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THE ASSESSMENT OF POPULATION ABUNDANCE AND FACTORS INFLUENCING THE DISTRIBUTION OF SAIGA ANTELOPE IN WESTERN MONGOLIA

Final report prepared for the

Saiga Conservation Alliance, and
U.S. Fish and Wildlife Service

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EXECUTIVE SUMMARY

- Our goal in implementing this survey is to estimate population abundance of endangered Mongolia saiga and examine factors influencing their distribution in western Mongolia.
- Distance sampling techniques were successfully used to obtain density and abundance estimates for Mongolian saiga. During February and August of 2014, a total of 40 systematic line transects (the length of transects varied between 2.60 and 98.64 km) with spacing of 10 km across 14,713-km^2 were surveyed.
- In total, 148 groups and 1,934 individuals of saiga observed during the winter and 243 groups and 1,738 individuals of saiga observed during the summer survey, respectively. For pooled data across two seasons, saiga were formed larger groups in winter (*t* test; t = 5.67, $p < 0.001$, $df = 389$).
- In the ca. 14,000 km^2 survey area, estimated densities of saiga individuals during winter and summer were 1.20 (SE = 0.25) and 0.81 (SE = 0.22), respectively, but were not statistically different between seasons. This analysis gives an average estimate of **14,869** animals (CV = 15.00) across its entire range of **14,713** km^2 area.
- The best GLM model explaining spatial distribution of saiga included covariates of NDVI, elevation, and distances to water. Distances to water were emerged as a significant factor with their second-order polynomials, indicating the selection of intermediate values of this variable by saiga (e.g. the first being positive and the second negative). Moreover, the saiga tended to occur in areas with greater NDVI value (e.g. higher vegetation productivity), but they avoided areas with higher elevation. However, proximity to settlements (i.e. soum center), and slope were less important to determine spatial distribution of saiga and did not appear in the top model.

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LIST OF ACRONYMS

AIC	Akaike's Information Criterion
CDS	Conventional Distance Sampling
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
EPA	Environmental Protection Agency
GEM	Geospatial Modelling Environment
GIS	Geographic Information System
GLM	Generalized Linear Model
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
MAS	Mongolian Academy of Sciences
MCDS	Multiple Covariate Distance Sampling
MODIS	Moderate Resolution Imaging Spectro-radiometer
NDVI	Normalized Difference Vegetation Index
SCA	Saiga Conservation Alliance
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator
WWF	World Wide Fund for Nature
WCS	Wildlife Conservation Society

INTRODUCTION

The saiga antelope (*Saiga tatarica*) is a migratory herding species of semi-arid ecosystems of Central Asia (Bekenov et al. 1998). Two subspecies exist, the nominate form (*S.t. tatarica*) in Russia, Kazakhstan and Uzbekistan, and the Mongolian saiga (*S.t. mongolica*; Kholodova et al. 2006). Saigas are categorized as critically endangered globally (Mallon, 2008); however, Mongolian saigas have been assessed as endangered (Clark and Javzansuren, 2006). While the nominate subspecies under-takes large scale migration tracking greenness of vegetation (Bekenov et al. 1998; Singh et al. 2010a), the Mongolian subspecies does not show nomadic behavior with pronounced seasonal movements (Bannikov, 1954).

Estimates of population size are vital for understanding species ecology and for monitoring population trends to inform species management. Especially for threatened species, population estimates are crucial for developing conservation strategies and assessing their effectiveness. However obtaining estimates of species that occur at low numbers and inhabit large geographical areas is logistically difficult. Methods used previously for estimating population sizes of Mongolian saiga provided only a measure of relative abundance or were restricted to smaller geographic regions (Amgalan et al. 2008; Young et al. 2010). Although population-wide aerial survey has been conducted in 2010, it is unlikely feasible to carry out the survey on regular basis in terms of logistically and economically (WWF Mongolia 2008). Distance sampling methods are flexible, efficient, and cost-effective for sampling sparse populations distributed over large regions to properly assess and monitor their population size (Thomas et al. 2010), and these methods have been successfully applied to many ungulate species (Olson et al. 2005; Ransom et al. 2012).

Livestock husbandry is the most important industry in Central Asia and Mongolia is no exception. The influence of livestock grazing on pasture condition can affect wildlife populations in various ways (Berger et al. 2013). Our research on food habits of Mongolian saiga, funded by the Saiga Conservation Alliance, showed quite high dietary overlap between saiga and livestock, suggesting they would potentially be pasture competitors (Buuveibaatar et al. 2011). Similar research on Mongolian gazelles (*Procapra gutturosa*) and argali sheep (*Ovis ammon*) in the Gobi region showed potentially competitive interactions with livestock for food (Yoshihara et al. 2008; Wingard et al. 2011). Moreover, in Eastern Mongolia, the presence of herder households (or livestock) reduced Mongolian gazelle density by more than 80% (Olson et al. 2011). After the change from Soviet-influenced Mongolian socialist governance to democratic reform, the abundance of livestock in western Mongolia increased 5-fold since 1990s (Berger et al. 2013). For the future conservation of Mongolian saiga, a quantitative identification of human factors that influence or limit saiga movements and distribution within their current range is essential.

Understanding temporal variability in habitat suitability has important conservation implications. Changes in resource availability can occur at broad spatial scales and increase area requirements of ungulate populations, which make them more vulnerable to habitat loss and fragmentation (Berger et al. 2004; Harris et al. 2009; Ito et al. 2013). Numerous studies demonstrate that NDVI can be used to predict suitable habitats for ungulates and it has been used successfully to test the relationship between ungulate diversity and plant productivity (Mueller et al. 2008; Singh et al. 2010a; Kaczensky et al. 2014). Saiga are considered the most northern antelope and they live in a highly seasonal environment that driven by unpredictable climate patterns. Thus, it is likely their spatial distribution is closely tied to high vegetation productivity areas. Despite the importance of understanding how saiga respond to a dynamic and heterogeneous landscape nothing is known for the Mongolian subspecies.

Survey Objectives

Our overarching aims of the proposed project are to 1) estimate population size of saiga with associated confidence intervals across its entire range in western Mongolia, and 2) conduct spatial modelling on the survey data to assess the human and environmental factors influencing the distribution of the saiga.

