Mongolian Gobi supports the world's largest populations of khulan *Equus hemionus* and goitered gazelles *Gazella subgutturosa*

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Abstract Mongolia's Gobi Desert ecosystem, a stronghold for populations of the Asiatic wild ass (khulan) *Equus hemionus* and the goitered gazelle *Gazella subgutturosa*, faces conservation challenges as a result of rapid economic development, including mining-related infrastructure projects. There is a paucity of reliable data on population abundance for these ungulates in the region, which makes it difficult to assess how they are responding to increasing anthropogenic pressure. Our aim was to obtain abundance estimates for khulan and goitered gazelles to inform their management and form the basis of a long-term monitoring programme. Each year during 2012–2015 we surveyed a total of 64 line transects spaced 20 km apart, with a total of 3,464 km of survey effort across 78,717 km². Distance sampling analysis provided annual estimates of density and abundance, which were cross-referenced with the results of an aerial survey conducted in 2013. Overall, we observed 784 groups (14,608 individuals) of khulan and 1,033 groups (3,955 individuals) of goitered gazelles during the four surveys. The abundance estimates for 2013 were 35,899 (95% CI 22,680–40,537) khulan and 28,462 (95% CI 21,326–37,987) goitered gazelles. These estimates were congruent with the results from the aerial survey, which overlapped spatially and temporally with our ground-based survey. Our findings confirm that Mongolia's Gobi Desert supports the largest population of khulan and goitered gazelles in the world, and we provide a critical update on the status of the two species.

Keywords Distance sampling, *Equus hemionus*, *Gazella subgutturosa*, Gobi Desert, Mongolia

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Introduction

The rangelands of Central Asia provide habitat for a large number of migratory ungulates (Mallon & Jiang, 2009). One of the most important regions for the conservation of these ungulates is the Gobi–Steppe ecosystem of Mongolia, which comprises the largest area of intact grassland in the world (Batsaikhan et al., 2014). Mongolia's Southern Gobi area, in particular, is an iconic ungulate stronghold that supports substantial populations of the Asiatic wild ass (khulan in Mongolian) *Equus hemionus* and the goitered (or black-tailed) gazelle *Gazella subgutturosa* (Reading et al., 2001).

An increasing human population, expanding exploitation of natural resources, and the development of infrastructure in the region are placing increasing pressure on these species and their habitats (Kaczensky et al., 2011b; Ito et al., 2013; Batsaikhan et al., 2014). As the footprint of human development continues to expand in the landscape, conservation management to ensure the survival of these species requires long-term datasets that provide accurate information on changes in abundance and distribution both spatially and temporally.

The khulan is categorized as Near Threatened on the IUCN Red List, and the species has lost as much as 70% of its range (Kaczensky et al., 2015b). Poaching has been the primary driver of past population declines (Stubbe et al., 2012), although habitat loss and fragmentation across the species' range may also be contributory factors (Batsaikhan et al., 2014). The goitered gazelle is categorized as Vulnerable (Mallon, 2008), with a decreasing population trend attributed primarily to exploitation, habitat degradation and human disturbance (Clark et al., 2006). Past population surveys of khulan and goitered gazelles in Mongolia were based on limited survey efforts and non-standardized survey protocols, and produced imprecise and potentially biased estimates (Lhagvasuren, 2007; B. Lhagvasuren & S. Strindberg, unpubl. data).

The effectiveness of mitigation measures aimed at reducing the impacts of mining-related activities and infrastructure development cannot be evaluated without proper monitoring. Consequently, obtaining unbiased and precise estimates of density and abundance for the plains ungulates inhabiting this landscape is crucial. Despite population size estimation being one of the most critical prerequisites for conservation planning, long-term monitoring is often hindered by lack of funds and logistical constraints. For this reason robust monitoring programmes using contemporary scientific methods are still not widely employed in Central Asia (Singh & Milner-Gulland, 2011).

Distance sampling techniques for estimating the density and abundance of wildlife are well established (Buckland et al., 2001), with associated survey design and analysis software (Thomas et al., 2010). Distance sampling line transect surveys are increasingly used for population estimates of wild ungulates in Mongolia (e.g. Olson et al., 2005; Young et al., 2010; Wingard et al., 2011) and have been shown to be an appropriate and cost-effective method for estimating the abundance of relatively large and conspicuous species at low population densities over vast open areas (Sutherland et al., 2006). However, most surveys have been conducted only once or twice, and have rarely if ever been compared to simultaneous surveys employing alternative methods.

