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Original Article

Argali Sheep (*Ovis ammon*) Movement Corridors Between Critical Resources in Ikh Nart Nature Reserve, Mongolia

James D. Murdoch[1], Richard P. Reading[2], Sukh Amgalanbaatar[3], Ganchimeg Wingard[4] and Badamjav Lkhagvasuren[5]

[1]*University of Vermont, Rubenstein School of Environment and Natural Resources, Wildlife and Fisheries Biology Program, George D. Aiken Center, 81 Carrigan Drive, Burlington, Vermont 05405 USA, jmurdoch@uvm.edu (JDM)*
[2]*Department of Biological Sciences & Graduate School of Social Work, University of Denver, Denver, Colorado 80208 USA, rpreading@gmail.com (RPR)*
[3]*Argali Wildlife Research Center, Ulaanbaatar, Mongolia, amgalanbaatars@yahoo.com (SA)*
[4]*Denver Zoological Foundation, Conservation and Research Department, 2300 Steele Street, Denver, Colorado 80205 USA, gwingard@denverzoo.org (GW)*
[5]*Mongolian Academy of Sciences, Institute of General and Experimental Biology, Mammalian Ecology Laboratory, Jukov Avenue 77, Ulaanbaatar 210351, Mongolia, lkhagvazeer@gmail.com (BL)*

Abstract

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Correspondence:
jmurdoch@uvm.edu

Understanding how animals move through a landscape can reveal corridors or narrow paths of movement that connect discrete parts of a landscape. Identifying corridors can be important for planning conservation activities, especially for threatened species. We synthesized information on the ranging behavior and distribution of argali sheep to quantify linkages and potential pinch points of movement between critical resources in Ikh Nart Nature Reserve, Mongolia. We used a cost-weighted distance approach to quantify the relative cost of movement between water sources (springs), which represent critical resources. We used values to map a corridor of movement and examined movement flow through the corridor using a circuit theory approach. We identified a corridor connecting all springs that covered 50.6 km^2. Most of the corridor overlapped the reserve (77%) and reserve's core area (62%). A least-cost path between the furthest separated springs (18 km) was 26.4 km. Most movement flow through the corridor concentrated around springs, especially those in the southern and central portions of the corridor. The analysis also revealed several pinch points that represent a conservation concern. We recommend prioritizing activities at pinch points and extending protected area boundaries to encompass all springs to effectively protect the entire corridor.

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Introduction

Effective population management relies on an understanding of how individuals move through a landscape (Wiens *et al*., 1993; Kareiva & Wennergren, 1995; Crooks & Sanjayan, 2006). This is especially the case for large mammals, which often move great distances between food patches or other critical resources (Swihart *et al*., 1988). The landscape 'matrix' or spatial distribution of landscape features, such as habitats and topography, influences movement and can be important to understand to better plan conservation activities (Dunning *et al*., 1992; Ricketts, 2001). One approach to conservation planning is to identify corridors of movement (Hilty *et al*., 2006). Corridors represent pathways of movement that link two or more areas and can help managers visualize where and how animals move. Corridors can also reveal 'pinch points' or constriction zones that may represent a conservation concern (Cushman *et al*., 2013). For example, Mongolian saiga (*Saiga tatarica mongolica*; IUCN Critically Endangered species) migrate seasonally in the Altai Mountains of western Mongolia. Analysis of GPS telemetry data identified three narrow pinch points along a migratory route (Berger *et al*., 2008). Disruptions or changes to one of the pinch points in particular (~ 5 km wide) could effectively cease migration and cause negative demographic consequences and even population collapse (Berger *et al*., 2008). For many species, information on the movement patterns of individuals across the landscape is lacking, but needed especially for imperiled species and small populations vulnerable to extinction (Crooks & Sanjayan, 2006).

