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Original Article

Identifying Potential Conservation Corridors Along the Mongolia-Russia Border Using Resource Selection Functions: A Case Study on Argali Sheep

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Abstract

Key words: argali, *Ovis ammon,* habitat selection, Resource Selection Function, fence, transboundary conservation

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The disruption of animal movements is known to affect wildlife populations, particularly large bodied, free-ranging mammals that require large geographic ranges to survive. Corridors commonly connect fragmented wildlife populations and their habitats, yet identifying corridors rarely uses data on habitat selection and movements of target species. New technologies and analytical tools make it possible to better integrate landscape patterns with spatial behavioral data. We show how resource selection functions can describe habitat suitability using continuous and multivariate metrics to determine potential wildlife movement corridors. During 2005–2010, we studied movements of argali sheep (*Ovis ammon*) near the Mongolia-Russia border using radio-telemetry and modeled their spatial distribution in relation to landscape features to create a spatially explicit habitat suitability surface to identify potential transboundary conservation corridors. Argali sheep habitat selection in western Mongolia positively correlated with elevation, ruggedness index, and distance to border. In other words, argali were tended use areas with higher elevation, rugged topography, and distances farther from the international border. We suggest that these spatial modeling approaches offer ways to design and identify wildlife corridors more objectively and holistically, and can be applied to many other target species.

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Introduction

Anthropogenic barriers in a landscape can seriously disrupt ungulate migrations (Bolger *et al.,* 2008), and the impacts of such barriers on free-ranging wild ungulate populations is increasingly well documented (Berger, 2004; Ito et *al*., 2008; Harris *et al.,* 2009). Human generated barriers such as fences, pipelines, and other linear structures influence habitat selection of large ungulates as they prevent access to large tracts of continuous habitat (Bolger *et al.,* 2008). Fragmentation of habitat into small patches decreases carrying capacity by preventing temporary escape from poor, local habitat conditions, often resulting in dramatic population declines (Berger, 2004; Wilcove & Wikelski, 2008). Moreover, habitat fragmentation can dramatically impact the genetics of populations, partly because reduced gene flow between populations can result in greater inbreeding and loss of genetic diversity within fragments (Frankham *et al*., 2002).

Security infrastructure along international boundaries threatens to degrade connectivity for wildlife (Flesch *et al.,* 2010). Transboundary development, including barbed-wire fences, roadways, vegetation clearing, and increased human activity, threatens to alter connectivity at large scales (Atwood *et al.,* 2011). The international boundary between Mongolia and Russia traverses a diverse region that includes shared steppes, mountain ranges, rivers, and wetlands in several climatic zones and harboring notable biodiversity. In Mongolia, border fences pose a serious problem for nomadic ungulates by restricting movements and increasing mortality (Olson *et al.,* 2009; Kaczensky *et al.,* 2011; Ito *et al.,* 2013). In regions with continuous, impermeable fencing, crossing structures or fence gaps for wildlife, therefore should be considered (Olson *et al.,* 2009; Ito *et al.,* 2013; Batsaikhan *et al*., 2014), yet placement of these structures requires careful evaluation of regional connectivity. Mitigating the effects of transboundary development on wildlife requires information on movement behavior and landscape structures that foster connectivity.

Argali sheep (*Ovis ammon*) are the largest mountain sheep in the world and inhabit mountains, steppe valleys, and rocky outcrops (Reading *et al*., 1997; Amgalanbaatar & Reading, 2000). Categorized as Near Threatened globally (IUCN, 2011), argali in Mongolia have been assessed as Endangered (Clark & Javzansuren, 2006). Moreover, argali sheep are listed in Appendix II of both CITES and CMS international conventions. Regionally, general hunting of argali has been legally banned since 1953 and the species is listed as Rare in the Mongolian Law on Fauna (Badam & Ariunzul, 2005). The most recent population estimates suggest approximately 18,000 individuals survive in Mongolia (Lkhagvasuren *et al.,* 2010). Main threats to this species include unsustainable trophy hunting, displacement or competition with domestic livestock, poaching, and habitat fragmentation (Reading *et al.,* 2001; Amgalanbaatar *et al.,* 2002; Zahler *et al.,* 2004; Wingard *et al.,* 2011; Berger *et al.,* 2013).