Survey team

The each survey was conducted by three teams simultaneously approximately 15 day period during winter and summer of 2014 (Figure 1, 2). Each survey team was led by one of the following three experienced Mongolian field biologists: Buuveibaatar Bayarbaatar from Wildlife Conservation Society; Galsandorj Naranbaatar from Institute of Biology, Mongolian Academy of Sciences; and Buyanaa Chimeddorj from Mongolia Programme of World Wide Fund for Nature. These individuals were selected based on their expertise with the target species in the western Gobi region, local experience, and availability. Each team leader worked with 1 field technician or saiga ranger.

Figure 1: Mongolian saiga winter survey team in western Mongolia

Figure 2: Mongolian saiga summer survey team in western Mongolia

STUDY AREA

Our research was conducted in western Mongolia across the entire range of Mongolian saigas; we excluded the tiny Mankhan subpopulation as it has only 20–30 animals. Our survey efforts covered three main subpopulations of saigas: Sharga Gobi, Khuis Gobi and Dorgon Plain (Figure 3). The study area is bounded by the Altay Mountains to the south and west; elevations range from 900 to > 4000 m. During 1975–2007, average air temperature during summer and winter was 18 and -20°C, respectively (Buuveibaatar et al. 2013a). The study area receives ~100 mm precipitation annually. Domestic livestock consists primarily of goats and sheep with small numbers of camels and horses. There is a lack of permanent surface water and local herders rely heavily on hand-drawn wells or snow. The Gobi ecosystem is characterized by constant fluctuations in precipitation patterns resulting in nonequilibrium dynamics with respect to the quality and availability of forage (von Wehrden et al. 2012). Vegetation is sparse and onions (*Allium* spp.), grasses (*Stipa* spp.) and anabasis (*Anabasis brevifolia*) are the most common plants (Buuveibaatar et al. 2011). Common predators in this system are grey wolves (*Canis lupus*), red foxes (*Vulpes vulpes*), and raptors, such as golden eagles (*Aquila chrysaetos*) and cinereous vultures (*Aegypius monachus*) (Buuveibaatar et al. 2013b).

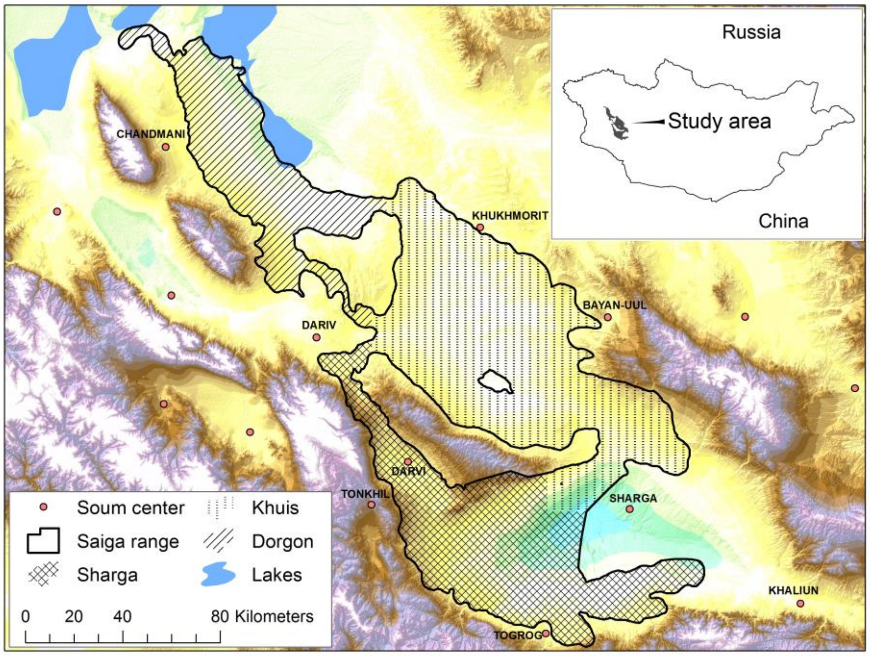

Figure 3: A map of study area in western Mongolia

SURVEY DESIGN

Population estimates

As with any sampling exercise, obtaining reliable results from a distance sampling survey depends critically on good survey design. Sufficient replicate lines or points ensure that variation in encounter rate (number of objects detected per unit survey effort) can be adequately estimated (Thomas et al. 2010). For this reason, a systematic survey design with a random start (Strindberg et al. 2004) was generated using the Distance 6.2 software to afford better spatial coverage and lower variance. The final survey design consisted of 39 transects (range = 2.60 – 98.64 km) with spacing of 10 km totaling a 1,505 km survey effort (Figure 5). The transects were oriented in an east-west direction to facilitate their coverage in the field.

Transects were driven during daylight hours using a Global Positioning System for orientation. Observers scanned the area in front of them out to 90° on either side. When a feature of interest (e.g. group of saiga, other wildlife species) was detected location, group size, radial distance (r) and sighting angle (θ) were recorded, using a GPS, compass, binoculars, spotting scope and rangefinder. Saiga groups often began to run after we detected them and, in these cases, we used a landscape feature at the point of detection to measure r and θ. From these data we calculated perpendicular distance as $x = r\sin(\theta)$. These distances are used to estimate a detection function, which gives the probability that an animal is detected, as a function of distance from the line. In the case of ungulates that occur in groups, the unit of observation is the group and thus the distance and bearing angle to the center of the group are recorded.

Spatial modeling

All spatial data preparation was conducted in ArcMap 10.2 (ESRI, California) and Geospatial Modelling Environment software (Beyer 2010). To develop a habitat model, we split the survey transects into 519 3x3 km blocks (e.g. 1.5 km to each side). Number of saiga groups calculated in each block to derive a response variable. We developed five variables such as NDVI, elevation, slope, distances to nearest settlement and surface water. We calculated Euclidean distance to nearest settlement, road, and surface water, for the center of the each blocks using the "Near" function of Analysis Tool in ArcMap 10.3. Elevation data extracted for the center of each blocks from the Digital Elevation Model with 30 m^2 resolution using Extraction Tool in ArcMap 10.0. To estimate environmental condition, we used Normalized Difference Vegetation Index (NDVI) data acquired by the Moderate Resolution Imaging Spectro-radiometer (MODIS) on board the TERRA satellite. For the survey period, we obtained a 16-day NDVI composite in 250-m resolution from NASA's Earth Observing System Gateway (http://reverb.echo.nasa.gov) and re-projected the data to Transverse Mercator (UTM zone 46 N). The mean NDVI raster cell value for the each 3×3 km blocks was calculated using Focal Statistics Tool.