Our overarching goal was to develop research techniques and implement field surveys to provide baseline and long-term data. We present the results of extensive ground-based distance sampling surveys of khulan and goitered gazelles for consecutive years during 2012–2015 in the Southern Gobi of Mongolia, and compare the results to those of an independent aerial survey conducted in 2013 across a larger area. We also make recommendations for further improvements to ground-based ungulate survey efforts to ensure a robust long-term monitoring programme.

Study area

The 98,216 km² study area in Mongolia's Southern Gobi (Fig. 1) was defined based on existing information on the distribution of khulan, which have the larger range of the two study species (Kaczensky et al., 2011b). Elevations in the study area are 683–1,884 m. Mean annual precipitation is c. 150 mm, and the annual temperature range is −35–40°C. Surface water is restricted to springs, some of which are permanent, primarily located in or near mountain ranges. The few tree species include saxaul *Haloxylon ammodendron* and elm *Ulmus pumila*, which are confined to the river valleys and basins. The most common vegetation includes *Stipa* spp., *Artemisia* spp., *Allium* spp. and *Anabasis* spp. Argali *Ovis ammon* and ibex *Capra sibirica* are present in the mountainous areas, and larger mammalian predators include wolves *Canis lupus*, lynx *Lynx lynx*, red foxes *Vulpes vulpes* and corsac foxes *Vulpes corsac*.

There are four protected areas, which comprise c. 20% of the study area (Fig. 1). Human populations in the region are concentrated in *soums* (villages/towns; Fig. 1), with the rural population consisting primarily of semi-nomadic livestock herders. The Southern Gobi is the centre of the cashmere goat industry in Mongolia, the key source of income for local herders (Berger et al., 2013). Thus, domestic livestock consists primarily of goats and sheep, with small numbers of camels and horses. The study area is bordered to the south and east by two impermeable linear infrastructures constructed in the 1950s, namely a fenced border with China, and the Trans Mongolian Railroad corridor (fenced on both sides). To the west there are two parallel paved roads that connect major mines with the Chinese border crossing.

Methods

We conducted distance sampling line transect surveys using a systematic survey design, with a random start point and a spacing of 20 km between transects (Strindberg et al., 2004). A survey design with 28 transects (mean = 166.19 km; range 41.92–221.38 km) and a total survey effort of 4,820 km was generated using *Distance 6.2* (Thomas et al., 2010). Transects were oriented north–south to minimize potential visibility problems caused by glare. Given the ruggedness of the topography (mountains and sand dunes), we truncated 28% of the total transect length, resulting in 64 shorter transects (mean = 54.07 km; range 4.25–204.78 km). This resulted in a total survey effort of 3,464 km across 78,717 km², excluding those portions of the original 98,216 km² area that were inaccessible (Fig. 1). The final design provided a sufficient number of replicate lines to ensure that variation in encounter rate could be estimated with adequate precision, and ensured sufficient observations per ungulate species to fit the detection function (Buckland et al., 2001).

The ground-based surveys were conducted in the first half of October 2012, and in late May and early June in 2013, 2014 and 2015; each survey lasted 14–18 days. We drove along transects at 20–30 km per hour during daylight hours, using a global positioning system (GPS) for orientation. Observers scanned the area in front of them and out to 90° on either side. When a group of khulan or goitered gazelles was detected, the location, group size, radial distance (r), and sighting angle (θ) were recorded using a GPS, compass, binoculars, spotting scope and rangefinder. The ungulates often began to run after we detected them, and therefore we used a landscape feature at the point of detection to measure r and θ. The unit of observation was the group, and measurements were recorded to the centre of

