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Human activities negatively impact distribution of ungulates in the Mongolian Gobi

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ABSTRACT

The Southern Gobi of Mongolia is an iconic ungulate stronghold that supports the world's largest populations of Asiatic wild ass (or khulan – *Equus hemionus*) and goitered gazelle (*Gazella subgutturosa*). A growing human population, intensifying exploitation of natural resources, and the development of infrastructure in the region place increasing pressure on these species and their habitats. During 2012–2015, we studied factors influencing the distribution of these two ungulate species in the Southern Gobi to better inform management. We built Generalized Linear Mixed Models (GLMMs) to predict the location of suitable habitat for the two species using environmental and human-associated factors. These models were validated using independent telemetry data for each species. The GLMMs suggest that the probability of ungulate presence decreased with increasing human influence and increased in areas with intermediate values of elevation and Normalized Difference Vegetation Index (except for goitered gazelle). Notably, human-associated factors were more important than environmental variables in explaining the distribution of the two species. Habitat models predicted between 45 and 55% of the study area to be suitable for khulan and between 50 and 55% suitable for goitered gazelles during 2012–2015. Models for both species had good predictive power, as nearly 90% of khulan and 100% of goitered gazelle telemetry locations from separate data sets were found within the predicted preferred areas. Our approach quantifies the key drivers of their distribution and our findings are useful for policy makers, managers, and industry to plan mitigation measures to reduce the impacts of development.

1. Introduction

The Mongolia's Southern Gobi Desert is among the world's largest and most intact arid rangelands, and thus is of global importance (Batsaikhan et al., 2014). This region supports a unique assemblage of native wildlife, including the largest populations of Asiatic wild ass (or khulan, *Equus hemionus*) and goitered (or black-tailed *Gazella subgutturosa*) gazelle in the world (Buuveibaatar et al., 2016). For both species, poaching is primary driver of population declines throughout their range (Mallon and Zhigang, 2009; Stubbe et al., 2012), although habitat loss and fragmentation across the species' range may also be important (Clark et al., 2006; Ito et al., 2013a; Batsaikhan et al., 2014). The khulan is categorized as Near Threatened (Kaczensky et al., 2015), while goitered gazelles are listed as Vulnerable on the IUCN Red List (Mallon, 2008).

The desert ecosystem is characterized by seasonal extremes of heat and cold, unpredictable precipitation, and accompanying low and dramatically variable pasture productivity (von Wehrden et al., 2012). The overall sparse environment with tremendous interannual variability in high-quality pasture resulted in the development of a nomadic ungulate system. Well-adapted ungulate species in the region survive because of their ability to move long-distances to find suitable habitat (Olson et al., 2010; Kaczensky et al., 2011a). Conservation of this highly dynamic system is particularly challenging because of the large areas required to provide enough pasture for viable populations (Ito et al., 2013b).

The Southern Gobi also is rich in mineral deposits (World Bank, 2006), and a number of mining-related development and infrastructure projects are underway or planned (Walton, 2010; Batsaikhan et al., 2014). As extractive industry developments expand across the region, they disrupt migratory movements, fragment habitat, and cause direct or indirect habitat loss (Ito et al., 2008; Kaczensky et al., 2011a). However, little is known about the impacts of mining development and operations on khulan and goitered gazelles and their habitats. Consequently,

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determining key variables influencing distribution of and the amount of potential habitat available to khulan and goitered gazelle in the vast landscape of the Southern Gobi is crucial to policy makers, managers, and industry for developing mitigation measures and planning landscape-level conservation strategies (Kaczensky et al., 2008; Mallon and Zhigang, 2009).

In this manuscript, we present results of statistical analyses using observations of khulan and goitered gazelle group locations, remotely sensed variables, and disturbance indices to produce spatially explicit habitat models for these ungulates. We were particularly interested in determining whether environmental or human associated factors are the main drivers in influencing the distribution and habitat of both species. These results are important for understanding the current drivers of distribution, determining critical habitat for these species, and offering guidance to mitigate impacts from mine and associated infrastructure developments in the region.

2. Material and methods

2.1. Study area

We conducted our study across a 98,216-km^2 area in Mongolia's Southern Gobi (Fig. 1), where elevation ranges from 683 m to 1884 m. Average annual precipitation is 150 mm in the southeast part of the study area, but considerably less (≤100 mm) toward the north and west. The average annual temperature is around 5 °C, but daily means may reach 40 °C in summer and drop to −35 °C in winter. Vegetation is sparse and in many areas is dominated by drought-adapted central Asian desert species, particularly *Artemisia spp.*, *Allium spp.*, *Stipa spp.*, and *Anabasis brevifolia* (von Wehrden et al., 2012). There are a few tree species, including saxaul (*Haloxylon ammodendron*) and elm (*Ulmus pumila)*, which are confined to the river valleys and basins. Surface water is restricted to springs, some of which are permanent, primarily located in or near mountain ranges. Khulan are capable of accessing water by digging in dry riverbeds where the ground water table is high, thereby also creating temporary water points for other wildlife, including gazelles. In addition to the two study ungulates, there are Mongolian gazelle (*Procapra gutturosa*), argali sheep (*Ovis ammon*) and ibex (*Capra sibirica*) present. Mammalian carnivores include the wolf (*Canis lupus*), lynx (*Lynx lynx*), red fox (*Vulpes vulpes*), and corsac fox (*Vulpes corsac*).