STATISTICAL ANALYSIS

Population estimates

Data were analyzed using the Distance 6 software to estimate abundance of Mongolian saiga (Thomas et al. 2010). Density of saiga groups within the area surveyed was estimated as:

$$\hat{D}_g = \frac{n\hat{f}(0)}{2L}$$

where *L* denotes the aggregate length of the transects, n is the number of saiga groups observed and $f(0)$ is the probability density function of observed perpendicular distances evaluated at x = 0 (Buckland et al. 2001). Thus, density estimates are obtained from estimates of $f(0)$ and encounter rate (n/*L*). $f(0)$ is equal to $1/\mu$, where μ is the effective strip half-width, corresponding to the perpendicular distance from the transect line within which the number of undetected groups is equal to the number of groups detected beyond it. Multiplying double the effective strip half-width by the aggregate length of the transects yields the effective area surveyed. Density (*D*) of saiga is obtained by multiplying the estimated group density by the estimated expected group size $\hat{E}(s)$. The density of individuals is multiplied by the surface area of the study area or survey stratum to obtain the corresponding abundance estimate (*N*). Encounter rate variance was estimated empirically using the replicate transect lines as samples. Maximum likelihood methods were used to estimate the variance of the effective strip width. Exploratory analyses were first conducted to examine options for truncation and grouping intervals to improve model fit for the detection function. Following Buckland et al. (2001), a variety of key functions and adjustment term combinations were considered to model the detection function (e.g. uniform + cosine or simple polynomial, half-normal + cosine or simple polynomial, hazard rate + cosine or hermite polynomial). Goodness of fit tests were used to identify violations of assumptions. Akaike's Information Criterion for small sample sizes (AICc) was used in model selection, with particular attention paid to model fit at distances near zero since the fit of the shoulder near zero is most important for robust estimation (Buckland et al. 2001).

Spatial modeling of saiga distribution

The Generalized Linear Models (GLM) with Poisson error structure was used to predict saiga distribution in relation to a set of environmental and human variables (Manly et al. 2002; Boyce et al. 2003). Saigas were present in 21% of surveyed blocks (110 of 519 sampled blocks) during the winter and were present in 22% of the blocks (112 of 519 sampled blocks) during the summer survey. To eliminate sample asymmetry (more absent than present data) and balance statistical analysis we randomly subsampled the absence blocks to equal the number of presence samples in each survey. We quantified the collinearity among the environmental and human associated covariates using pairwise correlation. The second order polynomial ($y \sim x + x^2$) was used to test all continuous variables, and if a second order polynomial was not significant, it was eliminated and the model was rerun in the non-polynomial form ($y \sim x$). If the model was still not significant, the variable was considered nonsignificant and excluded from later analysis. Model selection was performed using the Akaike Information Criterion (AIC) (Burnham and Anderson 2002). Relative importance of variables explaining distribution of ungulates in relation to a suite of variables we identified was evaluated using the method of hierarchical variance partitioning with R library ‘’hier.part’’ (Walsh and MacNally 2004). The hierarchical partitioning examines all model combinations jointly to identify average influences of predictive variables rather than just from the single best model (MacNally 2002).

Statistical testing to predict spatial pattern is often complicated by spatial autocorrelation as it violates the basic assumption of non-independence of data. In other words, spatial auto-correlation occurs when the values of variables at nearby locations are not statistically independent from each other (Dormann et al. 2007). This phenomenon is common in habitat study as species’ spatial patterns are often controlled by habitat types, such as habitat complexity and substrate types and therefore natural systems almost always have autocorrelation in the form of patchiness or gradient (Legendre, 1993; Dormann et al. 2007). To deal with this, we explicitly modeled spatial autocorrelation (Augustin et al. 1996) by including as an autocovariate the number of neighboring block where saiga did occur. A size of buffer for neighboring blocks was determined using the correlograms of the residuals for the GLM models.

RESULTS

Saiga grouping patterns

- We have carried out the ground-based Distance sampling survey during winter (04 – 15 February, 2014) and summer (15 – 27 August, 2014) in western Mongolia to estimate population abundances of saiga and determine factors influencing their spatial distribution.
- In total, 148 groups and 1,934 individuals of saiga observed during the winter and 243 groups and 1,738 individuals of saiga observed during the summer survey, respectively.
- For pooled data across two seasons, overall mean (± SD) group size was 9.39 ± 13.04 individuals (n = 391, Range = 1 - 104). During the two survey periods, saiga were formed larger groups in winter (*t* test; t = 5.67, *p* < 0.001, *df* = 389) in comparison to the summer survey period (Figure 4).
- In winter, groups of 2–5 animals were the most (35.8%) frequent, followed by 6–10 individuals (22.9%), 11–20 individuals (22.2%), and 21-50 individuals (11.4%); groups with > 50 individuals were rare (e.g. 4.1% of the total groups; Figure 5). The similar grouping pattern was observed for saiga during the summer survey and groups of < 5 individuals were commonly (59.4%) observed; whereas groups of > 50 individuals comprise of 1.2 % (e.g. only 3 of the total groups) (Figure 5).

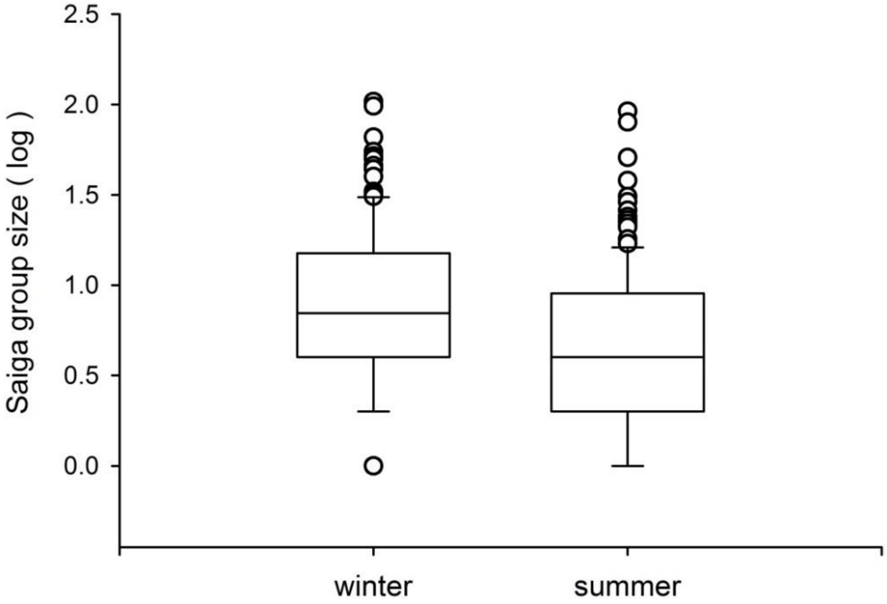

Figure 4: Comparison of saiga group sizes (log transformed) between two seasons in western Mongolia