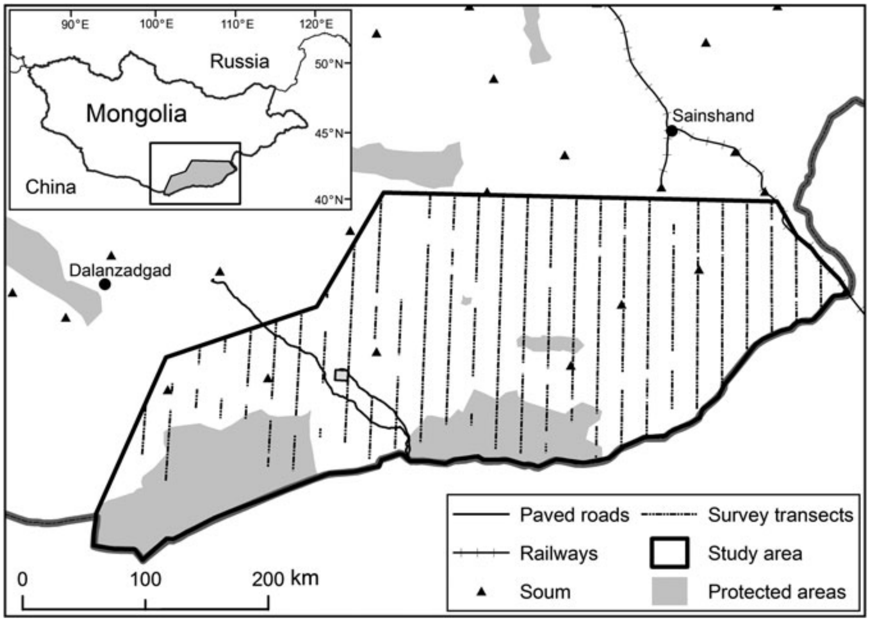

FIG. 1 Location of line transects surveyed for khulan *Equus hemionus* and goitered gazelles *Gazella subgutturosa* in the Southern Gobi, Mongolia, during 2012–2015.

the group. The perpendicular distances of observations from the transect line, calculated as $x = r\sin(\theta)$ in *Distance*, were used to estimate a detection probability function. The detection function gives the probability of a group being detected, as a function of distance from the line $g(x)$.

Data analysis

Grouping patterns Differences in ungulate group sizes between autumn and spring were examined using a *t*-test. One-way analysis of variance was used to test for variability in group size among the three spring surveys. The group sizes were log transformed to ensure the data met the assumption of following a normal distribution.

Population estimate Data were analysed using *Distance* to obtain density and abundance estimates for each of the study species (Thomas et al., 2010). Densities were estimated as:

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

where L denotes the aggregate length of the transects, n is the number of groups observed, $f(0)$ is the probability density function of observed perpendicular distances evaluated at $x = 0$, and $\hat{E}(s)$ is the estimated expected group size (Buckland et al., 2001). The density of individuals is multiplied by the surface area of the study area to obtain the corresponding abundance estimate ($\hat{N}$). Exploratory analyses were 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, with data either stratified by survey season or pooled across seasons. Histograms of the data and goodness of fit tests were used to identify any 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, which is important for robust estimation (Buckland et al., 2001). The data were always stratified to facilitate estimation of encounter rate and expected group size specific to each survey season. To deal with potential size bias in the estimation of group size we used the expected group size rather than the mean group size when the regression line fit to the natural logarithm of group size vs $g(x)$ was significant at a 15% alpha level. We used a *z*-test to determine if a change in density could be detected between surveys (Buckland et al., 2001) at the 10% significance level (more conservative for management purposes). As a result of poaching activities in some areas, ungulates sometimes moved before distance and angle measurements could be taken. To avoid potentially negatively biased density estimates caused by responsive movement away from the observer, the survey teams looked far ahead to detect animals and attempted to obtain measurements before movement occurred. In contrast, heaping at zero, where there are more observations than expected on or close to the line, can produce positively biased estimates of density.