The study area is limited to the south and east by a fenced border with China and by the Trans Mongolian Railroad corridor, respectively, which create nearly impermeable barriers to ungulate movement (Linnell et al., 2016). In addition, two parallel paved roads connecting major mining activities and the Chinese border crossings are present to the west (Fig. 1). There are four protected areas, which comprise approximately 20% of the study area (e.g., 18,949 km^2). Human populations in the region are concentrated in *soums* (villages/towns), with the rural population primarily consisting of semi-nomadic livestock herders. The region is at the center of the cashmere goat industry in Mongolia, and livestock products generate the main income of local herders (Berger et al., 2013).

2.2. Data collection

Each year during 2012–2015, we surveyed of the same 64 transect lines totaling 3464 km of survey effort across the 98,216-km^2 area (Table S1; Fig. 1). The transect lines were randomly located and systematically spaced 20 km apart using the Distance software (Strindberg et al., 2004; Thomas et al., 2010). The survey was conducted using distance sampling line transect approaches (see Buuveibaatar et al., 2016 for details), in accordance with guidelines recommended by Buckland et al. (2001). To develop a habitat suitability model for the two species, the entire length of each transect driven was divided into 724 5×5 km blocks. We calculated presence/absence of ungulates in each block to derive a binary response variable. We then selected a set of environmental and human associated covariates for habitat modelling that we hypothesized to be important predictors of the two species based on other studies (Buuveibaatar et al., 2014; Farhadinia et al., 2009; Kaczensky et al., 2008, 2011a). Predictor variables used in the spatial modelling included the Normalized Difference Vegetation Index (NDVI), elevation, slope, distribution of households, human disturbance, and distance to the

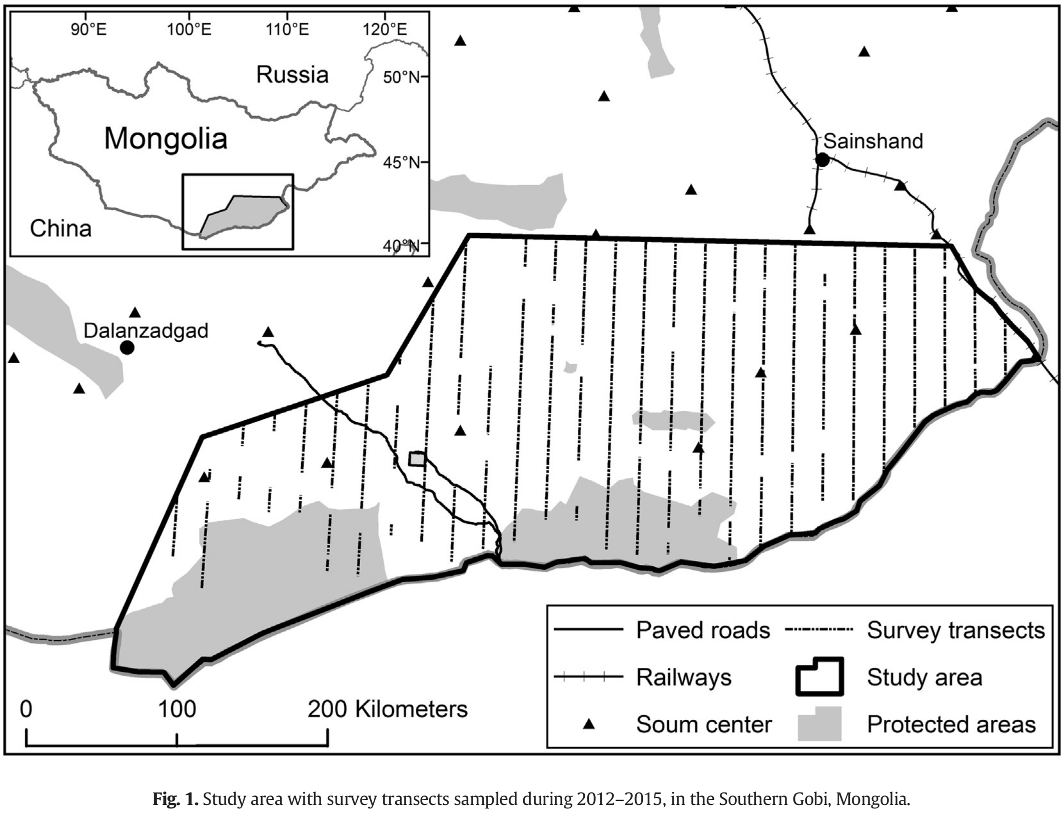

Fig. 1. Study area with survey transects sampled during 2012–2015, in the Southern Gobi, Mongolia.

