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Predicting global population connectivity and targeting conservation action for snow leopard across its range

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Movements of individuals within and among populations help to maintain genetic variability and population viability. Therefore, understanding landscape connectivity is vital for effective species conservation. The snow leopard is endemic to mountainous areas of central Asia and occurs within 12 countries. We assess potential connectivity across the species' range to highlight corridors for dispersal and genetic flow between populations, prioritizing research and conservation action for this wide-ranging, endangered top-predator.

We used resistant kernel modeling to assess snow leopard population connectivity across its global range. We developed an expert-based resistance surface that predicted cost of movement as functions of topographical complexity and land cover. The distribution of individuals was simulated as a uniform density of points throughout the currently accepted global range. We modeled population connectivity from these source points across the resistance surface using three different dispersal scenarios that likely bracket the lifetime movements of individual snow leopard: 100 km, 500 km and 1000 km.

The resistant kernel models produced predictive surfaces of dispersal frequency across the snow leopard range for each distance scenario. We evaluated the pattern of connectivity in each of these scenarios and identified potentially important movement corridors and areas where connectivity might be impeded. The models predicted two regional populations, in the north and south of the species range respectively, and revealed a number of potentially important connecting areas. Discrepancies between model outputs and observations highlight unsurveyed areas of connected habitat that urgently require surveying to improve understanding of the global distribution and ecology of snow leopard, and target land management actions to prevent population isolation. The connectivity maps provide a strong basis for directed research and conservation action, and usefully direct the attention of policy makers.

Movements of individuals over their lifetime resulting in gene flow and demographic exchange between populations are essential for maintaining genetic variability and long term species survival (Manel et al. 2003, Ronce 2007, Broquet et al. 2010, Clobert et al. 2012). Geographic isolation of populations can have negative genetic effects leading to inbreeding depression and increased extinction risk (Frankham 2005). Conversely, connected habitats across a landscape can increase trophic diversity and sustain ecosystem functions (Olds et al. 2012). Movement events may occur infrequently and unevenly throughout an individual's lifetime (Baguette et al. 2013), but population benefits can arise even when movement rates are very low. For example heterozygosity increased due to the immigration of a single wolf *Canis lupus* to a population in southern Scandinavia (Vila et al. 2003). Movements also promote gene flow throughout the global population of wide-ranging large mammals, such as the Canada lynx *Lynx canadensis* (Row et al. 2012). Broad-scale movements are often facilitated by corridors of suitable habitat or across stepping stones between patches of suitable habitat (Baguette et al. 2013, Saura et al. 2014). Identifying and preserving corridors or stepping-stones that permit movement and create linkages across the landscape are therefore key objectives for biodiversity conservation.

Populations of large carnivores can be distributed over wide areas at low densities and exist within a matrix of naturally fragmented and human-dominated landscapes (Crooks et al. 2011). Large carnivore populations are highly vulnerable to habitat loss and fragmentation due to increasing human development, transboundary politics, climate change and changes in landscape use (Morrison et al. 2007). Gaining information on movements of large mammals can be difficult due to the infrequency of events over a long life span, the spatial scale of ranges and lifetime travel distances. For example, straight-line dispersal distances of around 1000 km

have been recorded for Canada lynx *Lynx canadensis* (Poole 1997), while for wolf *Canis lupus*, travel distances have been recorded at several thousand kilometers (Wabakken et al. 2007). Effective conservation for large carnivores, therefore, must address connectivity at very broad scales that match the scales of movement and dispersal of these species. Given the lack of extensive information on distribution, dispersal and relationships between movement and landscape features for most large carnivore species, landscape connectivity modeling approaches offer potentially useful tools to evaluate potential corridor and stepping stone locations based on hypotheses of distribution and landscape resistance, and then to guide further research, policy and management actions (Epperson et al. 2010, Landguth et al. 2012a). This study demonstrates how modeling connectivity across the global range can be used to inform hypotheses about potential locations of critical movement routes and stepping stones for a wide-ranging large carnivore, the snow leopard *Panthera uncia*.