The argali sheep, *Ovis ammon* (Linnaeus, 1758) is a large mountain ungulate that occurs in discrete populations across northern and central Asia (Fedosenko & Blank, 2005). In Mongolia, most populations are small and relatively isolated (Clark *et al*., 2006a). The species is classified as IUCN Endangered in the Mongolian Red List of Mammals, and Very Rare under the Mongolian Law on Fauna and declines have been due to several factors including poaching, livestock competition, and habitat loss, conversion and degradation (Wingard & Odgerel, 2001; Clark *et al*., 2006a; Clark *et al*., 2006b). The decline of argali is a concern as the species provides valuable ecosystem services to local people and foreign visitors (e.g., hunters and tourists) and may exert large functional roles in steppe ecosystems (Amgalanbaatar *et al*., 2002; Fedosenko & Blank, 2005; Reading *et al*., 2005; Surenjav & Flores, 2015; Sarmento & Reading, 2016; Murdoch *et al*., 2017). Argali ranging behavior and the relative influence of habitats in shaping distribution have been studied (Reading *et al*., 2003; Reading *et al*., 2005; Ekernas *et al*., 2017; Murdoch *et al*., 2017). However, few efforts have synthesized these data to predict how argali move across a landscape.

We examined argali movement patterns in and around Ikh Nart Nature Reserve, Mongolia. Ikh Nart is a dry steppe and semi-desert landscape and harbors one of the largest remaining populations of argali in the country (Reading *et al*., 2011). Our goal was to provide information to help local, regional, and national managers set conservation priorities for the species. Our objectives were to 1) quantify and map argali movement corridors and least-cost movement paths between critical resources identified for the species, 2) estimate movement flow through corridors, and 3) identify pinch points of movement flow.

Materials and Methods

Study area. Ikh Nart Nature Reserve is a 666 km^2 protected area located in Dornogobi Province (*aimag*) (Fig. 1) (Reading *et al*., 2011; Reading *et al*., 2016). The reserve overlaps two districts (*soums*), Dalanjargalan (in the north) and Airag (in the south) and is administered locally by a Mongolian non-profit organization (Argali Wildlife Research Center) with oversight by district and province authorities and some additional input from the national government. We conducted the study in and around the northern part of the reserve in a region bounded by N45.84334° to E108.48854° and N45.54236° to E108.75731° (ca. 525 km^2; Fig. 1). The northern part of the reserve has a core protected area that receives greater protection than its other parts (Fig. 1). The core area includes a key habitat zone and two regulated use zones. A local protected area (Dalan) surrounds part of the reserve (Fig. 1). Argali have been intensively studied in the region since 2000, and represent a flagship species of the reserve (Reading *et al*., 2007b).

The study area is a multi-use landscape (Schneider, 2014). Herder families (ca. 110) live in and around the reserve seasonally and raise livestock (mostly sheep and goats) for subsistence (Davie *et al*., 2014). The relative number of livestock in the landscape has important conservation implications as it impacts argali abundance by mediating predator numbers (Ekernas *et al*., 2017). Nature-based tourism is a