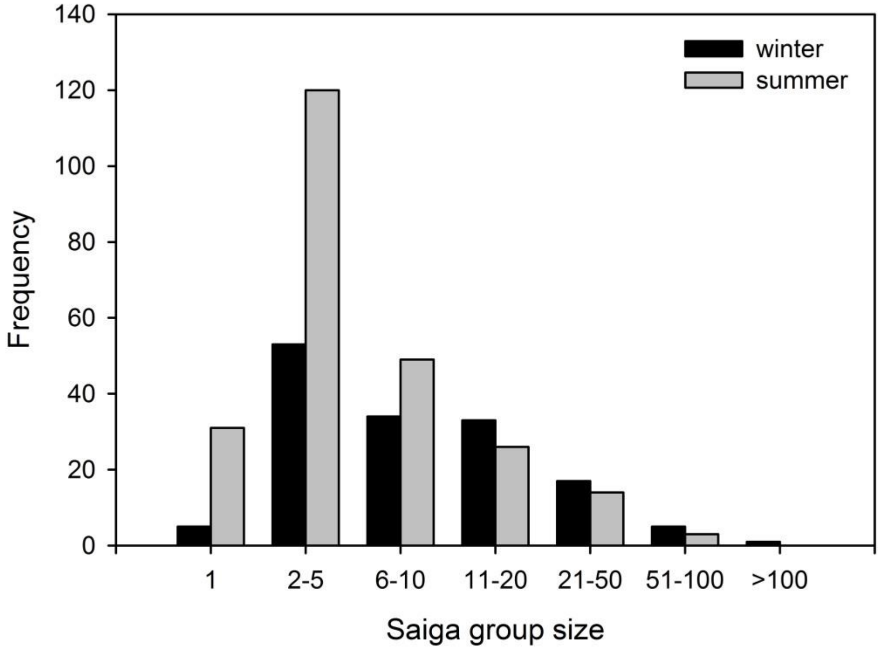

Figure 5: Grouping patterns of saiga antelope observed along the line transects during winter and summer of 2014 in western Mongolia

Population estimates

- To estimate density and population abundance, the half-normal, hazard rate, and uniform function with a variety of adjustment terms were considered. The expected group size rather than the average group size was used when the regression line fit to ln(group size) versus g(x) was significant at a 15% alpha level. Final models for saiga population estimates were chosen based on the AIC and the fitted functions (Buckland et al. 2001). The half-normal function with right-truncated 10% of the data (at approximately 1.1 km) produced the best fitting model (Figure 6). We stratified encounter rate and cluster size by season, while a single detection function was fitted by pooling the data across seasons.
- The survey efforts in winter and summer was the same, but the encounter rate almost doubled in summer (Table 1). In addition, the group sizes are markedly different between seasons with much larger groups in winter (hence also smaller encounter rate). For both season there was indication of size bias and expected group size was used in the estimation. The group density reflects the encounter rate for each season, so larger in summer, but given the enormous group sizes in winter compared to summer the individual density in winter is larger (Table 2).
- Global estimate of detection probability was 0.44 (95% CI = 0.41 – 0.47, CV = 3.49; Figure 9) with an associated effective strip width of 488.97 (SE = 95% CI = 455.64 – 524.74). Estimated densities of saiga individuals during winter and summer were 1.20 (SE = 0.25) and 0.81 (SE = 0.22), respectively, but were not statistically different between seasons (Z = 1.21, *p* = 0.11). This analysis gives an average estimate of **14,869** animals (CV = 15.00) across its entire range of **14,713** km^2 area (Table 2).
- Uncertainty in the abundance estimate in winter was mostly due to estimation uncertainty in the encounter rate, followed by the cluster size, and the detection probability. Similarly, contribution of encounter rate to the variance in abundance estimate was considerably greater than cluster size and detection probability in summer survey period (Figure 7).

Table 1: Estimates of the encounter rates (*n/L* - number of objects detected per unit survey effort) in groups/km, estimates of expected group size *E*(s), and density of groups (D_g) for each species with their 95% confidence intervals (95% CI)

Season	n/L	**95% CI**	$\hat{E}(s)$	**95% CI**	$\hat{D}_g$	**95% CI**
Winter	0.08	0.06 – 0.13	13.10	10.63 – 16.14	0.09	0.06 – 0.13
Summer	0.15	0.11 – 0.22	5.03	4.37 – 5.78	0.16	0.11 – 0.22

Table 2: Estimates of ungulate density (*D* per km2) and abundance (*N*) with their 95% confidence intervals (95% CI) and overall percent coefficient of variation (% CV)

Season	$\hat{D}$	**95% CI**	$\hat{N}$	**95% CI**	**(%CV)**
Winter	1.20	0.78 – 1.83	17,696	11,584 – 27,034	21.50
Summer	0.81	0.56 – 1.17	12,202	8,371 – 17,265	18.24
Average	**1.01**	**0.75 – 1.35**	**14,869**	**11,066 – 19,978**	**15.00**