The snow leopard is endemic to mountainous areas of central Asia and occurs within 12 countries (McCarthy and Chapron 2003). Habitat for large terrestrial carnivores in this region is highly fragmented with little connectivity (Crooks et al. 2011), due to both natural heterogeneity and human influence on the landscape. Mountain habitats are highly vulnerable to environmental change and anthropogenic influences (Schröter et al. 2005, Nogues-Bravo et al. 2007, Grêt-Regamey et al. 2012). Climate change and increasing human activity that further increase fragmentation of suitable habitat, amplify concerns about the persistence of large mammal populations (Cardillo et al. 2005, Morrison et al. 2007), the possibility of genetic isolation and the maintenance of ecological processes in these mountain ranges (Ripple et al. 2014).

Listed as endangered by IUCN (Jackson et al. 2008), the snow leopard, of all the felids, presents the greatest opportunity for successful conservation action to reduce extinction risk (Di Marco et al. 2012). The current global snow leopard population size remains uncertain, but is estimated at 4000–7500 (Fox 1992, McCarthy and Chapron 2003, Jackson et al. 2008). The harsh environment inhabited by snow leopard and the felid's secretive nature, have limited ecological knowledge about this species. The current predicted global range of the snow leopard is principally based on elevation models (Jackson and Ahlborn 1984, Hunter and Jackson 1997) and is reportedly highly fragmented (Jackson et al. 2008). The global population may now be disconnected at numerous points where snow leopards have been lost from previously occupied habitat patches (McCarthy and Chapron 2003). However, as survey effort in these mountains increases, new records are emerging that reconfirm populations of snow leopard (Shi et al. 2009) and other species, such as dhole *Cuon alpinus* (Riordan et al. 2015a). Assuming the global snow leopard range was historically intact, population connectivity would have been maintained by dispersal along habitat corridors and via stepping stones of optimal or suboptimal habitat within unfavoured habitats, such as large valleys, forests, areas of intense human use, and extensive open areas, including much of the Qinghai-Tibetan Plateau (QTP) and nearby deserts. Apparently low likelihood of occupation or low-density resident populations have resulted in some areas being regarded as lower priority for snow leopard conservation. For example, the overarching goal of the World Bank's recent Global Snow Leopard and Ecosystem Protection Program (GSLEP) was the protection of 20 areas of relatively high density breeding populations ('20 by 2020': World Bank 2013). We believe that the loss of stepping stone patches and other routes of connectivity may jeopardize the global population in the longer-term and threaten local populations more immediately. Such areas should be identified and their importance recognized so that effort can be directed to maintaining and enhancing connectivity.

Landscape connectivity patterns result from gradients of varying resistances to movement by individuals (Zeller et al. 2012). Resistance varies both spatially and temporally as a factor of direct and indirect factors (With et al. 1997, Clobert et al. 2012, Baguette et al. 2013) including prey availability, ease of movement, predation risk, competitors (including conspecific animals), human activity and climatic effects (Krosby et al. 2010, Wasserman et al. 2012). Resistant kernel modeling can be used to estimate the effects of different landscape features on movement and connectivity within and between populations (Compton et al. 2007, Cushman et al. 2010). This technique has been used in various situations, for example to model the habitat connectivity for species (Cushman and Landguth 2012), to evaluate protected area networks (Cushman et al. 2012) and to simulate the effects of climate change on population connectivity (Wasserman et al. 2012). The resistant kernel approach has a number of advantages as a connectivity modeling approach, including that it is spatially synoptic, simultaneously predicting connectivity through all locations, is computationally efficient, and has been shown to produce highly informative and robust predictions. For example, Cushman et al. (2014) found that resistant kernel modeling had the best overall performance out of several different approaches for predicting the locations of actual movements of American black bear *Ursus americanus*. In the face of limited field data, we estimate spatial resistance through different terrain, and predict the plausible routes of snow leopard movement throughout the global range.

We examine two approaches to defining the starting points of simulated individual movements. For the first scenario we used known data on snow leopard locations from across their range previously gathered in a questionnaire survey sent to snow leopard conservationists and researchers (Williams 2006). However, there were concerns that these data might be spatially incomplete, with disproportionately more responses from counties with a longer history of snow leopard conservation. We therefore developed a second scenario with an idealized regular snow leopard distribution across the hypothesized global range. Our focus was thus on patterns landscape connectivity across the species' range, rather than occupancy or abundance, which wee anticipate may be helpful for developing hypotheses about the pattern and extent of connectivity across the snow leopard's global range. Identification of reasonable movement routes provides an important foundation to guide further ecological research, conservation planning and policy development.