Evaluation of population estimates An aerial survey was completed in 2013 and covered an area of 150,000 km² across much of the Southern Gobi (Norton-Griffiths et al., 2015). This provided an opportunity to contrast the results produced by two independent survey methods. We assessed the accuracy of the 2013 ground survey by comparing the results with those of the aerial survey, which used a photograph-based method. The plane followed north–south transects at 5 and 10 km spacing, and photographs (n = 101,000) were taken every 250 m, on average. The camera was angled straight down at an altitude of c. 427 m, and each photograph covered an area of c. 125 × 185 m^2. The aerial survey included the entire ground survey area except for a 15-km-wide strip with an area of 10,781 km^2 along the Mongolia–China border, where the plane was not allowed to fly (Supplementary Fig. S1). No type of terrain was excluded. In total, the overlap zone between the aerial and ground surveys comprised 75,281 km^2, when the areas inaccessible to the ground survey were removed. The aerial survey was conducted during 23 May–2 July 2013, covering the 24 May–7 June period of the 2013 ground survey. Population estimates for the study species based on the aerial survey data were made using method 2 of Jolly (1969) for unequal sized sampling units. There were difficulties distinguishing between goitered and Mongolian gazelles *Procapra gutturosa* in aerial survey photographs. However, there is no reason to assume that the total gazelle count is inaccurate. During the ground survey 279 groups of goitered gazelles and 75 groups of Mongolian gazelles were observed, with a mean group size of 3.1 and 9.1 individuals, respectively. There were few, if any, instances of gazelles being captured in two adjacent photographs taken during the aerial survey. We can therefore assume that each group of gazelles was captured by a single photograph. Thus a ratio of Mongolian to goitered gazelle groups obtained from the temporally coincident ground survey (where species identification is not a significant problem) was applied to the total gazelle estimate from the aerial survey to obtain separate estimates for each of the gazelle species.

Results

Grouping patterns

Overall, 784 khulan groups and 14,608 individuals, and 1,033 goitered gazelle groups and 3,955 individuals, were observed during 2012–2015 (Table 1). Both species formed significantly larger groups in autumn (t-test; khulan: $t = 5.62$, $P < 0.001$, goitered gazelle: $t = 5.84$, $P < 0.001$) compared to spring. There was no significant difference in group size of khulan among the three spring surveys ($F = 1.48$, $P = 0.22$); however, the mean group size of goitered gazelles was significantly larger in spring 2015 ($F = 6.68$, $P < 0.001$). For the pooled data across 4 years, overall mean group size was 20.26 ± SD 36.78 for khulan and 3.88 ± SD 3.70 for goitered gazelles (Table 1).

Khulan groups most frequently comprised 2–5 individuals (range 24.0–42.1% of groups; Fig. 2a), and only 4–12 groups (2.0–9.3%) of > 100 individuals were observed. The distribution of goitered gazelle group size was also skewed towards smaller groups; groups of < 5 individuals comprised 67.1–88.5% of all groups recorded during the four surveys (Fig. 2b). Goitered gazelle groups with > 10 individuals were rare, comprising only 3.4–8.4% of groups observed for all years.

Population estimates of khulan

Pooling the data across the first three survey seasons provided a larger data set to better deal with the likely inaccuracies resulting from responsive movement and heaping at zero, and to fit an unbiased detection function. A separate detection function was fit to the spring 2015 data as there was no evidence of substantial violations of assumptions. The pooled data for the first three surveys were right-truncated at 1,400 m (4% loss of data) and placed in six equal-sized intervals for the final model (Fig. 3a). The resulting estimate for the detection probability was 0.42 (95% CI 0.38–0.46), with an associated effective strip width ($\hat{\mu}$) of 584.53 m (95% CI 526.41–649.08). The spring 2015 data were right-truncated at 1,250 m (8% loss of data) and placed in seven equal-sized intervals (Fig. 3b). The subsequent estimate for the detection probability was 0.48 (95% CI 0.42–0.54), with an associated $\hat{\mu}$ of 596.42 m (95% CI 530.22–670.88). Mean group size, $\bar{s}$, was smaller than the expected group size, $\hat{E}(s)$, for the first two surveys, and larger than $\hat{E}(s)$ for the last two surveys. Size bias was statistically significant for all spring surveys, and thus $\hat{E}(s)$ was used in the estimation for these surveys, and $\bar{s}$ for the autumn 2012 survey. The encounter rate (n/L) was lowest (0.03 groups km^{-1}) and the group sizes markedly larger in autumn 2012 (Table 2), with the latter leading to the largest individual density for that survey (Table 3). Density estimates varied from 0.45 individuals km^{-2} in spring 2013 to 0.83 km^{-2} in autumn 2012, with total population estimates of 35,899 and 65,739, respectively (Table 3). Despite the larger density and abundance estimate for the autumn 2012 survey, differences among the surveys were not statistically significant, because of large confidence intervals. Uncertainty in the density estimates in all four surveys was mostly attributable to estimation uncertainty in the encounter rate (63.6–67.4% of the variance), followed by the group size (29.4–31.2%), and detection probability (3.0–6.4%).