To conserve this ecologically and economically important species, quantitatively identifying the factors influencing or limiting argali movement and distribution is essential. In this paper, we assessed the influence of landscape structure on the spatial distribution of argali sheep and explicitly modeled suitable habitat across the border regions of Mongolia and Russia to identify areas to target for border fence removal to facilitate conservation and improve transboundary connectivity.

Study Area

We conducted our study in and around the 267.72 km^2 Gulzat Local Protected Area (thereafter, GLPA). The GLPA has established in 2008, to manage the northernmost population of argali sheep in Mongolia. The study area encompasses two soums (Bukhmurun and Sagil soums) in Uvs aimag and borders on Mungun Taiga Mountain of Russia to the north. Argali populations surrounding the GLPA receive protection within the Tsagaan Shuvuut-Turgen Mountains and Siilkhem Nuruu Strictly Protected Areas (Figure 1). The GLPA is only the area that permits trophy hunting of argali in the region. The area is located in northern mountain ranges characterized by short summers, long and severe winters, and large interannual variations in climatic and vegetation conditions (Yu *et al.,* 2004). Droughts in summer and cold conditions and large snowpacks in winter cause mass mortalities of livestock and wildlife (Begzsuren *et al.*, 2004; Tachiiri *et al.,* 2008). The location of suitable habitat for ungulates likely changes from year to year (Mueller *et al.,* 2008). Population estimates suggest that about 220–240 individuals occupy 453 km^2 within and around the GLPA (Munkhtogtokh, 2012). Grasses (*Stipa* spp.), sedges (*Carex* spp.), forbs (*Festuca lenensis*, *Koeleria macranta*), and shrubs (*Amygdalus pedinculata*, *Caragana stenophylla*) are common plants of the region. Goitered gazelle (*Gazella subgutturosa*) also occur in the study area, as do red foxes (*Vulpes vulpes),* gray wolves (*Canis lupus*), snow leopards (*Panthera uncia*), and raptors, such as golden eagles (*Aquila chrysaetos*), cinereous vultures (*Aegypius monachus*), and bearded vulture or lammergeier (*Gypaetus barbatus*).

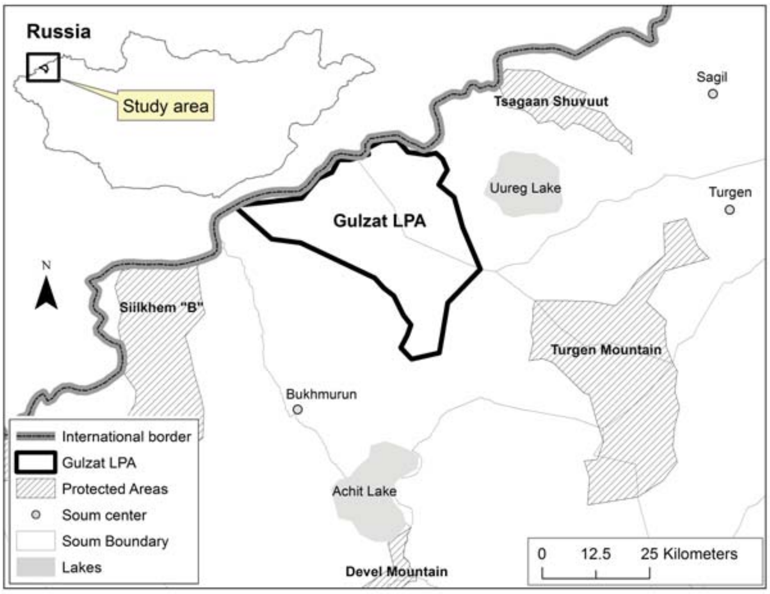

Figure 1. A map of study area in north-western Mongolia.