Methods

We used a resistant kernel approach (Compton et al. 2007) based on least-cost movement from the set of source locations across a resistance map. Resistant kernel modeling was carried out using UNICOR (Landguth et al. 2012b). Starting locations were firstly defined using 1496 reported snow leopard occurrences, compiled from multiple sources through a questionnaire survey (Williams 2006). These data were filtered to exclude records with no means of verification, such as recorder identity and dates, but included sightings, sign records and camera trap data gathered up to 2005. The filtered dataset containing 1191 points, was examined to assess potential bias arising from uneven geographical spread by regressing the number of records against the area of snow leopard habitat for each country. The alternative scenario defined starting locations as a set of 8000 locations set uniformly on a 20 km grid throughout the potential global range of suitable habitat (Hunter and Jackson 1997, Jackson et al. 2008). The number of points was chosen as a conservative upper bound of the global population estimated by Fox (1992), rounded to the nearest 1000. Given that the objective was to examine variability in the landscape permeability, not abundance nor habitat preference, the actual number of points is less important than their distribution across the entire range of available habitat areas.

Both approaches used the same landscape resistance model as a foundation. The landscape resistance model was derived from the combined effects of topographic complexity and habitat, using spatial data on elevation and land cover types for central Asia from Global Land Cover Ground Truth (GLCGT) database at 1 km^2 scale (Tateishi et al. 2002). Topographic complexity was included as snow leopards reportedly prefer broken rocky terrain and irregularly sloping areas (McCarthy and Chapron 2003) and are not thought to persist in flatter, open landscapes at either high or low elevations (e.g. across the Qinghai-Tibetan Plateau or Taklamakan Desert). Sporadic reports of snow leopard in desert areas are known (Heptner and Sludskii 1972, McCarthy 2000) but this is still considered the least suitable of the habitat types with the highest barrier to movement. Topographic complexity was measured as the standard deviation of elevation within a 5×5 cell window with highly variable elevations indicating high complexity. A cost value of 10 was given for flat areas with a standard deviation < 80 m, whereas all other areas were assigned a cost value of one. Habitat categories were defined simply, according to reported preferences (McCarthy and Chapron 2003, Jackson et al. 2008) assessed for their relative influence on snow leopard movement. Desert and other open areas were assigned a cost value of 10, forests were given cost value of five and other areas were given a cost value of one.

Given lack of data about the movement behaviour of the snow leopard, we analysed three distance thresholds that likely bracket the range of plausible lifetime movement for this species (McCarthy and Chapron 2003). Specifically, we ran the resistant kernel model at thresholds of 100 000, 500 000 and 1 000 000 cost units, which represent movement abilities of 100, 500 and 1000 km respectively through suitable habitat. To improve computational efficiency across the vast extent of snow leopard range the resistance model was resampled to 5 km pixel size by bilinear interpolation. Connectivity models are robust to grain coarsening with relatively little effect on the strength of predicted genetic connectivity (Cushman and Landguth 2010).

The resistance model is the foundation for analyses of population connectivity in these analyses, but explicit prediction of connectivity across the resistance surface is required to provide key information for conservation and management (Cushman et al. 2012). In resistant kernel modelling the resistance surface values are used as weights in the movement function, such that the expected density of organisms in a pixel is down-weighted by the cumulative cost from the source following the least-cost route (Compton et al. 2007, Cushman et al. 2010). The analysis begins with the specification of a resistance model describing the cost of movement across each location in the study area. The model then selects a single source cell and uses Dijkstra's algorithm (Dijkstra 1959) to produce a map of the movement cost from that source up to a specified distance threshold on the specified resistance map. The cost distance from the source is converted to an estimate of relative density by applying the movement function. The movement function utilized in our analyses predicts that the relative density of individuals decreases linearly with cumulative movement cost away from the source, up to the maximum movement ability of the species. A relative density of one is given to the source location itself, and decreases to zero at the maximum movement cost threshold. The model iteratively calculates expected relative density of individuals from all source cells. Then the kernels surrounding all sources are summed to give the total expected relative density at each pixel across the full landscape. The results of the model are surfaces of expected density (relative to that of an isolated source cell) of organisms at any location in the landscape.