Population estimates of goitered gazelles

The data were pooled across four survey seasons and distances were grouped into eight equal-sized intervals to

TABLE 1 Results of driven line transect surveys for khulan *Equus hemionus* and goitered gazelles *Gazella subgutturosa* in the Southern Gobi, Mongolia (Fig. 1), during 2012–2015, with year and season, number of groups, number of individuals, median, mean and range.

Year (season)	No. of groups	No. of individuals	Median	Mean ± SD	Range
Khulan					
2012 (Autumn)	140	4,941	12.0	35.29 ± 52.65	1–275
2013 (Spring)	247	3,001	4.0	12.07 ± 25.71	1–250
2014 (Spring)	192	3,571	5.0	18.59 ± 34.37	1–302
2015 (Spring)	205	3,095	5.0	15.09 ± 34.41	1–351
Overall	784	14,608	5.0	20.26 ± 36.78	1–351
Goitered gazelle					
2012 (Autumn)	234	1,140	3.0	4.89 ± 4.28	1–30
2013 Spring)	279	863	2.0	3.10 ± 3.25	1–33
2014 (Spring)	269	894	2.0	3.34 ± 3.13	1–23
2015 (Spring)	251	1,058	3.0	4.21 ± 4.15	1–32
Overall	1,033	3,955	3.0	3.88 ± 3.70	1–33

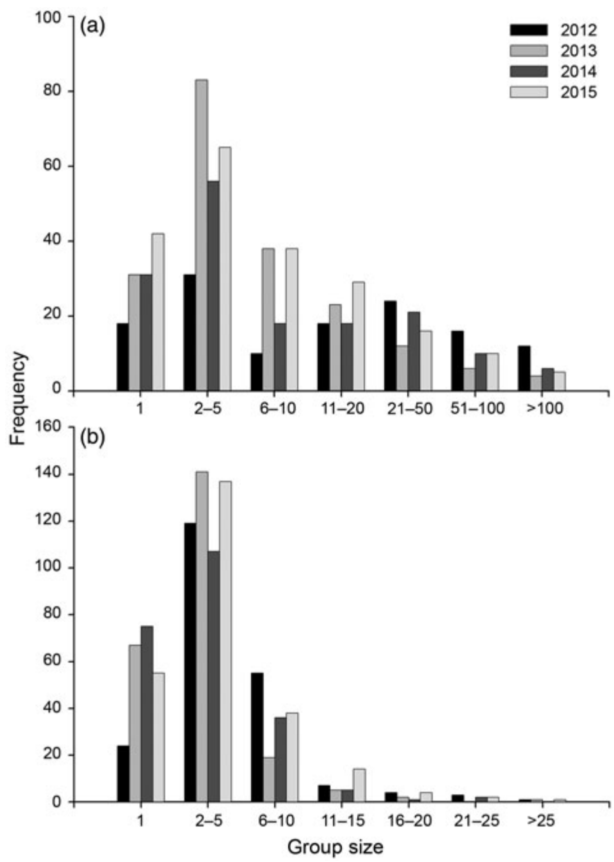

FIG. 2 Grouping patterns of (a) khulan and (b) goitered gazelles observed during ground surveys in 2012–2015 in Southern Gobi, Mongolia (Fig. 1). Note that the scales of the frequency axes differ.