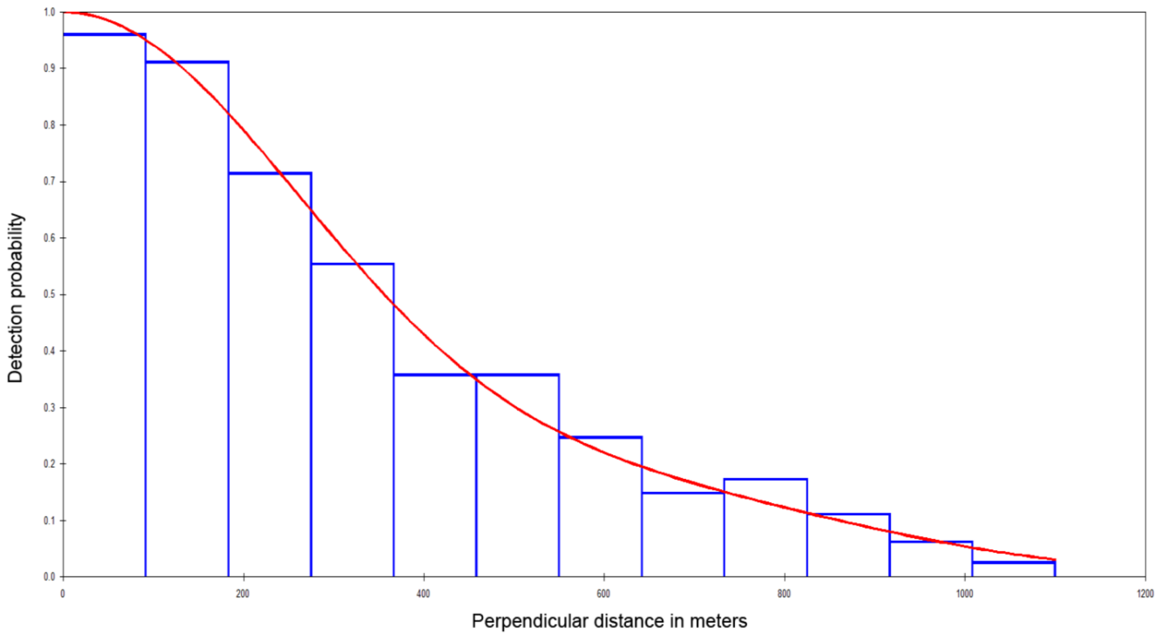

Figure 6: Detection probability functions derived from pooled data for saiga antelope during February and August of 2014, in western Mongolia

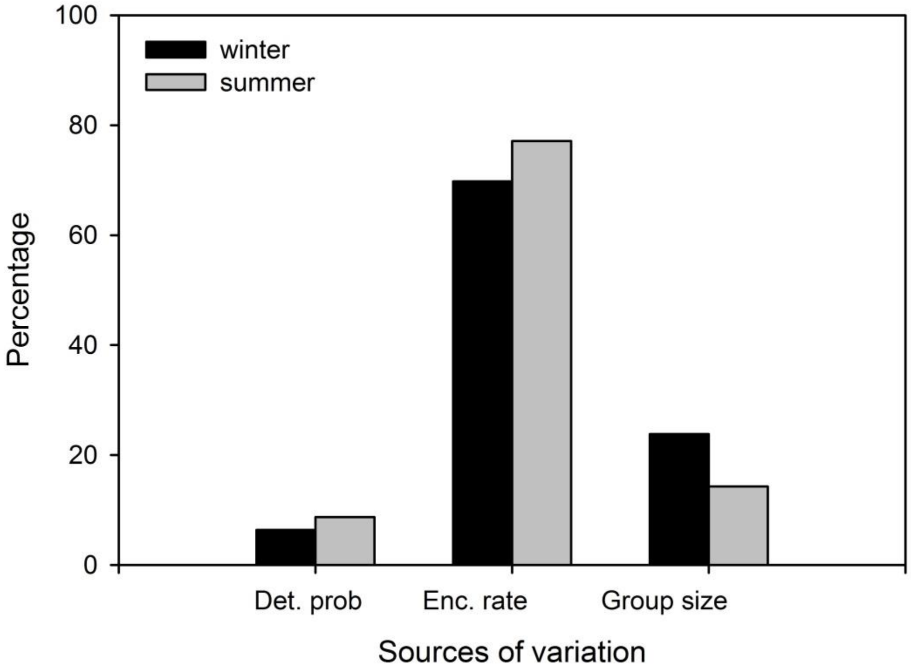

Figure 7: Contributions of encounter rate (Enc.rate), detection probability (Det.prob), and cluster size to the variance in abundance estimate of Mongolian saiga during winter and summer surveys in 2014, western Mongolia

Spatial distribution of saiga

Saiga groups were observed in 25 of 39 survey transects (64%) during winter and 27 of 39 survey transects (69%) during summer in western Mongolia, respectively (Figure 8). During the summer survey, only 53 (22% of total group) groups of 334 (19% of total individuals) saiga individuals encountered in protected areas (Figure 8). Whereas, 31 (21 of total groups) groups of 350 (18% of total saiga individuals) individuals observed within protected areas during the winter (Figure 8).