Data available from the Dryad Digital Repository: <http://dx.doi.org/10.5061/dryad.314b5> (Riordan et al. 2015b).

Results

The distribution of known snow leopard data points on the landscape resistance map mainly occurred in areas of predicted low resistance (Fig. 1). Notable areas of potentially highly connected habitat, for example in southwest China around the southeastern edge of the QTP had few or no records. Furthermore, some reported occurrences occur outside the currently accepted idealized range of the snow leopard. These include records during the 1960s to the late 1990s from the Hentiyn Range in Mongolia (Khentiïn Nuruu) and the connected Russian Yablonovy Range (Yablonovy Khrebet; Kashkarov et al. 2008).

Examining the snow leopard records further, we found that the number of records per country was biased towards India, Mongolia and Nepal, where research and conservation programmes have been in operation for many years. No relationship was found between the area of suitable habitat within each country, derived from Hunter and Jackson (1997), and the number of snow leopard records (linear regression: $F_{1,11} = 0.681$; $p = 0.427$; $R^2 = 0.06$). The number of records from India, Mongolia and Nepal appeared as

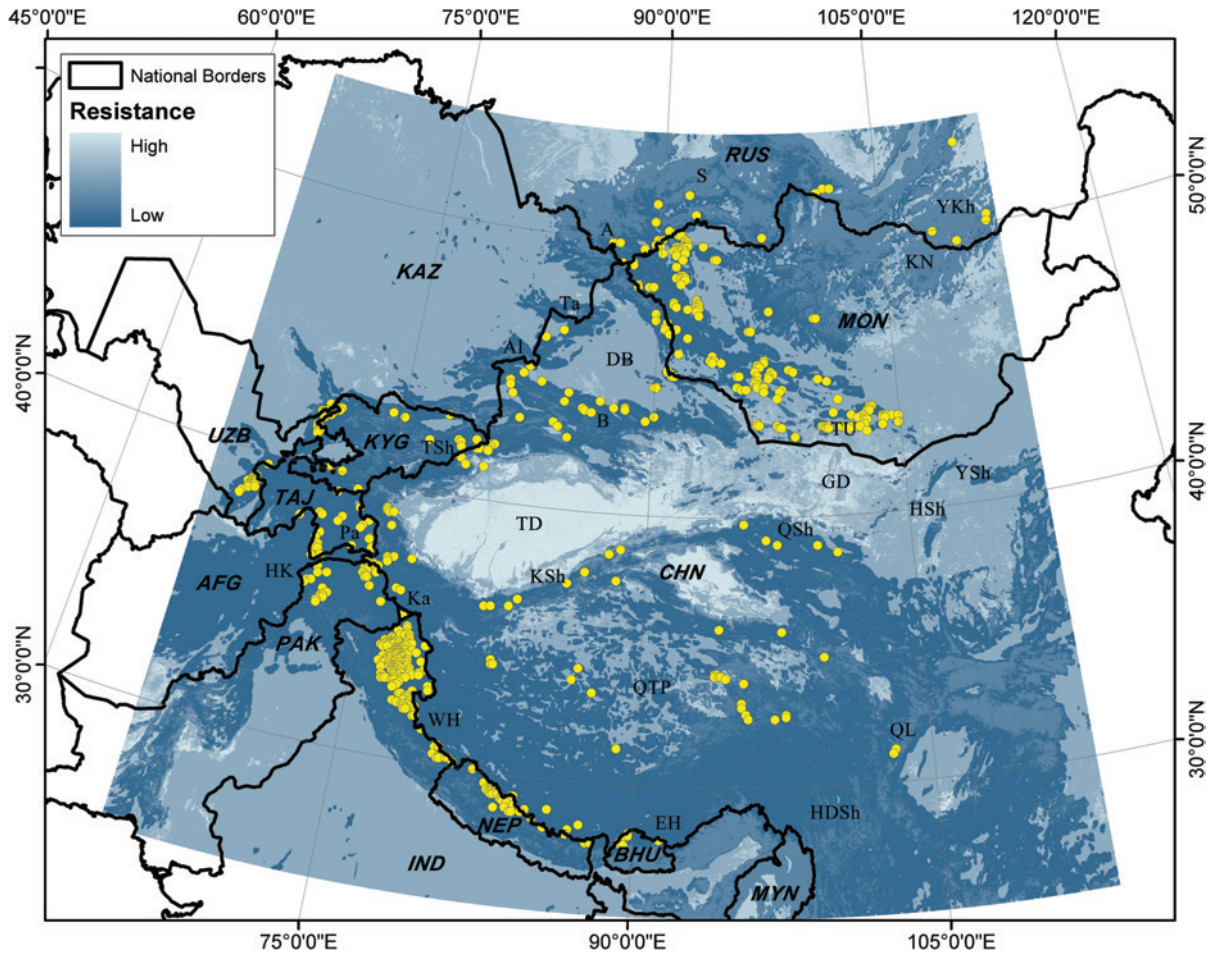

Figure 1. Resistance landscape for snow leopard dispersal throughout its global range showing areas of low to high resistance on a dark to light scale. Circle markers show the verifiable records of snow leopard occurrence from Snow Leopard Network data (Williams 2006). Country boundaries are shown though neither endorse nor discount areas under international territorial dispute. Country names are abbreviated and shown in italic font: Afghanistan (AFG); Bhutan (BHU); China (CHN); India (IND); Kazakhstan (KAZ); Kyrgyzstan (KYG); Mongolia (MON); Myanmar (MYN); Nepal (NEP); Pakistan (PAK); Russia (RUS); Tajikistan (TAJ); Uzbekistan (UZB). Key mountain ranges and other geographic features are indicated: Alatau Mountains (Al); Altay Mountains (A); Borohoro Mountains (B); Dzungarian Basin (DB); Gobi Desert (GD); Helan Shan (HSh); Hengduan Shan (HDSh); East Himalayas (EH); Western Himalayas (WH); Hindu Kush (HK); Karakorum Mountains (Ka); Khentiïn Nuruu (KN); Kunlun Shan (KSh); Pamir Mountains (P); Qilian Shan (QSh); Qionglai Mountains (QL); Qinghai-Tibetan Plateau (QTP); Sayan Mountains (S); Tarbagatai Mountains (Ta); Tian Shan (TS); Tost Uul Mountains (TU); Yablonovy Khrebet (YKh); Yin Shan (YSh).

outliers and when excluded from the analysis, a significant positive relationship between record count and range areas was apparent for the remaining countries ($F_{1,8} = 19.65$; $p < 0.01$; $R^2 = 0.71$).

Given the apparent bias in the records of known snow leopard occurrence, connectivity analysis was only performed using the simulated start-point data. All movement scenarios highlight a core area of high permeability for the global snow leopard population. All connectivity models show a high level of connectivity from the southwest of the QTP, through the west Himalaya, Karakorum, Pamir, and Tian Shan Mountain ranges (Fig. 2). A second area of high connectivity is predicted in Altai-Sayan ranges in Mongolia and Russia, particularly apparent at the 500 km and 1000 km movement abilities (Fig. 2B, C). Connectivity between the north and south regions of the snow leopard range under 100 km and 500 km movement scenarios is predicted to be limited to relatively narrow corridors in the northwestern fringe of the range around the Dzungarian Basin, linking the Altai Mountains to the Tien Shan Mountains along the Alatau and Tarbagatay Mountains to the west, and to the south along the Borohoro Range (Fig. 2A, B).

