precipitation and January temperature cannot be exactly defined and might be influenced by numerous factors (e.g. prey status and relocations restriction at the beginning of winter).

Elevation and ruggedness, though proving less influential in our model than precipitation, still had a certain impact on the outcome. From the ecological standpoint this can be explained by the fact that rugged highlands, apart from offering a unique set of biotic and abiotic conditions (geomorphology, vegetation, wind and water regimes etc.), also make it difficult for people to access the area, thus decreasing disturbance. Stressing anthropogenic pressure in connection with altitudes as a special environmental factor is enhanced by the fact that the snow leopard may inhabit relatively low altitudes (from 560 to ~2000 m) in the northern limit of its range, if a sufficient level of territory protection is ensured.

Currently only 1/3 of snow leopard's potential habitat overlaps with Protected Areas of different status. (see Table 2). Thus, the following large territories, potentially suitable for leopard, still remain outside Protected Areas: Yuzhno-Chuiskiy Ridge; Tchikhatcheva ridges, Tsagan-Shibetu and Kurtushibinskiy Ridge (Idgir Ridge). These spots can be included in several existing neighboring PAs through revision of their borders, creation of additional clusters (Altaysky Zapovednik, Sayano-Shushensky and Ubsunurskaya Kotlovina). Additionally, though one of the most significant and important parts of the potential habitat is located on the territory of the Sayano-Shushensky Zapovednik, according to our analysis, that habitat stretches farther to the right bank of the Yenisei river and, though it is even bigger than suitable spot within Sayano-Shushensky Zapovednik, it still remains unprotected. It is also important to create a PA on the Sangilen Plateau in South-Eastern Tuva, which is currently lacking any means of leopard protecting.

Our model demonstrates the optimization of PA necessity over snow leopard range on the territory of Russia. Establishment of PA territories in Sangilen mountains is crucially important.

It seems significant that environmental factors affecting potential leopard distribution in our model, are very much different from those we expected e.g. no anthropogenic factors were shown to be directly influencing habitat suitability.

Supporting Information

The share of suitable and transient habitat encompassed by different protected areas (Table 2) is available online.

Table 2. The share of suitable and transient habitat encompassed by different protected areas

Name	Designation	IUCN[a] category	Core habitat[b], sq. km	Transient habitat[c], sq. km
Zona pokoya Ukok	Nature Park[d]		562	1154
Shavlinskiy	Wildlife Refuge[e]	IV	603	982
Hanasi	Natural Landscape[f]	V	135	930
Uvs Nuur Basin	Strict Nature reserve[g]	Ia	592	722
Altaysky	Zapovednik[h]	Ia	28	691
Sayano-Shushensky	Zapovednik[h]	Ia	538	643
Altai Tavan Bogd	National Park[i]	II	750	605
Ak-Cholushpa	Nature Park		37	595
Pozarym	National Wildlife Refuge[j]	IV	19	442
Katon-Karagaisky	National Park	II	130	382
Sailyugemskiy	National Park	II	436	295
Ubsunurskaya Kotlovina (Khan-Deer)	Zapovednik	Ia	140	239
Sylkhemyn nuruu	National Park	II	479	420
Shuyskiy	Nature Park		350	169
Katunsky	Zapovednik	Ia	15	162
Sailyugemskiy (Saylyugem)	National Park	II	188	147
Ubsunurskaya Kotlovina (Kara-Khol)	Zapovednik	Ia	5	101
Ubsunurskaya Kotlovina (Mongun-Taiga)	Zapovednik	Ia	77	63
Tsambagarav mountain	National Park	II	25	50
Uch Enmek	Nature Park		0	35
Khan-Khokhi Khyargas	National Park	II	0	30
Khakassky (Maliy Abakan)	Zapovednik	Ia	0	21
Khakassky (Zaimka Lykovykh	Zapovednik	Ia	0	16
Ubsunurskaya Kotlovina (Ular)	Zapovednik	Ia	0	15
Sailyugemskiy (Ulandryk	National Park	II	0	13
Total area			5109	8922

[a] International Union for Conservation of Nature.
[b] The areas where the probability of the snow leopard presence is between 0.5 and 1.
[c] The areas where the probability of the snow leopard presence is between 0.25 and 0.49.
[d] Protected landscape.
[e] Area designated for wildlife protection.
[f] Protected landscape (in China).
[g] Protected area, where minimum of the human activity is allowed.
[h] Protected area, where almost all human activity is prohibited (in Russia).
[i] Protected area, designated for ecosystem preservation.
[j] Area designated for wildlife conservation, protected by national law (in Russia).
[k] Protected area, designated for wildlife, flora, fauna or other natural components preservation, where scientific research is allowed.

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ПОТЕНЦИАЛЬНЫЕ МЕСТА ОБИТАНИЯ СНЕЖНОГО БАРСА (*PANTHERA UNCIA*, FELINAE) В ЮЖНОЙ СИБИРИ И НА СОПРЕДЕЛЬНЫХ ТЕРРИТОРИЯХ НА ОСНОВЕ МОДЕЛИ РАСПРЕДЕЛЕНИЯ МАКСИМАЛЬНОЙ ЭНТРОПИИ

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Снежный барс – угрожаемый вид, единственный представитель крупных кошачьих, обитающий в высокогорье. Снежный барс населяет территории 12 государств Азии. Его места обитания в значительной степени рассеяны по обширным труднодоступным территориям, поэтому для картирования потенциальных местообитаний необходимо использовать адекватный современный метод. В настоящем исследовании создана модель потенциальных местообитаний снежного барса на северном пределе его ареала с использованием метода распределения максимальной энтропии (Maxent). Моделирование проведено для западной части ареала снежного барса в России, включая территорию Республики Тува. Для этой территории собрана надежная база данных точек встреч снежного барса. Результаты анализа показали, что подходящие местообитания снежного барса (вероятность присутствия животного колеблется между 0.5 и 1) занимают 16500 км^2 с буфером переходных территорий (вероятность от 0.25 и 0.49), охватывающим 32800 км^2 вокруг него. Наиболее подходящие местообитания в области исследования находятся в Горном Алтае, Цаган-Шибэту и Шапшала, в горах западных Саян, на нагорье Сангилен. Треть подходящих местообитаний входят в ООПТ различного статуса, однако несколько принципиально важных участков не охвачены ООПТ.

Ключевые слова: снежный барс, ирбис, *Panthera uncia*, Maxent, потенциальные местообитания, моделирование