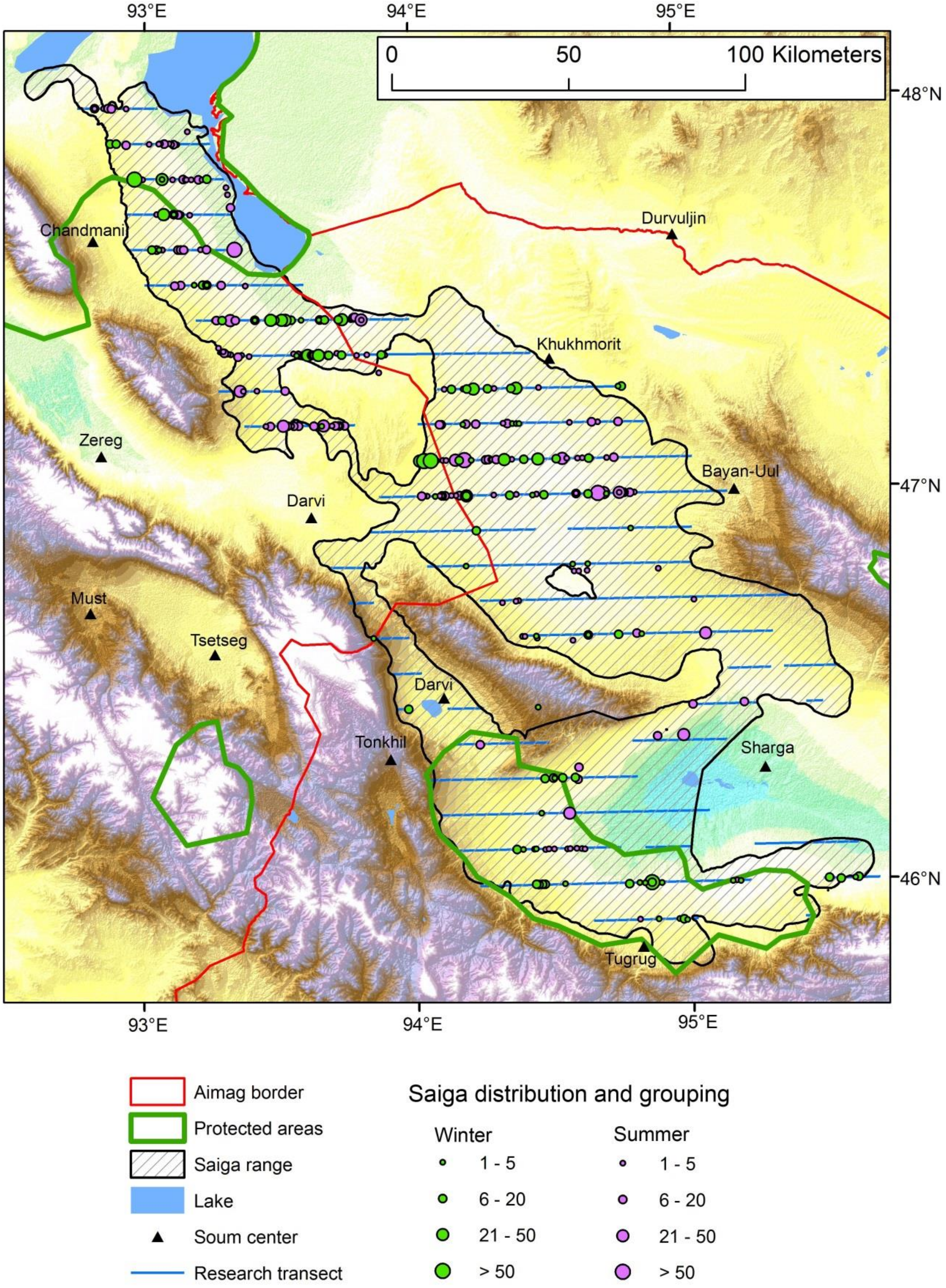

Figure 8: Spatial distribution and grouping patterns of Mongolian saiga observed along the line transects during winter and summer surveys in 2014, western Mongolia

Correlation between predictor variables

Correlations among continuous predictor variables are displayed in Figure 9. All variables are not significantly correlated and correlation of coefficients among predictor variables was < 0.5 (Figure 9). Given none of the variables showed a strong correlation; hence, they were included in the same model.

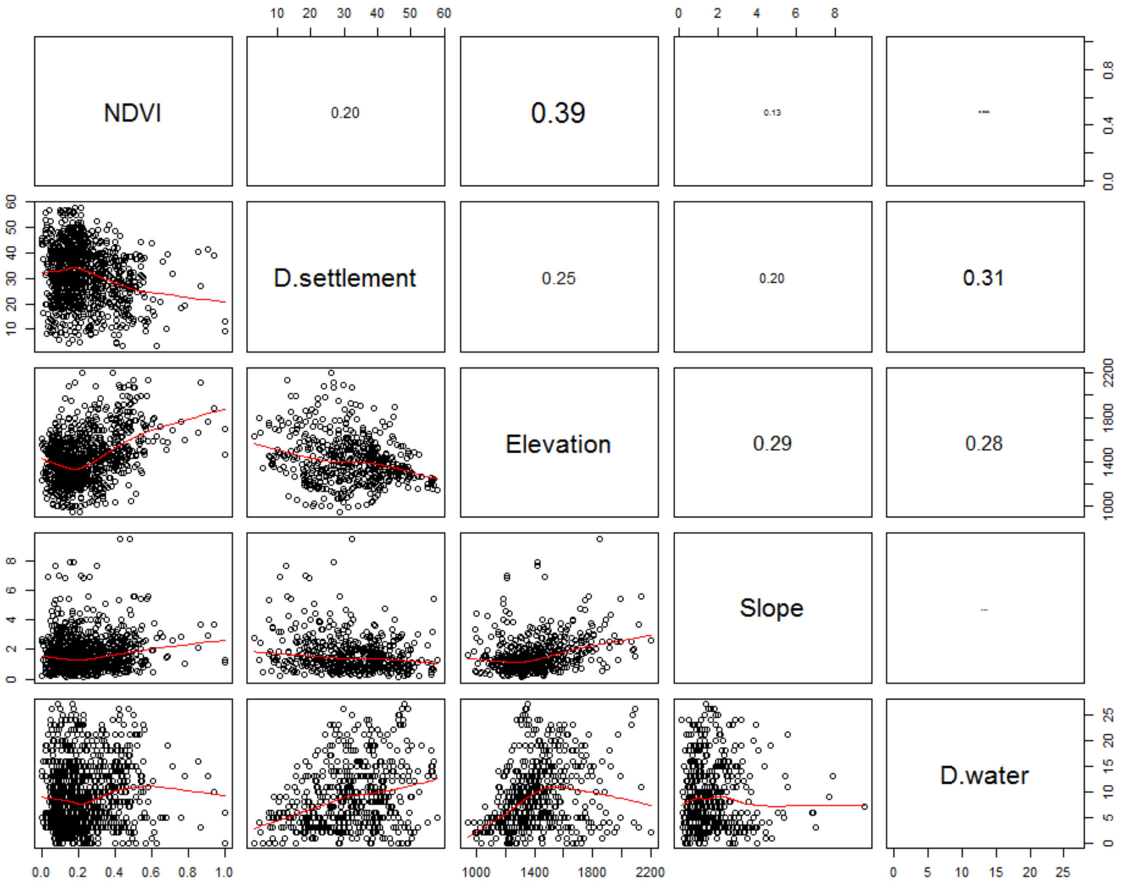

Figure 9: Scatterplot between all pairs of continuous variables with a smoothed fitted curve. The pairwise correlation coefficients displayed in the corresponding upper-right panels, with the font size scaled proportionate to the absolute value of the correlation

Correlograms for variables

The correlograms of the residuals for the GLM models determining saiga distribution are shown in Figure 10. The range of geographical distance was divided approximately 10 km in each distance class bin. Correlograms of saiga presence/absence suggests that the presence of saiga occurrences have strong positive spatial autocorrelation (e.g. the correlation becomes near zero) occur around 7 km (Figure 10). Thus the radius for autocovariance for autologistic regression model was set at 7 km, to eliminate spatial autocorrelation.