Materials and Methods

We searched for newborn argali lambs for during early spring (late March – early May) using sightings of lambs at a distance or behavioral cues from ewes to identify areas with lambs. We searched likely locations carefully for the highly cryptic lambs. We circled located lambs with team members and, while one or more people kept the lamb's attention, another person approached slowly from behind, grabbing the lamb by hand. During 2005–2010, we captured and radio-collared 33 argali lambs with a 70-g expandable, very high frequency (VHF), drop-off radio collar with an expected battery life of 1,128 days (model M4210; ATS – Advanced Telemetry Systems Inc., Isanti, Minnesota). Rangers tracked collared argali throughout the year using a telemetry receiver (model R-1000; Communication Specialists, Inc., Orange, California) and 3 element folding yagi antenna (ATS, Isanti, Minnesota). Location data were collected for each marked animal up to 2 times per month in the field until the animal died, signal lost, or collar dropped off. The tracking involves a local ranger travelling with a motorcycle across the entire study area and listening signals for the marked animals from elevated positions. Given the tracking of marked animals occurred every two weeks, we assume samples are independent. After finding animals, the rangers collected location data using a Global Positioning System (GPS) and recorded group size and structure when possible. In total, we collected 518 locations for the marked animals; mean number of location collected per animal was 16.51 ± 12.9 SD during the entire survey period.

Predictor variables. We calculated values of spatial landscape features for used and random locations using ArcMap 10.1 software (Environmental Systems Research Institute, Redlands, California, USA). We developed three spatial landscape features for each used and random location: elevation, ruggedness index, and distance to border fence. We extracted elevation values for locations from a 30-m resolution Digital Elevation Model (DEM) that acquired from Surface Radar Topography Mission data. The topographic ruggedness index was calculated as the square root of the average of the squared differences in elevation between the target centre cell and the eight cells immediately surrounding it (Riley *et al*., 1999). Using extraction tool in the Spatial Analyst toolbox we also extracted elevation and ruggedness index values for each used and random location. We calculated the nearest Euclidean distances to border for each used and random location point using the proximity tool in the Analysis toolbox of the ArcMap 10.1.

Statistical analysis. We used a Use-Availability design (Johnson *et al.,* 2006) to estimate Resource Selection Functions (RSFs). We ran logistic regression models, assuming a Bernoulli distribution for the response variable and a logit link, to derive resource selection functions (RSFs). RSFs provide estimates of relative probability of use for a given unit, which can be interpreted as a measure of habitat suitability (Boyce *et al.,* 2002). We first pooled all argali observations to determine the extent of the study area and we selected random sites for comparison from within the study area polygon. We used these variables in a use-availability framework to identify the differences between used (n = 518) and random locations (n = 551; Manly *et al.,* 2002). We coded presence as 1 and availability without presence as 0. We fit logistic regression models in R (R Development Core Team, 2008) with the 'MASS' library (Ripley, 2011) and assessed all combinations of variables, as we could not choose any subset a priori. We selected the best model using the Akaike's Information Criterion corrected for small sample size (AICc), and AICc weights (Burnham & Anderson, 2002). The AICc weights represents the likelihood of a given model relative to all other models and thus varies between zero and one (Wagenmakers & Farrell, 2004), with the model with the lowest AICc having the highest AICc weight. We evaluated the relative importance of variables affecting argali site select using hierarchical variance partitioning within the R library 'hier.part' (Walsh & MacNally, 2004).

Spatial predictions were prepared using model coefficients generated for the best models selected using AICc. We mapped all RSFs using the ArcMap 10.1 raster calculator from Spatial Analyst tool. The predictions were then categorized into 3 strata based on RSF values (range 0–0.99) as low (0–0.30), medium (0.31–0.60) and high (0.61–0.99) suitability. To determine the extent of potential areas where border fences should be removed around the GLPA, we used our closest observations of collared argali to the border fence. We then created a 2 km wide buffer (1 km on each side of the fence). We further split the buffered area into equal distanced intervals (i.e., 10 km), resulting in 5 zones with an area of 100 km^2 (50 km long x 2 km wide) (Figure 1). We calculated the proportion of suitable habitats (e.g. high, medium, and low) for the each zone using the "isectpolyrst" command in Geospatial Modeling Environment software (Beyer, 2010). We used chi-square tests to compare different habitat suitability indices between countries and among the zones.