nearest surface water (Fig. S1). Of these predictor variables, NDVI and distribution of households varied among years. We acquired NDVI data from the MODIS (Moderate-resolution imaging spectroradiometer) sensor on board the TERRA satellite. For each survey period, we obtained a 16-day (May 25–Jun. 09 for Spring and Sep. 22–Oct. 06 for Autumn) NDVI composite in 250-m resolution (http://reverb.echo.nasa.gov). We calculated the mean NDVI value for each block using Neighborhood function in ArcGIS version 10.2. Elevation and slope data were averaged and extracted for the each block, as well, based on Digital Elevation Models obtained from Shuttle Radar Topography Mission (http://srtm.usgs.gov) with 90 m resolution. To estimate the broader effect of households (e.g., livestock) on the distribution of ungulates, we used their presence or absence in each block, using data collected during the ground survey. In Mongolia, household distribution or density is a good proxy for livestock densities. To measure cumulative human impacts on ungulate distribution, we used the human disturbance data layer created by The Nature Conservancy for the Southern Gobi (Heiner et al., 2013). This layer was created using a wide range of human-associated factors, including road and railroad density, population centers and associated area of impact, and existing mines and infrastructure (for details see Heiner et al., 2013, 2016). We determined the spatial distribution of surface water using different sources such as our own observations during the ground surveys, other field work, and the geodatabase of a mining company in the region (i.e., Oyu Tolgoi mine). However, many water sources in our study area are ephemeral and our water layer probably is incomplete when considering the wider landscape.

2.3. Habitat modelling

We used binomial Generalized Linear Mixed Models (GLMMs) to predict ungulate distribution in relation to our set of environmental and human influence variables (Hedley and Buckland, 2004; Marques and Buckland, 2004). We quantified the collinearity among the environmental and human influence covariates using Pearson's correlation. All the variables were included in the spatial modelling as none showed a strong correlation (Fig. S2). To eliminate sample asymmetry (i.e., more absence than presence data) and have a balanced statistical analysis, we randomly subsampled the absence blocks to equal the number of presence samples in each survey (Mueller et al., 2008). Robustness of subsampling approach was tested by repeating our analyses 10 times. We used ‘z-score’ standardization to give all continuous predictor variables a mean of 0 and a standard deviation of 1 to allow the magnitude of coefficient estimates to be compared across variables. The GLMMs were fitted using the library ‘lme4’ (Bates et al., 2014) in the R statistical software (R Development Core Team, 2014). The year of each survey was included as a random term in the GLMM models to account for potential variability between years. The square terms of the continuous variables were included in the GLMM models to consider whether the ungulates showed a preference for intermediate variable values (e.g., Mueller et al., 2008; Kaczensky et al., 2014). Additionally, we explicitly modelled spatial autocorrelation (Augustin et al., 1996) by including as an autocovariate the number of neighboring blocks where the ungulate species did occur (Fig. S3).

Final spatial models were selected on the basis of minimum AIC (Burnham and Anderson, 2002). The relative importance of variables explaining the distribution of ungulates was evaluated using hierarchical variance partitioning within the R library ‘hier.part’ (Walsh and MacNally, 2013), which examines all model combinations jointly to identify average influences of predictor variables rather than just considering the single best model (MacNally, 2002).

2.4. Habitat variability

We created predictive habitat surface layers which assigned a probability as to the presence or absence of khulan and goitered gazelle. These surface layers were based on parameter estimates of the unscaled variables from reduced spatial GLMMs that excluded the autocovariate term. Although probabilities are generally more informative, thresholds are a helpful tool in conservation management and for simple and applied assessments (e.g., Mueller et al., 2008). Given equal number of presence/absence data used for the model development, we used a 0.5 probability threshold to classify predicted probability values into ungulate presence/absence areas. Spatiotemporal heterogeneities in ungulate habitats were examined by overlapping predicted suitable habitat across four season datasets for the two species. We then qualitatively compared the proportion of available habitat to selected habitat.

2.5. Model validation

We validated predictive performance of the GLMMs for the two species using independent data sets collected from individuals fitted with GPS collars. We had a total of 8638 GPS locations from 18 khulan (Mean ± SD, 479.9 ± 87.8) and 1051 GPS locations from 4 goitered gazelles (262.8 ± 10.5), for model evaluation that matched the ground survey periods in 2014 and 2015, respectively. We calculated the mean of all probability surface values corresponding to actual locations of the collared animals. To test whether this mean was significantly higher than would be expected by chance, we simulated 1000 random toroidal shifts (Fortin and Dale, 2005) of the ungulate movement paths within the study area. For each shifted point pattern we calculated the mean of the extracted prediction surface values. We determined the significance of our model by determining how many of the simulated patterns had a higher mean than the mean calculated from actual ungulate locations. The extent of habitat utilized by the collared goitered gazelles during the period when the ground survey was completed in 2015 was only 3454 km^2 (<5% of the study area), in part due to small sample size. Thus, we did not simulate the random shifts for the collared gazelle as the movement data insufficiently represent the study area.