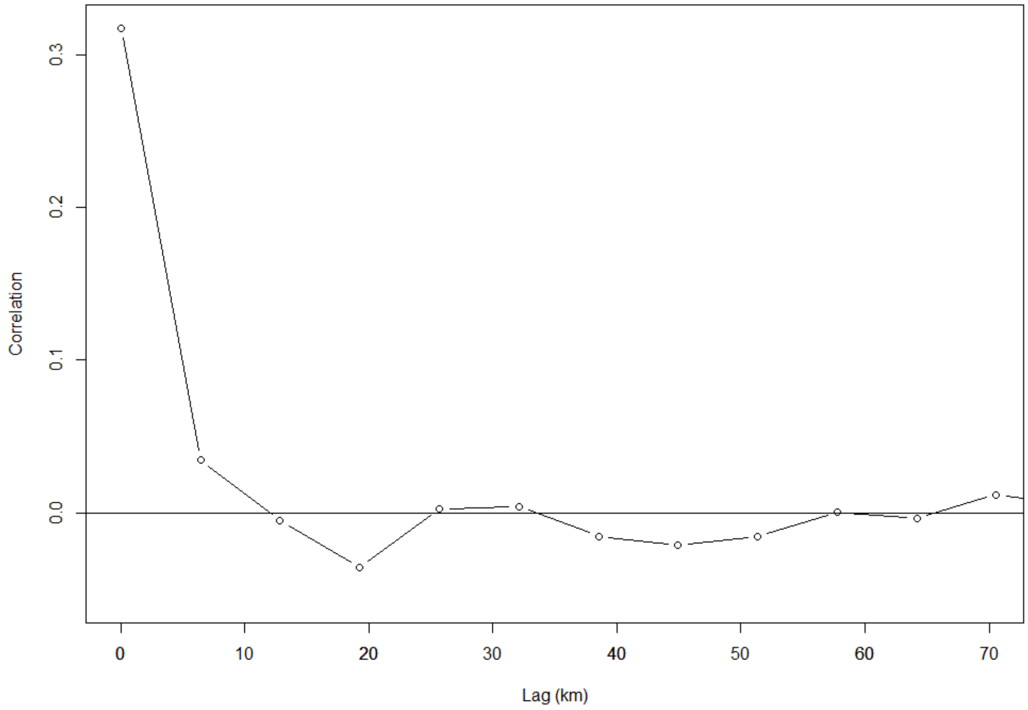

Figure 10: Correlograms of residual for the GLM to determine spatial distribution of saiga in western Mongolia

Factors affecting distribution of saiga

- Summary outcomes for the GLM (i.e. reduced model) and autologistic (i.e. full model) models that best explain the probability of saiga presence are shown in Table 3. The best model explaining spatial distribution of saiga included covariates of NDVI, elevation, and distances to water (Table 3). However, distances to water were emerged as a significant factor with their second-order polynomials, indicating the selection of intermediate values of this variable by saiga (e.g. the first being positive and the second negative). Moreover, the reduced model suggests saiga tended to occur in areas with greater NDVI value (e.g. higher vegetation productivity), but they avoided areas with higher elevation. However, proximity to settlements (i.e. soum center), and slope were less important to determine spatial distribution of saiga and did not appear in the top model.
- Although a strong positive spatial autocorrelation of saiga locations was observed at 7-km scale, when incorporating spatial autocorrelation into the GLM by adding autocovariance as a variable, the overall model fit improved (e.g. the values of model AIC and residual deviance decreased by 8 and 14%, respectively; Table 3), and a slight change in the relative magnitude of estimated coefficients was observed. The full model that included spatial autocorrelation as a predictor explained 61% of the overall variance, whereas reduced model explained 53% of the variance.
- According to the hierarchical variance partitioning approach, the relative importance of variable distance to water (36%), elevation (28%), and NDVI (23%) were greater than variables of distance nearest settlement (11%) and slope (2%) for explaining spatial distribution of saiga in Mongolia (Figure 11).

Table 3: Parameter estimates of the top ranked full (e.g. spatial autocovariance included) and reduced models explaining spatial distribution of saiga antelope in western Mongolia

Coefficient	**Full model**			**Reduced model**		
	Estimate	SE	Z	Estimate	SE	Z
Intercept	1.329	0.421	3.159**	1.523	0.390	3.898***
NDVI	1.771	0.330	5.362***	1.572	0.326	4.813***
Elevation	-0.002	0.0003	-5.944***	-0.002	0.0003	-6.223***
Distance to water	0.122	0.030	3.989***	0.160	0.029	5.444***
Distance to water^2	-0.003	0.001	-3.017***	-0.004	0.001	-4.106***
Autocovariate	0.494	0.042	11.758***	-	-	-
Model AICc		1356.6			1481.9	
Residual deviance		796.72			924.08	
Degrees of freedom		438			439	

The terms followed by ‘2’ denote second-order polynomials.
Significance codes: ‘***’ 0.001; ‘**’ 0.01