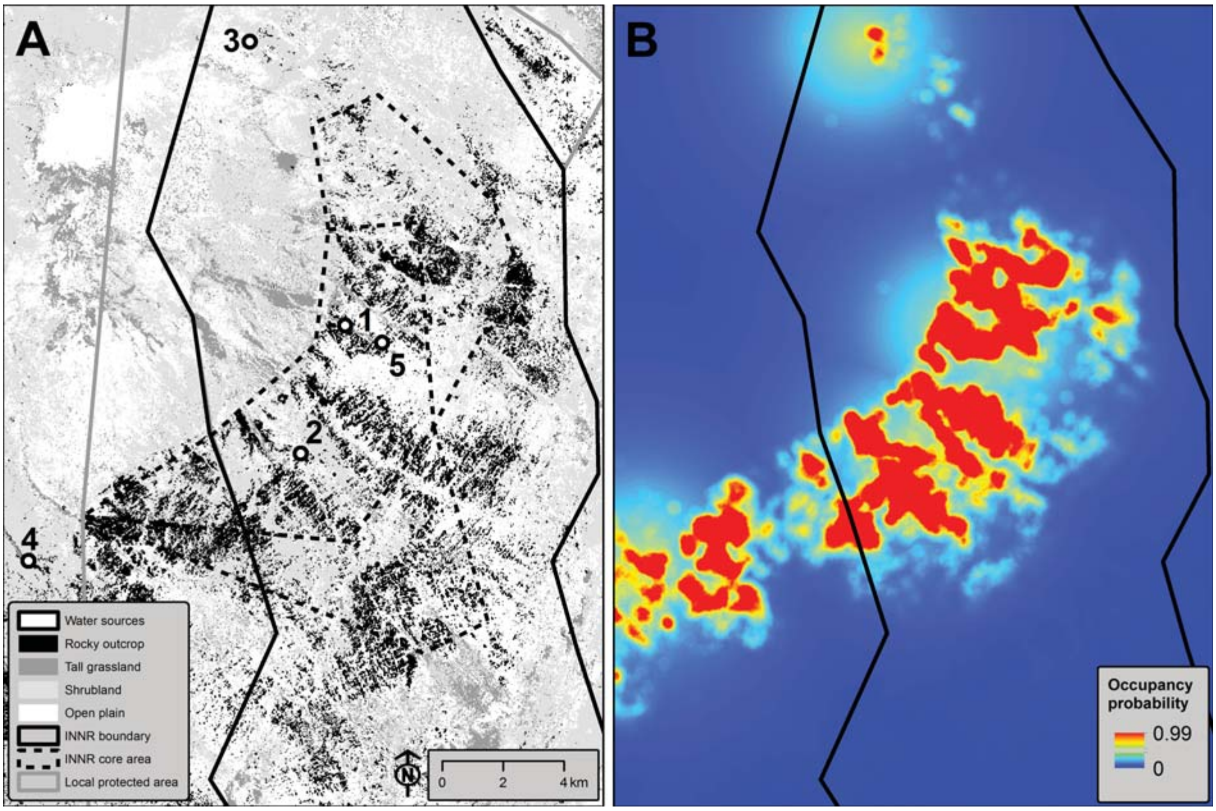

Figure 1. A) Map of the northern Ikh Nart Nature Reserve (INNR) region, Mongolia showing the distribution of water sources (i.e., springs, labeled 1-5), major habitats, and protected area boundaries. The core area includes a key habitat zone (center region of polygon) and two regulated used zones (upper and lower regions of polygon). (B) Argali sheep distribution based on an occupancy model from Murdoch et al. (2017). We used this map as a 'resistance map' to identify a movement corridor. Areas with high occupancy values were considered to have less resistance, or allow the species to move through more easily, than areas with low occupancy.

growing enterprise and both national and foreign tourists often visit the reserve for the opportunity to see argali and experience other natural and cultural aspects of the landscape (Surenjav & Flores, 2015).

Ikh Nart consists of a mix of dry steppe and semi-desert habitats (Jackson *et al.*, 2006; Reading *et al.*, 2011). Steppe habitats include grasslands, semi-shrublands, and forblands that extend across gently rolling terrain. Semi-desert areas are mainly dominated by rugged, rocky outcrops. The region is arid and typically receives < 200 mm of annual precipitation (Murdoch, 2009). Water is scarce, but occurs at five natural springs that are at discrete point locations usually covering ca. 1 to 10 m^2 (Murdoch *et al.*, 2017) Springs run for most the year, but freeze over in winter. Herders keep springs open during winter months by chiseling away ice to provide a source of water for livestock. Temperature often ranges from -35 to +40 throughout the year (Murdoch, 2009; Reading *et al.*, 2011).

Argali in Ikh Nart. Researchers estimated the argali population in Ikh Nart at between 500 and 700 in 2009, and >1,000 in 2015, making it one of the largest remaining populations in Mongolia (Wingard *et al.*, 2011). Ikh Nart provides unique opportunities to view argali regularly and from relatively close proximity (i.e. < 100 m) due to little poaching that occurs in the region (Reading *et al.*, 2011). Argali generally live in groups, with average group size in Ikh Nart being 15 individuals (Singh *et al.*, 2010). Adult males usually live in small bands of other males (or alone) and females usually live in larger herds with young, sub-adults, and immature males (Fedosenko & Blank, 2005). Males rut and gather herds of ewes for reproduction in fall and early winter. Average home range size is 57 ± 3.7 SE km^2 and argali do not migrate in the region (Reading *et al.*, 2003; Reading *et al.*, 2005).