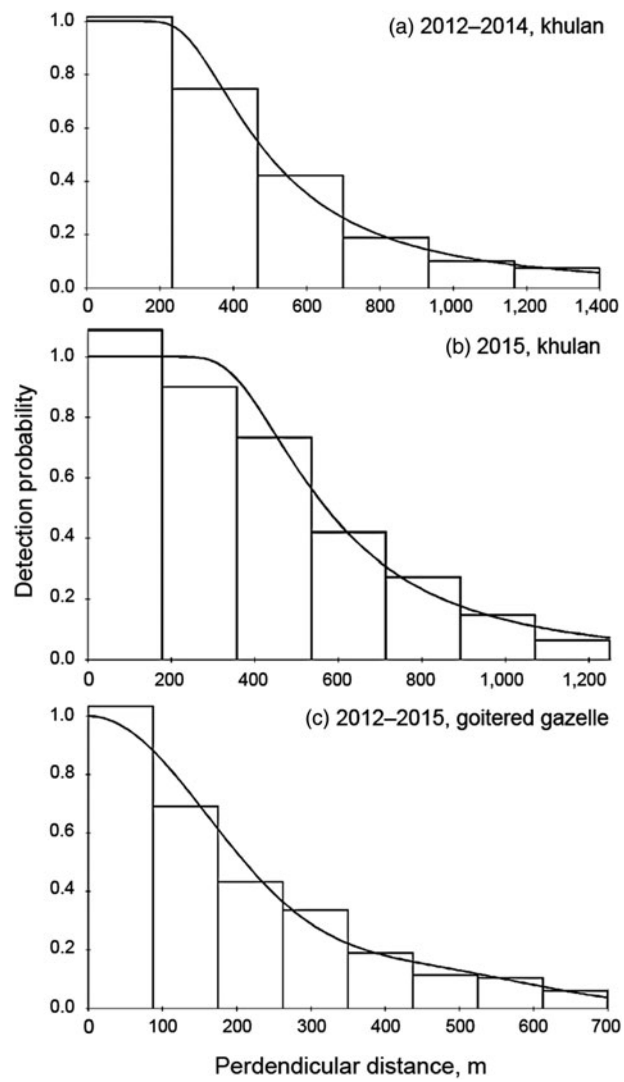

FIG. 3 The detection probability function fit to (a) the pooled data for 2012–2014, (b) the spring 2015 data for khulan, and (c) the pooled data from all four surveys (2012–2015) for goitered gazelles.

help fit an unbiased detection function because heaping at zero and responsive movement was evident in all surveys. The pooled data from the four surveys were right-truncated at 700 m (< 4% of the data) for the final model (Fig. 3c). The best fitting model was a half-normal function with cosine

Table 2 Estimates of encounter rates (groups km^{-1}), expected group size, and mean group size, with 95% confidence intervals, for khulan and goitered gazelles, based on line transect surveys conducted in the Southern Gobi, Mongolia (Fig. 1), during 2012–2015.

Year (season)	No. of groups km^{-1} (95% CI)	Expected group size (95% CI)	Mean group size (95% CI)
Khulan			
2012 (Autumn)	0.03 (0.02–0.05)	28.96 (19.31–43.41)	27.05 (20.59–35.53)
2013 (Spring)	0.06 (0.04–0.08)	8.24 (6.78–10.01)	11.21 (8.25–14.97)
2014 (Spring)	0.04 (0.03–0.07)	12.62 (9.32–17.08)	17.85 (13.32–23.91)
2015 (Spring)	0.05 (0.03–0.07)	11.01 (8.29–14.63)	14.71 (10.78–20.05)
Goitered gazelle			
2012 (Autumn)	0.06 (0.05–0.08)	4.23 (3.77–4.74)	4.77 (4.23–5.37)
2013 (Spring)	0.07 (0.05–0.09)	2.79 (2.52–3.10)	3.13 (2.73–3.59)
2014 (Spring)	0.06 (0.05–0.08)	3.14 (2.78–3.54)	3.40 (3.01–3.84)
2015 (Spring)	0.06 (0.05–0.08)	3.45 (3.05–3.90)	4.17 (3.65–4.75)

Table 3 Estimates of density (individuals km^{-2}) and abundance of khulan and goitered gazelles, with 95% confidence intervals and their percent coefficient of variation (%CV), based on line transect surveys conducted in the Southern Gobi, Mongolia (Fig. 1), during 2012–2015.