3. Results

3.1. Habitat models

On basis of minimum AIC, the top-ranked model determining spatial distribution of khulan included the covariates: NDVI, elevation, presence of households, and human disturbance (Table 1). NDVI and elevation emerged as significant terms in the model with their second-order polynomials, indicating the preference for areas associated with intermediate values of these variables by khulan (Fig. S4a). The model also suggested probability of khulan presence decreased with increasing human disturbance and aggregations of households. Slope and

Table 1
Parameter estimates of the top ranked full (i.e. spatial autocovariance included) and reduced models explaining the spatial distribution of khulan in the Southern Gobi, Mongolia.

Coefficient	Full model			Reduced model		
	Estimate	SE	Z	Estimate	SE	Z
Intercept	−2.029	0.108	−18.779[d]	−1.451	0.107	−13.554[d]
NDVI	0.168	0.074	2.257[b]	0.318	0.074	4.268[d]
NDVI^2	−0.142	0.051	−2.783[c]	−0.225	0.052	−4.333[d]
Disturbance	−0.404	0.110	−3.673[d]	−0.543	0.110	−4.915[d]
Household	−0.592	0.156	−3.777[d]	−0.519	0.150	−3.452[d]
Elevation	0.011	0.073	−0.159[a]	0.026	0.070	−0.381[a]
Elevation^2	−0.181	0.063	−2.841[c]	−0.214	0.061	−3.497[d]
Autocovariate	0.077	0.059	12.917[d]			
Model AICc			2073.7			2240.9
Residual deviance			2055.7			2224.9
Random effect (SD)			9.286e-08			0.108
Degrees of freedom			2287			2288

The terms followed by ‘2’ denote second-order polynomials.

[a] 0.1.

[b] 0.05.

[c] 0.01.

[d] 0.001.

proximity to surface water were less important drivers of khulan distribution and did not appear in the top model. With the addition of the autocovariance term, the overall model fit improved somewhat; the AIC of the full model decreased from 2241 to 2074 and residual deviance decreased from 2225 to 2056 (Table 1).

The best model explaining distribution of goitered gazelles included the covariates: disturbance index, presence of households, and the first- and second-order polynomials of elevation (Table 2). The probability of goitered gazelle presence decreased with increasing human disturbance and presence of households, and they preferred an intermediate range of elevation (Fig. S4b). Surprisingly, both the first- and second-order polynomial of NDVI did not appear in the top model. Similar to the spatial model of khulan, slope and proximity to surface water also were weak predictors explaining the distribution of goitered gazelles. With the addition of the autocovariance term, the AIC of the full model decreased from 2733 to 2728 and residual deviance decreased from 2721 to 2714 (Table 2); only a slight change in the relative magnitude of estimated coefficients was observed (Fig. S4b).

The relative importance of the disturbance index (59%) and presence of household (23%) were much greater than other variables for predicting khulan distribution (Fig. 2). Similarly, disturbance index and household in addition to the elevation appeared to best explain goitered gazelle distribution. Notably, combined effects of human associated factors (82% for khulan and 65% for goitered gazelle) were higher than those for environmental variables in explaining the distribution of the two species.

3.2. Habitat variability

During the 2012–2015 surveys, on average, 50 and 52% of the study area was delineated as khulan (range = 45–55%) and goitered gazelle (range = 50–55%) habitat, respectively (Figs. 3 and 4). When overlapping suitable habitat for both species across four survey seasons, 71% and 60% of the study area was consistently predicted as khulan (69,733 km^2) and goitered gazelle (59,055 km^2) habitat during 2012–2015. With exclusion of the autumn data, proportion of habitat overlap between spring seasons increased particularly for goitered gazelles; i.e., habitat overlap across three spring surveys was 72% for khulan and 89% for goitered gazelle during 2013–2015. In addition, our model predicted 44% and 57% of the four protected areas as khulan and gazelle habitat, respectively, throughout all four surveys (Figs. 3 and 4).

3.3. Model validation

Using the independent tracking data to test the predictive power of the khulan distribution model we found that in only 50 out of 1000 ($p = 0.05$) permutations had a higher mean than the mean for the predicted probability values corresponding to the actual khulan locations. About 88% (7629 of 8638 locations) of all tracking locations were found within this predicted area (Fig. 5). The remaining khulan locations in lower suitability areas were close to the predicted suitable habitat, with an average distance of 2.30 ± 1.99 km (range = 0.001–13.77 km). For goitered gazelles, almost all gazelle locations (e.g. 99% of 1051 locations) were located in the habitat where they were predicted to occur.