A study of argali distribution collected radio-telemetry locations and developed a model to describe occupancy probability (Murdoch *et*

Table 1. Argali sheep occupancy model parameter (β) estimates along with standard errors and upper (UCI) and lower (LCI) 95% confidence intervals. The model was based on radio-telemetry locations collected in the northern Ikh Nart Nature Reserve region, Mongolia from 2009 to 2011. Parameters in the model included an intercept and covariates representing the interaction of distance to nearest water source and proportion of rocky outcrop habitat within 250 m of a site. Parameter estimates were based on z-score transformed covariate data. For details on the model, see: Murdoch et al. (2017). We used the model to map distribution, which we converted to a resistance map to estimate a movement corridor for the species.

Parameter	β estimate	*SE*	UCI	LCI
Intercept	-4.89	0.13	-4.62	-5.15
Rocky outcrop	-0.30	0.09	-0.12	-0.49
Water source	-2.26	0.08	-2.10	-2.42
Rocky outcrop*water source	-0.98	0.12	-0.75	-1.21

al., 2017). The modeling approach evaluated 67 candidate models that included combinations of 8 landscape variables. The model indicated that probability of occurrence at any given location in Ikh Nart was a function of the interaction of the distance to nearest spring and proportion of rocky outcrop habitat within 250-m (Table 1). Occupancy probability increased as distance to spring decreased and amount of rocky outcrop increased. Distance to spring had an especially strong effect year round. The simulated loss of springs resulted in a reduction in landscape quality of 98% in the reserve and 77% in the core area (Murdoch *et al*., 2017). As a result, the study concluded that springs should be considered critical resources for the species.

Corridor mapping. We identified and mapped corridors between springs using a cost-weighted distance approach (Washington Wildlife Habitat Connectivity Working Group, 2010). This approach estimates the ease of movement at a given location as a function of the distance to a core area and amount of landscape resistance encountered. We began by creating a map of springs to represent core areas. We defined a core area as the region within a 200-m radius around the spring. We used this radius because springs often create short, temporary streams that occur within this distance. We then created a map of occupancy probability by applying the occupancy model to each cell in a grid (raster) of 30 x 30 m cells across the study area based on a satellite map of the region (Fig. 1; Jackson *et al*., 2006). Occupancy probability in the map ranged from 0 to 0.99 and we reasoned that occupancy represented a measure of resistance – an animal passing through an area of high occupancy, which reflected high landscape quality, would encounter less 'resistance' than passing through an area with low occupancy. We then rescaled the map to range from 1 to 100, with 1 representing the highest occupancy value and 100 representing the lowest occupancy value, and used this new map as a 'resistance' layer (Washington Wildlife Habitat Connectivity Working Group, 2010; Beier *et al*., 2011). Corridors between all pairs of core areas were identified by scoring each cell with a cost-weighted distance value. This value represented the distance to a core area multiplied by the resistance at that cell. For example, the value of a cell immediately next to a core area would be its 'distance', which was 30 m (cell size), multiplied by its 'resistance', which let's say was 3. The final cost-weighted distance value would then equal 90 m. The next adjacent cell would then accumulate distance values, so its 'distance' would equal 60 m (30 m + 30 m) multiplied by its 'resistance', which let's say was 2. The final cost-weighted distance value of this cell would then equal 120 m. We estimated values for cells between all pairs of core areas. Values were summed for each cell and normalized (McRae & Kavanagh, 2014). We then truncated the resulting map to only show values up to 100 km. We used 100 km based on argali movements observed in the study area and expert opinion. We considered the truncated map to represent an argali corridor and mapped the least-cost path between core areas. We used Linkage Mapper v. 1.0.9 (McRae & Kavanagh, 2011) to conduct the analysis.

Movement flow and pinch points. We mapped movement flow and connectivity using a circuit theory approach (McRae *et al*., 2008), which treats animal movement like the movement of electricity through a circuit. A current source is connected to one core area and a ground is connected to another. The movement of current from source to ground is mapped based on the relative resistance encountered. Resistance in our case was the cost-weighted distance values in the argali corridor map. This approach identifies flow through a corridor and reveals pinch points that could compromise connectivity. We used the Circuitscape v. 4.0 (McRae & Shah, 2009; McRae & Kavanagh, 2011) to map movement flow and pinch points.