The predictive connectivity models show areas of limited linkage between parts of the global population that are narrow or fragmented, and may therefore be highly sensitive to disturbance, particularly if movement abilities of the snow leopard fall on the lower end of our simulated range. Range connectivity is predicted in the eastern edge of the range across the Gobi Desert only under the 1000 km movement scenario (Fig. 2C). If functional movement abilities are less, the position of stepping stones across this point, including the Helan Shan and Yin Shan Mountains in China, may offer connectivity between the extant populations in the Tost Uul Mountains in Mongolia with the Qilian Mountains in China. Predicted connectivity arising from the 1000 km movement parameter also draws attention to currently overlooked potential and former linkages. The connections along the Tian Shan mountain range through Kyrgyzstan and along the border area with China, and those along the borders between China and Kazakhstan, are examples of such potentially

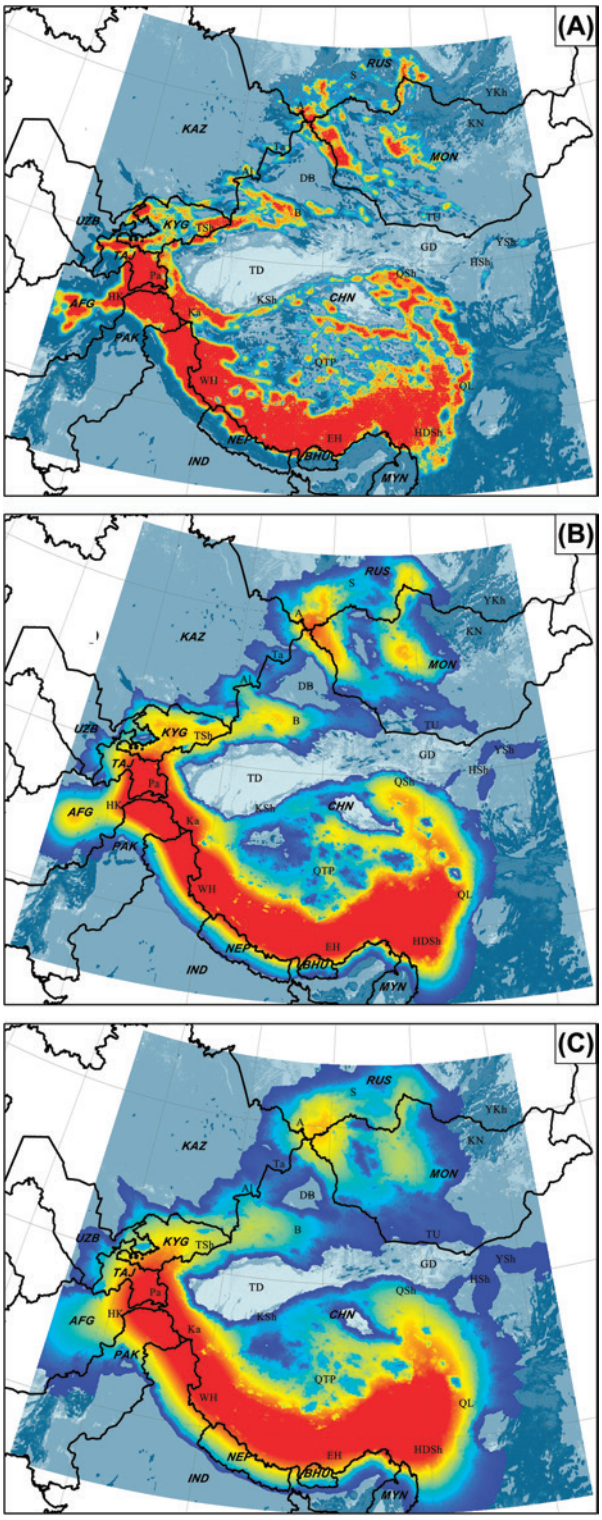

Figure 2. Resistant kernel predicted connectivity for snow leopard populations from a set of 8000 locations was set uniformly on a 20 km grid throughout the potential global range of suitable habitat at three dispersal thresholds that likely bracket the range of plausible lifetime movement for this species: (A) – 100 km; (B) – 500 km; and (C) – 1000 km. Connectivity (intensity of pixel use) is shown on a colour scale, from red to blue, with red indicating greater amounts of movement. Country names are abbreviated and capitalized: Afghanistan (AFG); Bhutan (BHU); China (CHN); India (IND); Kazakhstan (KAZ); Kyrgyzstan (KYG); Mongolia (MON); Myanmar (MYN); Nepal (NEP); Pakistan (PAK); Russia (RUS); Tajikistan (TAJ); Uzbekistan (UZB). Key mountain ranges and other geographic features are indicated: Alatau Mountains (Al); Altay Mountains (A); Borohoro Mountains (B); Dzungarian Basin (DB); Gobi Desert (GD); Helan Shan (HSh); Hengduan Shan (HDSh); East Himalayas (EH); Western Himalayas (WH); Hindu Kush (HK); Karakorum Mountains (Ka); Khentiïn Nuruu (KN); Kunlun Shan (KSh); Pamir Mountains (P); Qilian Shan (QSh); Qionglai Mountains (QL); Qinghai-Tibetan Plateau (QTP); Sayan Mountains (S); Tarbagatai Mountains (Ta); Tian Shan (TS); Tost Uul Mountains (TU); Yablonovy Khrebet (YKh); Yin Shan (YSh).