Results

On basis of minimum AICc, the best model determined by RSFs included the variables elevation, ruggedness index, and distance to border, and explained ~91% of the variation in the spatial distribution of argali sheep (Table 1). This model accounted for 69% of the AICc weights among the 7 subset models considered (Table 1). In the top model, argali strongly preferred areas with higher elevation (0.0978 ± 0.0683), rugged terrain (0.0027 ± 0.0001), and distances farther from the international border (0.0534 ± 0.0085; Table 2). The relative importance of the variables elevation (45%) and ruggedness index (39%) were greater than distance to border (16%) for spatial distribution of argali sheep.

Table 1. Model selection results of top 3 ranked models that have AICc weight >0.001 (although 7 subset models were considered), for estimation of factors affecting spatial distribution of argali sheep in western Mongolia during 2005 – 2010.

Model structure	AICc	Δ AICc	AICc weight	Deviance
elevation+ruggedness+dist.border	1201.241	0.000	0.690	0.91
elevation+ruggedness	1204.262	3.021	0.264	0.85
elevation+dist.border	1219.295	15.033	0.001	0.77

Table 2. Parameter estimates of the top model distinguishing observed and random points explaining spatial distribution of argali sheep in western Mongolia, during 2005 – 2010.

	Estimate	SE	*z value*	*p*
(Intercept)	-5.8324	0.6217	-8.378	< 0.001
Elevation	0.0978	0.0683	4.254	< 0.001
Ruggedness index	0.0027	0.0001	7.327	< 0.001
Distance to border	0.0534	0.0085	6.287	< 0.001

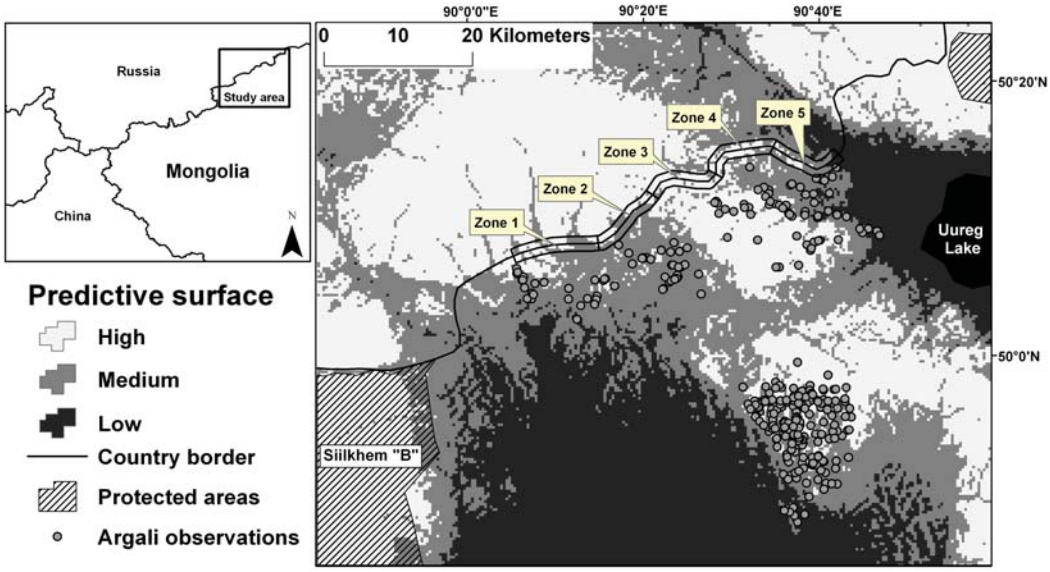

Figure 2. Habitat suitability model for argali sheep within and around the Gulzat Local Protected Area, in north-western Mongolia.