Results

A relatively narrow corridor connected all five springs and generally followed an arc of rocky habitat through the central part of the reserve that extended outside the reserve to the southwest (Figs. 1 and 2). Most of the corridor occurred within the reserve boundary (77%) and core protected area boundary (62%) (Figs. 1 and 2). The Dalan local protected area overlapped 17% of the corridor. Only 6% of the corridor fell outside of the reserve, core area, and local protected area (Figs. 1 and 2). The area of the corridor was 50.6 km^2.

The mean cost-weighted distance value among all cells in the corridor was 39.7 ± 31.5 SE km. Euclidean distance between pairs of springs ranged from 0.9 to 18.2 km (mean = 9.6 ± 1.7 SE) and cost-weighted distance values also between pairs ranged from 6.5 to 1,606.6 (mean = 688.1 ± 148.0 SE) (Table 2). The ratio of cost-weighted distance to Euclidean distance, which reflects corridor quality, indicated the relative cost of movement was least between springs #1 and #5 and most between springs #1 and #3 (Fig. 1, Table 2). The least-cost paths between springs ranged from 9% (springs #1 and 3) to 51% (springs #2 and #3) longer than Euclidean distances (Fig. 1, Table 2). The least-cost path between the furthest geographically separated springs (springs #3 and #4, 18.2 km) was 26.4 km.