Table 2
Parameter estimates of the top ranked full (i.e. spatial autocovariance included) and reduced models explaining the spatial distribution of goitered gazelles in the Southern Gobi, Mongolia.

Coefficient	Full model			Reduced model		
	Estimate	SE	Z	Estimate	SE	Z
Intercept	−1.207	0.078	−15.370[b]	−1.126	0.071	−15.651[b]
Disturbance	−0.700	0.107	−6.494[b]	−0.721	0.107	−6.701[b]
Elevation	−0.431	0.065	−6.554[b]	−0.438	0.065	−6.659[b]
Elevation^2	−0.264	0.057	−4.584[b]	−0.275	0.057	−4.793[b]
Household	−0.979	0.148	−6.590[b]	−0.964	0.148	−6.500[b]
Autocovariate	0.148	0.055	2.696[a]			
Model AICc			2728.3			2733.4
Residual deviance			2714.3			2721.4
Random effect (SD)			0.00			2e-07
Degrees of freedom			2829			2890

The terms followed by '2' denote second-order polynomials.
[a] 0.01.
[b] 0.001.

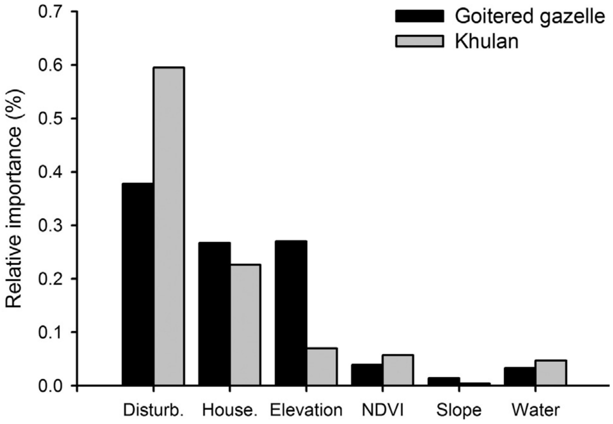

Fig. 2. Relative importance of predictor variables explaining the spatial distribution of khulan and goitered gazelles in relation to environmental and human factors in the Southern Gobi, Mongolia, during 2012–2014 (Disturb. – disturbance index; House. – household).

4. Discussion

Mining development is projected to continue to increase in the Southern Gobi and elsewhere in Mongolia (Walton, 2010) and thus is set to become a major driver of land-use change. As such, there is a pressing need for assessments of the nature of impacts on wildlife and the spatial extent to which these impacts extend. Spatial distribution of khulan and goitered gazelles was influenced predominantly by human disturbance, the presence of households, and to a lesser degree by elevation preferring areas associated with intermediate values of this variable; for khulan intermediate values of vegetation productivity (NDVI) were an additional factor. Our results advance understanding of how animals respond to a various environmental and human associated covariates, offering important insights for the implementation of measures to mitigate the impacts of human land-use change associated with development.

Given the anthropogenic disturbance had stronger influence, the growing development and associated increase in the human footprint in the region will inevitably diminish the range available for these nomadic ungulates. The spatial models predicted that approximately half the study area (~50,000 km^2) each year is unsuitable habitat for the two species. Further, about 29% and 40% of the study area was never classified as khulan and goitered gazelle habitat, respectively, during any of these four years. It is worth noting that the distribution of suitable habitat may shift considerably in years of extreme drought or during harsh winters (e.g., Kaczensky et al., 2011b). As the region accommodates the world's largest populations of khulan and goitered gazelles, and given that the human pressure in the region is increasing, there is pressing need to determine and implement conservation measures that ensure ungulate populations and their habitat can proliferate. Regional planning and implementation of mine development and construction of linear infrastructure should follow a mitigation hierarchy to avoid negative impacts on prime khulan and gazelle habitat,