Spatial predictions from the best model based on elevation, ruggedness index, and distances to border predicted that the study area, including Russian side, contained about 26.5% highly suitable habitat, 37.3% habitat of medium suitability, and 36.2% habitat of low suitability, (Figure 2). Furthermore, about 15.1%, 71.6%, and 13.3% of argali locations occurred in high, medium, and low suitability areas, respectively. When comparing the proportion of argali habitat suitability indices between two countries, the amount of suitable habitat was significantly greater on Russian side compared to the Mongolian side ($\chi2 = 48.66$, $df = 2$, $p < 0.001$; Figure 3).

Overall, habitat suitable for argali varied among border buffer zones and was greatest in Zone 3 ($\chi2 = 81.81$, $df = 4$, $p < 0.001$; Figure 4). The mean proportion of high suitability area in each zone was 54 ± 24 SD % (range = 19 – 85%). The greatest proportion of high suitable area (85%) occurred in Zone 3 (i.e. within N50^{0}11, E90^{0}23 – N50^{0}13, E90^{0}20) and the smallest amount of high suitability area fell within Zone 5. The smallest proportion of medium suitable area fell within Zone 3 and the largest proportion of medium suitable area occurred in Zone 5.

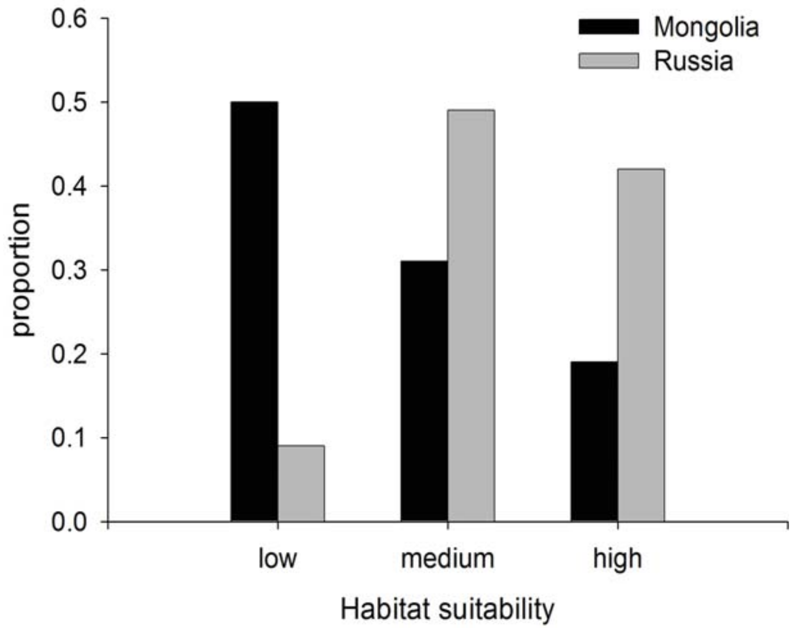

Figure 3. Comparison of habitat suitability categories of argali sheep in Mongolia and Russia.

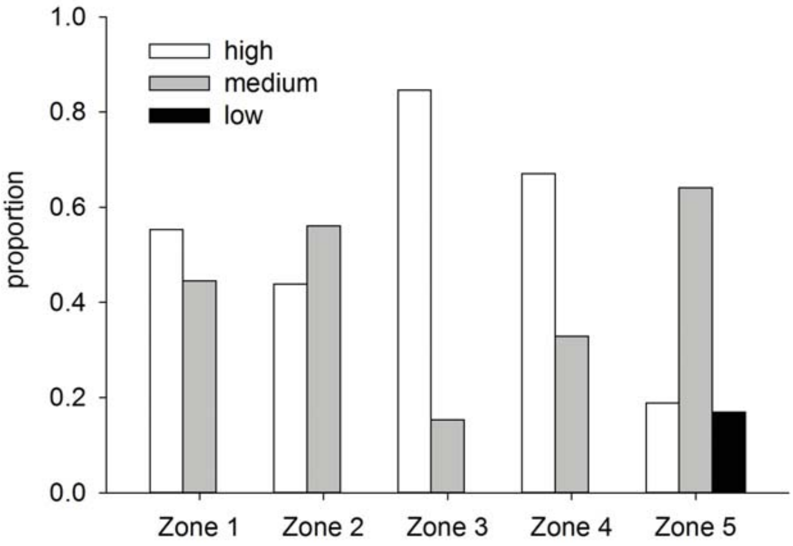

Figure 4. Proportion of different habitat suitability categories (e.g. high, medium, and low) fell in each zone.