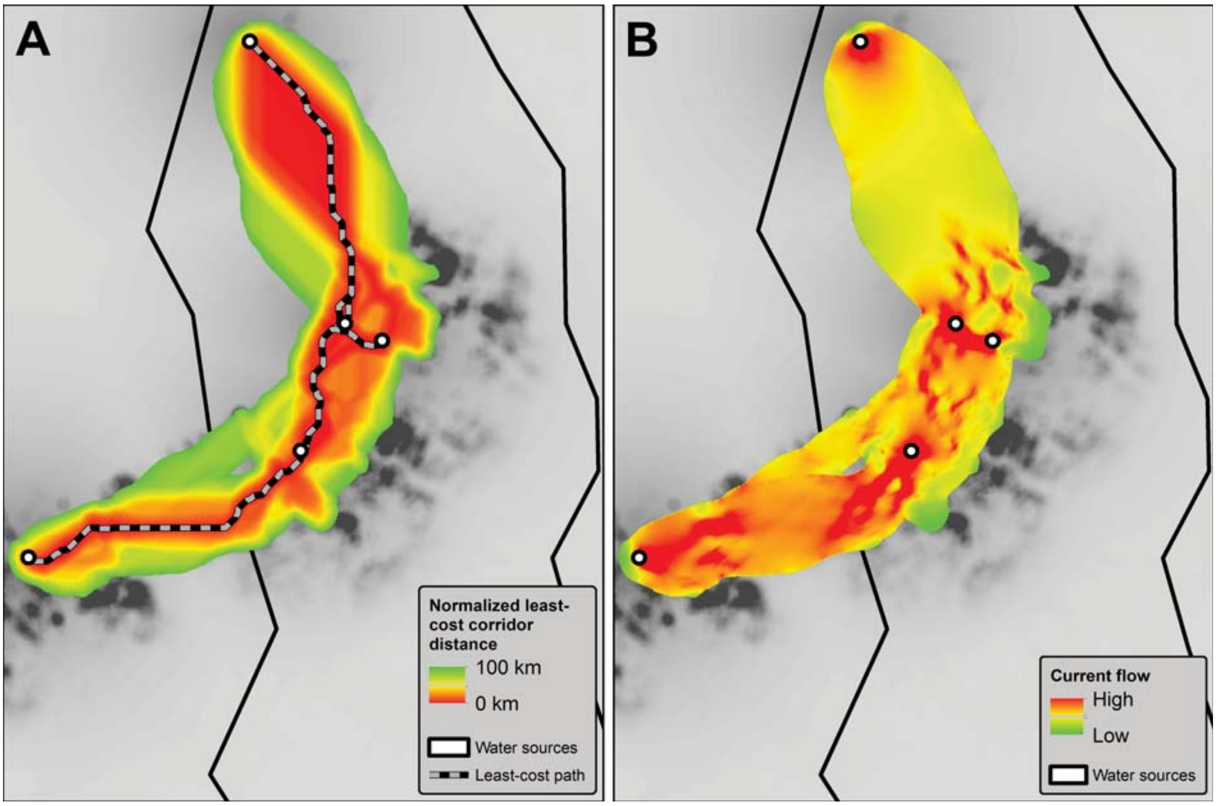

Figure 2. A) Map of an argali sheep movement corridor between springs in the northern Ikh Nart Nature Reserve region, Mongolia. We estimated the corridor using a cost-weighted distance approach and truncated the results to a normalized cost-distance value of 100 km. B) Map of movement flow in corridors showing potential pinch-points. We estimated flow using a circuit theory approach. The background map for A and B is the 'resistance' occupancy map (dark cells = low resistance, light cells = high resistance).

Table 2. Argali sheep cost-weighted distance (CWD), Euclidean distance (ED), ratio of cost-weighted to Euclidean distance, and least-cost path values between all pairs of water sources in the northern Ikh Nart Nature Reserve region, Mongolia. Cost-weighted values represent a measure of the resistance in traveling between springs (through the corridor) and Euclidean values represent straight-line distances. Ratio values provide a measure of corridor quality – lower values reflect linkages that accumulate the least cost per unit of Euclidean distance between springs, whereas higher values reflect linkages that accumulate the most cost per unit of Euclidean distance between springs. Least-cost path values represent the length of the least costly route (in terms of cost-weighted distance) between springs. See Figure 1 for spring locations.

From water source	To water source	Cost-weighted distance (km)	Euclidean distance (km)	Ratio (CWD:ED)	Least-cost path (km)
1	2	219.0	4.1	53.4	4.8
1	3	843.6	9.5	88.8	10.4
1	4	761.3	12.6	60.4	15.6
1	5	6.5	0.9	7.2	1.3
2	3	1,064.3	13.3	80.0	15.5
2	4	533.1	9.2	57.9	10.5
2	5	225.9	4.1	55.1	6.2
3	4	1,606.6	18.2	88.3	26.4
3	5	852.5	10.4	82.0	12.4
4	5	768.2	13.3	57.8	17.1

Movement flow mainly concentrated in areas immediately surrounding springs, especially spring #4, which occurred outside of the reserve, core protected area, and local protected area (Figs. 1 and 2). Flow was generally moderate in the northern portion of the corridor and high in the southwestern portion of the corridor (Fig. 2). Several distinct, relatively narrow and linear channels of flow reflecting pinch points occurred in the central and southern portions of the corridor (Fig. 2).

Discussion

Information on the relative quality and distribution of landscape characteristics can be used as a basis for understanding how animals move between resource patches (Wiens *et al.*, 1993). Assessments of connectivity between patches can reveal corridors of movement and potential bottlenecks or pinch points that could negatively impact populations (Cushman *et al.*, 2013). For threatened and endangered species and small populations vulnerable to extinction, identifying corridors and movements through them can provide an important tool for conservation planning at multiple spatial scales (Crooks & Sanjayan, 2006). In this study, we synthesized information on the ranging behavior and distribution of argali sheep to quantify and map corridors of movement between natural springs, which represent critical resources for the species (Murdoch *et al.*, 2017). We used a cost-weighted distance approach to identify a corridor and potential pinch points of movement through a heterogeneous landscape in Ikh Nart Nature Reserve, which harbors one of the largest remaining populations in Mongolia (McRae *et al.*, 2008; McRae & Kavanagh, 2011; Reading *et al.*, 2011).

The argali sheep is a rare and endangered species in Mongolia, and active management will be necessary to maintain or ideally increase population size and ensure the long-term persistence of the species (Clark *et al.*, 2006a). In Ikh Nart, the argali represents a flagship species for the reserve and region (Reading *et al.*, 2011). However, funds for active argali management are limited indicating that decisions about the species' management need to be efficient and effective (Schneider, 2014). The corridor we identified provides a means of setting management priorities. For example, areas identified as having the least cost of movement between springs (e.g., the entire corridor or perhaps areas with values below a certain cost-distance threshold within the corridor) can be prioritized as sites for management activities to increase population size. Activities may include minimizing livestock grazing to reduce the effects of competition, limiting herders' camps (*gers*) and tourist development that may alter movements, and even completely restricting access by the public to allow argali to freely move, undisturbed between critical resources. Our analysis of movement flow revealed pinch points that could also represent management priorities. Pinch points show areas of high expected movement and the loss of these sites could have a disproportionately large negative impact on the population by reducing access to critical resources.