sensitive linkages. A potentially important movement route is also highlighted around the northern edge of the QTP, through the Kunlun Mountains, connecting the east and west populations of snow leopard throughout China.

Unsurprisingly, connectivity was highest under the 1000 km movement scenario (Fig. 2C). The only connectivity models that predicted movement to the survey locations observed outside the accepted global range in Russia are at the 500 km and 1000 km movement abilities. Although little is known about the movement ability of the snow leopard, these maps suggest these occurrences would not occur if the lifetime movement ability of snow leopard were less than 500 km.

Discussion

The connectivity models developed here offer a basis for focusing research and conservation actions for the snow leopard to enhance movement across their global range in fragmented landscapes. The derived maps highlight locations that may support infrequent, but critical, movements between populations. These models use relatively simple rules for defining resistance and offer initial predictions about the potential routes for movement between regional populations. The need to refine and validate these models is clear, but they can assist in guiding urgent conservation and research efforts for this endangered species and its ecosystem. Increasing human development and the effects of environmental change in the central Asian mountains (Nogues-Bravo et al. 2007) continue to apply pressure to snow leopard populations (McCarthy and Chapron 2003). Maintaining several routes for movement throughout the global population is therefore essential for the resilience of the global snow leopard population.

Examination of predicted connectivity across the snow leopard range highlights three key areas with different implications for guiding future work. Firstly, the west Himalayan-Karakorum-Pamir region is predicted to have moderate to high levels of snow leopard movement across a wide area. Linkage between the southern (QTP) and northern (Altai-Sayan: AS) populations may ultimately depend on this region, although lower movement threshold models indicate dislocation corresponding to the Alai seismotechtonic range-front (Arrowsmith and Strecker 1999) between the Pamir and Tian Shan mountains (Fig. 2A, B).

The Dzungarian region shows a second important area of predicted connectivity, with two relatively restricted corridors, with low levels of movement around the Dzungarian

Basin. This suggests that the AS and QTP populations may be further isolated, with limited movement at these points. Limited movement is known to have occurred, for example in 2009 a male snow leopard was found dead, having apparently attempted to cross a section of the Dzungarian Basin approximately 50 km outside of the predicted snow leopard range (A. Abdukadkir pers. comm. 2009).

The Gobi Desert region in China presents a third important area of connectivity. Specifically, resistant kernel modeling at the 500 km movement threshold highlights potential stepping-stones, which are separated by areas of high-cost distances. Snow leopard populations historically occurred in these some of these patches, declining since the 1940s (Wang and Schaller 1996, Schaller 1998). Existing GPS telemetry studies in the Tost Uul Mountains in the Gobi region of Mongolia (McCarthy et al. 2005) suggest that snow leopards are moving through these desert regions (Snow Leopard Trust/Panthera unpubl., Global Snow Leopard Meeting, Bishkek 2012), but there is no clear indication of the relative importance of these movements, in terms of range expansion and permanent dispersal (C. Mishra pers. comm. 2012). Snow leopards have historically been reported occasionally in the Mongolia-China border area (Schaller 1998), and moving up to 65 km across open steppe between isolated hills in Mongolia (McCarthy 2000). A dead snow leopard was found in open desert 30 km south of Sevrei in southern Mongolia (B. Munkhtsog pers. comm. 2007) and snow leopard occurrence up to 600 km from the nearest mountains have been reported in Russia (Heptner and Sludskii 1972). More recently, in March 2013 livestock herders captured, and subsequently released, a young male snow leopard in Inner Mongolia, China, approximately 40 km from Helan Shan Mountain, an area where snow leopard have not been reported for over 30 yr (Ningxia and Inner Mongolia Forestry Administrations unpubl.).