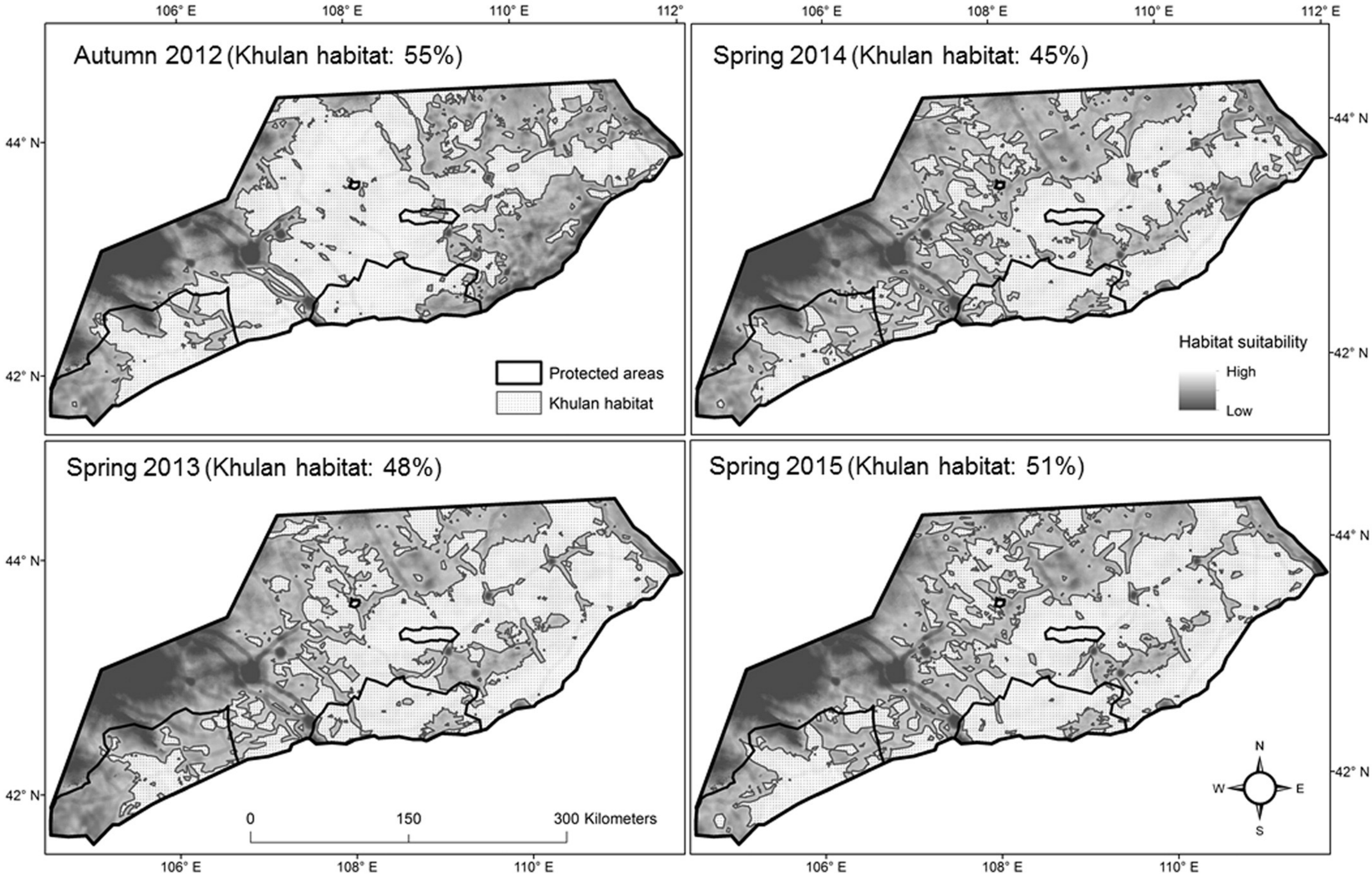

Fig. 3. Spatially explicit model predictions of khulan habitat for autumn 2012 and spring 2013–2015 seasons in Southern Gobi.

minimize potential disturbances, restore impacted habitats, and offset residual impacts by improving habitats elsewhere.

The distribution of the two species was negatively correlated with presence of households, similar to the pattern observed for Mongolian gazelle in eastern Mongolia (Olson et al., 2011). Khulan and goitered gazelles are regularly poached (Stubbe et al., 2012) and both species have long flight distances. They may additionally avoid households because of free-ranging livestock guarding dogs (Buuveibaatar et al., 2009), or grazing livestock that likely compete for resources around households (Yoshihara et al., 2008; Sheehy et al., 2010). Potential management solutions could include land-use regulations that limit the number of livestock herders that can reside in a region and improved law enforcement to reduce poaching pressure.

Khulan were encountered more frequently in areas associated with intermediate values of NDVI, suggesting a probable quality–quantity or quality-security trade-off in the vegetation being selected. A preference for areas of intermediate NDVI has also been found for other species such as Mongolian gazelles (*Procapra guttorosa;* Mueller et al., 2008), saiga antelope (*Saiga tatarica*; Singh et al., 2010), and wild Bactrian camels (*Camelus ferus*; Kaczensky et al., 2014), comparable species in terms of ecology. Unlike for the khulan, NDVI did not appear in the top model that explained distribution of goitered gazelles. Goitered gazelles are dryland adapted browsers (Clauss et al., 2002), and are likely able to feed on extremely sparse vegetation. We found very little interannual variation in spatial distribution of goitered gazelles, although there were considerable changes in vegetation biomass within and between seasons. Furthermore, where vegetation is very sparse the strong reflection from bare ground swamps affects the NDVI signal (Huete et al., 2002); this may explain why NDVI was a weak predictor in the spatial model for goitered gazelles.