A majority of the corridor occurred within the boundaries of the reserve, its core protected area zones, and a locally protected area adjacent to the western side of the reserve. However, the boundaries of all three areas do not extend far enough to include the western most spring (#4, Fig. 1), which is the only water point outside of the reserve. This spring represents a site of concentrated argali movement and consequently may have broader importance to maintaining the population. We recommend that managers seek to extend protected area boundaries to encompass this spring. One approach is to extend the westernmost corner of the core protected area approximately 3 km to the southwest. This would result in protection of nearly the entire corridor and may be more feasible than other options such as changing the Ikh Nart reserve boundary, which would require approval at the national level. The local protected area boundary could also be shifted slightly to west.

Protecting a corridor of movement relies on the assumption that animals will use it. We used a cost-distance approach to identify a corridor based on best available information on argali ranging behavior and distribution in Ikh Nart. The cost-distance approach has been shown to perform well over other methods at identifying corridors of movement (Chardon *et al.*, 2003). However, our analysis involved assumptions that have not been validated and could have biased our results. For example, we used occupancy probability as a measure of landscape resistance and assumed that it related to ease of movement through an area. It is possible that occupancy probability does not fully reflect landscape resistance and that some other measure may be more appropriate. Estimates of resistance could be improved by incorporating other sources of information into the analysis. An expert opinion model of resistance could be developed and combined with empirical models (like the occupancy model) to potentially improve assessments of resistance in the landscape (Clevenger *et al.*, 2002). We also assumed that landscape resistance was equal among individuals in the population, which may not have been the case (e.g., due to social dynamics and factors like sex and age). Lastly, any efforts to protect the corridor should be coupled with a monitoring program to track argali demography and movements. This is an important step in validating the corridor and adapting management, if needed, over time (Cushman *et al.*, 2013).

Protecting corridors can be an effective means of facilitating movement across a landscape (Hilty *et al.*, 2006). For argali in the arid steppes of the Ikh Nart region, this could result in fitness benefits for individuals and help reach conservation or recovery targets for the species. It is important to recognize that efforts to protect areas of the landscape for argali (like corridors) may have negative consequences for other species. For example, protecting some areas may benefit argali, but negatively affect Siberian ibex (*Capra sibirica*), which occupy similar habitats and probably compete with argali for resources (Reading *et al.*, 2007a). Managers should seek to balance the trade-offs of argali management with the other biological, cultural, and economic objectives of the reserve. Simple decision-making frameworks, such as SMART (Single Multi-Attribute Ranking Technique) analysis, provide tools that can be used to inform how best to manage a landscape given the various objectives and consequences of management actions (Goodwin & Wright, 2004).

While corridors may be beneficial to particular species, others have cautioned that they can lead to unintended consequences (Ogden, 2015). Corridors can increase connectivity, which may reduce the likelihood of inbreeding depression and potential effects of demographic stochasticity (Simberloff *et al.*, 1992; Beier & Noss, 1998; Crooks & Sanjayan, 2006). However, they could decrease genetic diversity, and in some instances lead to outbreeding depression if the populations being 'connected' have locally adapted gene complexes linked to fitness (Crooks & Sanjayan, 2006). Corridors can also facilitate the movement of introduced species, disease, and fire; increase exposure to hunters, poachers, and predators as corridors inherently have a higher amount of edge habitat; and potentially act as low-quality ecological sinks or traps (Simberloff *et al*., 1992; Crooks & Sanjayan, 2006). Given the argali population characteristics, spatial scale of the study area, and ecological and cultural conditions in the Ikh Nart landscape, these potential consequences are probably minimal. However, managers should consider them when planning conservation activities in the region.

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