Notably, low suitability score occurred only in Zone 5.

Discussion

We present the first analysis of habitat selection by argali inhabiting a region adjacent to the Russia-Mongolia border in northwestern Mongolia, using locations from individual sheep observed over multiple years. Our results provide a foundation on which to gauge and mitigate issues relating to infrastructure development and disturbance. In our study, habitat selection by argali was best explained by a model that incorporated of the variables elevation, terrain ruggedness, and distance to border. The ruggedness has been well recognized as an integral component in the ecology of mountain sheep (e.g. Rachlow & Bowyer, 1998; Singh *et al.,* 2009). Many mountain ungulates evade predation by fleeing to precipitous, so called 'escape' terrain (Geist, 1971; Namgail *et al.,* 2004). However, build as more of a coursing animal, argali typically descend from escape terrain and flee from potential predators (Namgail *et al.,* 2004; Walker *et al.,* 2007). Predators, especially domestic dogs and wolves, represent the leading cause of mortality for argali sheep in Ikh Nart Nature Reserve on the northern edge of Mongolia's Gobi (Reading *et al.,* 2009). The topographic heterogeneity also affects the amount of solar radiation a site receives; exposed sites accumulate less snow and provide better forage availability. Convex curvatures and more limited plant growth at higher elevations enable mountain sheep to better detect predators by improving sight lines (Bleich, 1999; Frid & Dill, 2002). However, these were not the only parameters that explained resource selection, and more site-specific variation occurred among other parameters. Other factors such as predator densities, distribution of surface water, households and human activity, food quality, and forage abundance also may be important and require further analyses.

The lack of wildlife crossing structures or fence gaps for the existing Russia–Mongolia borders effectively divides wildlife populations inhabiting the regions, including argali. In the case of argali in Mongolia, the border fence prevents the animals from accessing the high quality habitat on the Russian side of the border, possibly limiting population growth. Adequate argali conservation management, therefore requires transboundary cooperation and joint conservation initiatives. Focusing on mitigation measures such as removal of border fences along some segments (e.g. particularly in Zone 3) could represent a reasonable starting point for developing conservation programs aimed at maintaining argali meta-population structure and viability. In the near term argali conservation urgently requires joint international efforts to collaborate effectively with the border defense agencies, local herders, government officials, and ecologists. Preliminary efforts to create a transboundary movement corridor have begun (Chimeddorj, pers. comm.), but require additional work at both high and local levels. Conservation measures for argali population also benefit sympatric populations of ibex (*Capra sibirica*), snow leopard (*Uncia uncia*), and other species.

Our results suggest that spatially explicit models based the RSF can help guide identification of corridor areas for free-ranging species and enhance our understanding of the factors affecting species distribution and habitat selection. While such a RSF-informed approach offers an important advance in addressing functional connectivity, there is no guarantee that the identified corridors will ensure population persistence (Taylor *et al.,* 2006). A fundamental challenge is linking corridor planning with regional landscape management and developing research to identify the contribution of corridors to population persistence (Carroll, 2006). Construction of an impermeable border fence would disrupt an extensive population network of argali sheep. In addition to preventing transboundary movements, that barrier would eliminate or weaken linkages among some populations on the same side of the border. Small population sizes and high environmental stochasticity in populations of argali sheep may experience frequent population extinctions. Detailed demographic data and metapopulation models could shed further light on the probability of local extinctions. Perhaps most importantly, effective conservation of argali sheep and other sympatric species requires creating transboundary protected areas to maintain the biodiversity of the border region.

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