Connectivity across these three routes, particularly linking the QTP and AS populations, would have important implications for demographic processes, genetic diversity and conservation planning for snow leopard. Assessing movements through these areas and determining the importance of stepping-stones should be a priority (Saura et al. 2014) as urgent protection may be required. Stepping stones have been shown to be important for numerous wide ranging species, including brown bear (Mateo-Sánchez et al. 2014); lynx (Kramer-Schadt et al. 2011); and birds (Uezu et al. 2008).

The potential of protected areas for facilitating connectivity by acting as stepping stones may also be important (Cushman et al. 2012). Currently, protected areas alone are considered insufficient to protect snow leopard (McCarthy and Chapron 2003, Jackson et al. 2008), but they may be able to maintain connectivity between populations by permitting movement through unsuitable landscapes. Protected areas may support prey populations, thereby acting as temporary refugia for snow leopard between core populations. Furthermore, as the effects of climate change become apparent throughout the central Asia region (Xu et al. 2009), with temperatures altering tree-lines (Forrest et al. 2012) and vegetation communities at higher altitudes (Shen et al. 2011), protected area networks may become more important for enabling snow leopards to adapt to changing communities and environment.

There are clearly limitations to this predictive connectivity approach and appropriate caveats should be considered. The resistance values, whilst broad, are based on expert opinion: a necessary but potentially flawed source of information (Shirk et al. 2010). The connectivity models from simulated occurrence assume both a fully occupied range and uniform density. However, these are starting points for simulated movements within a resistance landscape, not home range centers for breeding animals. We have assumed unverified lifetime movement distances, however these bracket a wide range of plausible options. The differences in predicted connectivity between the three movement scenarios further highlights the importance of improving knowledge about movement ability and the need for assessing a range of alternative distances in the face of uncertainty (Cushman et al. 2013) Large areas remain insufficiently surveyed, but are potentially important for snow leopard, such as the southeast of the QTP, the Qionglai Mountains throughout western Sichuan and the Hengduan Shan mountains in Yunnan Province of China (Riordan and Shi 2010). Surveys in these areas are a priority to assess the validity of current distribution maps and strengthen population estimates.

Finally, in all models, international border areas are apparently important potential routes for connectivity or strongholds for extant snow leopard populations. The majority of the suitable habitat occurs within China, however the maintenance of the global population, movement routes and gene flow requires cooperation between all 12 countries in the region. In a region of limited resources and vast inhospitable landscapes, international collaboration may be the most significant action that will ultimately protect the iconic snow leopard.

We hope this initial analysis will be useful to guide future research. For example, future research should prioritize optimizing the resistance model based on empirical data, such as by using multivariate optimization of gene flow models (Shirk et al. 2010, Mateo-Sánchez et al. 2015), or by modeling relationships between movement behavior and landscape features (Cushman and Lewis 2010, Zeller et al. 2014). Furthermore, it is important to improve understanding of snow leopard distribution and density, since accurate depiction of distribution and density fundamentally drives predictions of connectivity models (Cushman et al. 2013). This could be done by implementing large scale, range wide survey efforts to document snow leopard occurrence, ideally coupled with methods to enable estimation of effective population sizes, such as standardized camera trapping and collection of scat samples for genetic analysis (Shirk and Cushman 2014). Assessing movement and dispersal, and estimation of landscape resistance using genetic methods and telemetry studies across the range would also prove informative. Such approaches are essential to accurately quantifying lifetime movement distances of snow leopard, which will be important to improving the understanding provided by the analyses presented here, given that movement ability often has a dominant effect on predicted population connectivity (Cushman et al. 2013). We hope that the results presented in this paper will motivate and guide extensive and focused research to improve knowledge of snow leopard distribution, movement behavior and responses to different attributes of landscape composition and configuration. In the interim we hope that these results

will provide a basis for geographically focused conservation efforts to protect the areas identified as potentially important corridors, stepping stones and core areas.

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