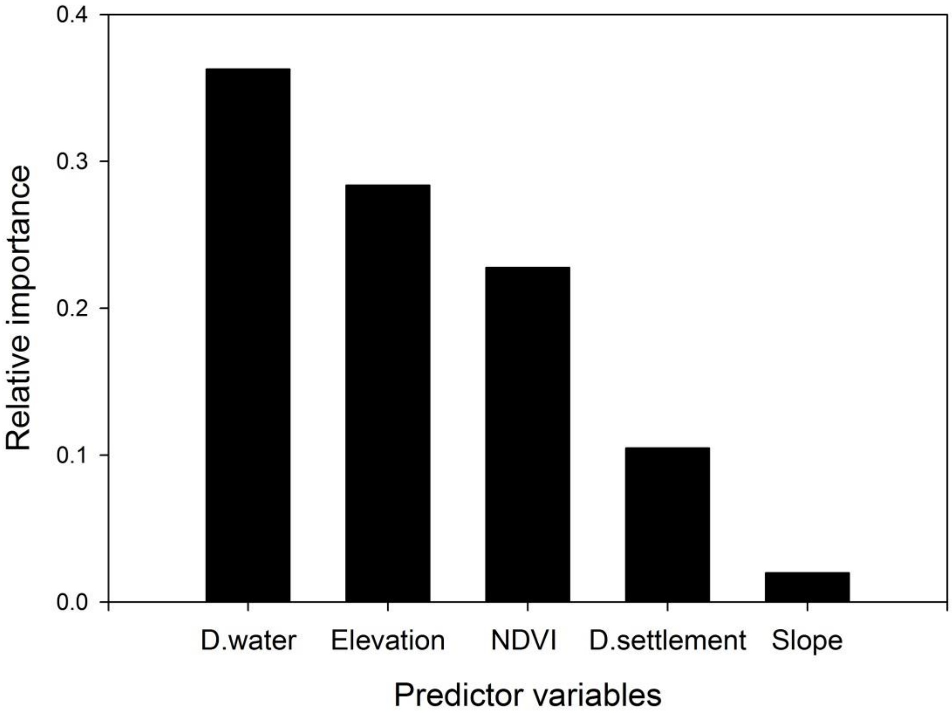

Figure 11: Importance of predictor variables explaining spatial distribution of saiga antelope in western Mongolia

DISCUSSIONS

Population estimates of ungulates

This is the first survey for Mongolian saiga to utilize statistically rigorous methodology, using line transect distance sampling to obtain population estimates across its entire range. Our population estimate for saiga in the western Mongolia is considerably larger than previous estimates, based on minimum counts (Amgalan et al. 2008; Chimeddorj et al. 2009). In addition, our density estimates was higher than the results obtained from distance sampling survey of saiga population in Shargyn Gobi region (Young et al. 2010). We suggest saiga population in Mongolia has been increased in a last decade, probably due to favorable climate and enhanced law enforcement (Chimeddorj, 2009).

Improving the precision of population estimates is a prerequisite for evaluating the effectiveness of conservation measures, as wide confidence intervals complicate detection of any trends (Young et al. 2010). Such evaluations also depend on the magnitude of fluctuations in population size due to factors such as disease and weather relative to the impact of conservation actions such as anti-poaching measures. Our population estimates had somewhat high variance, making it difficult to determine changes in population size over time. Because it is difficult to detect changes in population abundance of small and widely distributed populations, an important next step in developing a standardized monitoring protocol is to identify methods that improve precision, thereby increasing our ability to detect changes that result from a reduction in threats.

The analytical variance of a density or abundance is estimated by the delta method that comprises three components, corresponding to estimation of encounter rate, the detection function and mean cluster size in the population (Buckland et al. 2001). A key assumption of the distance sampling is that the distribution of target species is homogenous across the landscape (Thomas et al. 2010). However, grouping pattern and distribution of saiga in Mongolia is closely tied to season due to seasonal variability in resources, predation risk, and anthropogenic disturbances. For example, group size of Mongolian saiga is highly variable throughout the year and seasonality exerts strong effects (Buuveibaatar et al. 2013a). This was confirmed during the ground surveys and the group sizes are markedly different between seasons with much larger groups in winter (hence also smaller encounter rate). In addition, the survey efforts in winter and summer studies were the same, but the encounter rate almost doubled in summer (e.g. 0.08 in winter vs. 0.15 in summer). For these reasons, conducting a ground based Distance sampling survey during the summer is suggested to obtain more precise estimates. Although variance needs to be reduced and the field protocol for distance sampling improved, our results demonstrate that distance sampling can be an effective technique for monitoring saiga populations in western Mongolia.

Factors affecting spatial distribution of saiga

We have shown that multiple factors affecting distribution of saiga antelope in western Mongolia. Our model demonstrate that the spatial distribution of saiga best explained by factors of NDVI, elevation, and distances to nearest surface water. Distances to the nearest water source, however, appeared as a significant predictor with its second-order polynomials, indicating the selection of intermediate values of this variable by saiga. In addition, saiga preferred the habitat with greater NDVI (e.g. vegetation productivity) value, but they avoided areas with higher elevation. Whereas, proximity to the settlements (e.g. human disturbance), and slope were less important to determine spatial distribution of saiga and did not emerge in the top model.

Large herbivores inhabiting arid environments face unique challenges when securing resources, including forage and water (Marshal et al. 2006; Bleich et al. 2010), which are necessary for survival and reproduction and that ultimately influence population dynamics and persistence. According to the spatial model, it is suggested that the probability of saiga presence increases in areas that are located in an intermediate distance from the nearest source of water, and might be explained as a trade-off between disturbance water, safety, and requirements. Similar habitat use behavior was observed for wild Bactrian camel (*Camelus ferus*) in Transaltai Gobi of southwestern Mongolia (Kaczensky et al. 2014).

Unsurprisingly, the NDVI emerged as an important covariate to explain distribution of saiga in western Mongolia. In eastern steppe, more productive environment, Mongolian gazelle select for areas of intermediate NDVI values, which reflects the trade-off may relate to low NDVI limiting ingestion rates and areas with high NDVI having mature forage with low digestibility (Mueller et al. 2008). Vegetation study and fecal analysis suggest that saiga have a preference for feeding on high quality plants such as onion (*Allium spp.*), grasses (*Stipa spp.*) and *Anabaisis brevifolia*, although vegetation availability and diversity is low relative to other parts of the country (Buuveibaatar et al. 2011), which reflect more NDVI values in comparison to saxual (*Haloxylon ammodendron*) and shrub communities (Heiner et al. 2013).

To improve the model predictability, three additional factors that potentially influence saiga habitat selection are particularly worth considering. First, saiga habitat use could be influenced by predator density or behavior, because saiga are prey for a number of predators

(Buuveibaatar et al. 2013b). Second, variation in plant species composition may go along with differences in nutritional quality (Reich et al. 2001), while productivity rates are similar. Information about species composition and their spatiotemporal dynamics may thus aid efforts to predict saiga presence. Lastly, anthropogenic influences, despite the area's sparse human population, may be important, and spatial variation in density of herders may be an informative covariate. Detailed data on any of these covariates were not available to apply to the saiga survey data used in this study, and would require additional extensive and repeated field surveys.

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