There was slight spatiotemporal variation in khulan and goitered gazelle habitats among the four surveys. A low degree of spatiotemporal heterogeneity of ungulate habitats in the region may facilitate enhanced conservation planning for these species. Furthermore, our results show that 27% of khulan and 23% of goitered gazelle suitable habitats were located within a protected area network consisting of the four nature reserves. Protected areas can benefit wildlife population by limiting poaching and restricting development (Reading et al., 2006); however, effective management on individual protected areas may not necessarily guarantee successful conservation of these ungulates as they need to move across large areas. The telemetry study in the region revealed that khulan only spend a small fraction of their time within the protected area network (Kaczensky et al., 2011a). Consequently, conservation of plain ungulates in the region requires expansion of the existing reserves to protect important habitat (e.g. calving ranges) and maintain maximum landscape permeability to accommodate unpredictable movements of these nomadic species.

Our surveys were carried out during one autumn and three spring (and early summer) seasons; hence, distributional data of the two species during summer and winter seasons are missing in our analysis. The winter period is particularly critical for both species, due to the limited food resource, cold temperatures, and occasional deep snow cover, which can increase mortality (Tachiiri et al., 2008; Kaczensky et al., 2011b). There is a need for similar analyses to be conducted for the winter season. Satellite telemetry could provide an alternative and effective way to gather this sort of data, especially given the logistical challenges of ground surveys in the winter months. Further efforts therefore could include running habitat suitability analyses for the khulan and goitered gazelles using tracking data. While the current approach provides a snapshot of the khulan and gazelle populations, the telemetry data

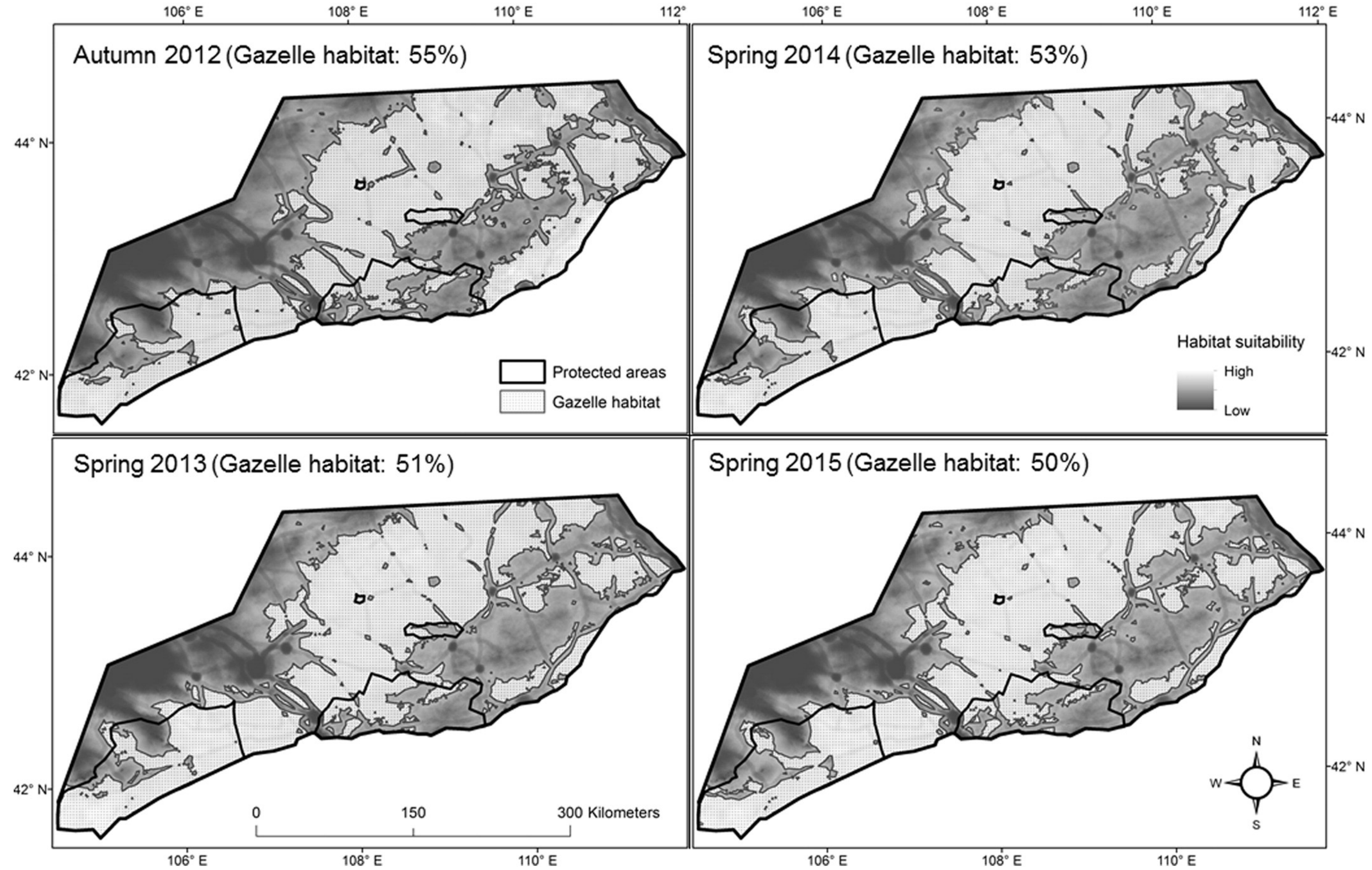

Fig. 4. Spatially explicit model predictions of goitered gazelle habitat for autumn 2012 and spring 2013–2015 in the Southern Gobi.

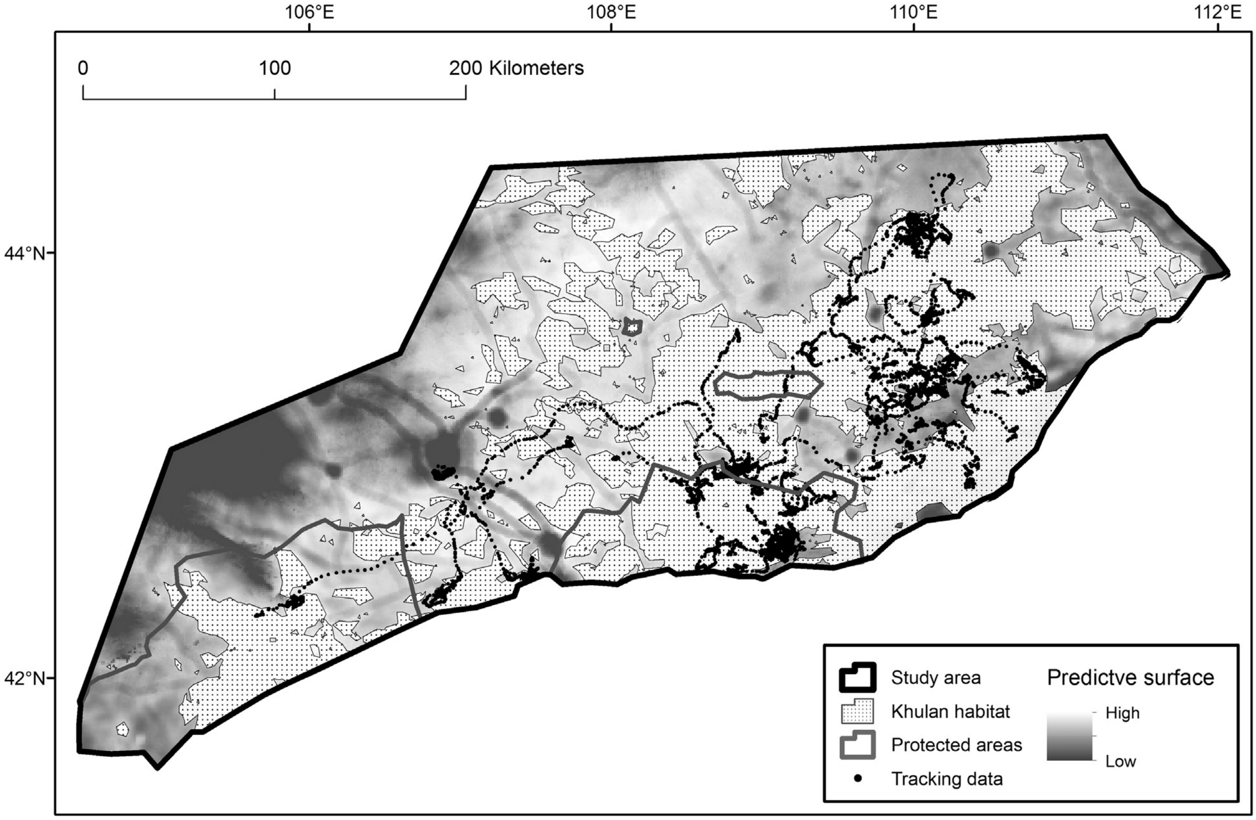

Fig. 5. A probability surface map predicting khulan habitat (probability threshold of >0.5) for the Spring 2014 ground survey period, overlaid with independent khulan tracking data for the survey period May 25–June 10, 2014 in the Southern Gobi, Mongolia.

allow for dynamic habitat suitability modelling across years, using a small subset of the population.

Understanding the impacts of human disturbance on distribution and extent of the ungulate habitat is critical for developing effective mitigation strategies. Given that mining development is projected to thrive in the region, developing monitoring frameworks for consistently assessing the habitat loss of ungulates resulting from this land-use change is a crucial need. The approaches we present are important for understanding the current drivers of distribution and the amount of suitable habitat in the areas of concern. It is certain that future developments will have far greater impact than the current anthropogenic landscape changes, and thus our findings can provide an important reference state for disturbance at its current level. Although khulan and gazelle are already impacted by human development, additional potential application of our approach is the evaluation of various mitigation efforts such as reductions in human influences or projection of potential impacts from the planned developments in the future.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.09.013.

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