Year (season)	Density, individuals km^{-2} (95% CI)	Abundance (95% CI)	(%CV)
Khulan			
2012 (Autumn)	0.83 (0.52–1.29)	65,739 (40,462–106,810)	24.92
2013 (Spring)	0.45 (0.31–0.67)	35,899 (22,680–40,537)	18.47
2014 (Spring)	0.50 (0.30–0.86)	39,998 (25,234–42,153)	26.81
2015 (Spring)	0.46 (0.27–0.78)	36,298 (21,447–61,434)	27.08
Goitered gazelle			
2012 (Autumn)	0.50 (0.38–0.68)	39,602 (29,638–52,916)	14.69
2013 (Spring)	0.36 (0.27–0.48)	28,462 (21,326–37,987)	14.62
2014 (Spring)	0.39 (0.30–0.50)	30,744 (23,833–39,658)	12.92
2015 (Spring)	0.43 (0.33–0.55)	33,627 (26,090–43,340)	12.88

adjustment terms giving an estimated detection probability of 0.37 (95% CI 0.34–0.40), with an associated $\hat{\mu}$ of 258.45 m (95% CI 241.11–277.05). Encounter rate was similar between the four surveys (c. 0.06 groups km^{-1}), although the expected group size was largest in autumn 2012 (Table 2). For all seasons there was significant size bias, with $\bar{s}$ being consistently larger than $\hat{E}(s)$, probably as a result of smaller groups being missed at larger distances. Thus $\hat{E}(s)$ was used in the estimation of density and abundance. Density estimates varied (0.36–0.50 individuals km^{-2}), with total population estimates of 28,462–39,602 (Table 3). There was no detectable difference in density estimates among the surveys, although the larger $\hat{E}(s)$ resulted in larger individual density and abundance estimates for autumn 2012. Similarly to khulan, most of the variance in the abundance estimate was attributable to the encounter rate (68.8–81.8%), whereas group size and detection probability contributed 13.0–23.6 and 5.8–7.6% of the variance, respectively.

Evaluation of population estimates

The reliability of the abundance estimates of khulan based on the ground survey data was supported by the congruent estimate obtained from the aerial survey (25,838 from the ground survey compared to 26,969 from the aerial survey in the 75,281 km^2 overlap area; $z = 0.21$, $P > 0.83$). Furthermore, the precision (coefficient of variation) of the estimates is similar: 21% vs 19%. Dealing with the problem of gazelle species identification by applying the ratio of gazelle groups (75/279 = 0.269) during the ground survey to the total gazelle estimate from the aerial survey (39,112) yields an estimate of 28,598 goitered gazelles in the overlap zone. This is comparable with the estimate from the ground survey (27,892; $z = 0.14$, $P > 0.88$). The precision of the estimates is also similar: 18% for ground surveys and 17% for the aerial survey.

Discussion

This is the first attempt to produce consecutive population estimates for khulan and goitered gazelles in the Southern Gobi using a standardized survey protocol. Our results confirm that Mongolia's Gobi ecosystem contains the largest populations of khulan and goitered gazelles. Our population estimates for khulan are c. 2–3 times larger than a previous estimate in 2009 (B. Lhagvasuren & S. Strindberg, unpubl. data). Although we cannot rule out that high poaching pressure in the early 2000s reduced the khulan population in the

TABLE 4 Hypothetical scenarios for 6-, 12-, and 18-year monitoring programmes in which surveys take place every 2 years. The power (the probability of being able to detect a certain change, with values in bold indicating acceptable power) is given for various positive and negative changes in population size, with precision expressed as the percent coefficient of variation (%CV) associated with the survey estimate. We assume exponential population changes and a significance level of 10 or 15%, the latter being more conservative for management purposes.

	%CV = 15		%CV = 20		%CV = 25	
Annual population change (%)	$\alpha = 10\%$	$\alpha = 15\%$	$\alpha = 10\%$	$\alpha = 15\%$	$\alpha = 10\%$	$\alpha = 15\%$
6-year monitoring programme						
1	10	15	10	15	10	15
5	14	21	12	18	12	17
10	23	33	18	26	15	23
−1	10	15	10	15	10	15
−5	14	21	12	19	12	17
−10	25	36	19	29	16	24
12-year monitoring programme						
1	14	20	12	18	11	17
5	73	**82**	52	63	40	50
10	**100**	**100**	**95**	**98**	**84**	**91**
−1	13	19	12	18	11	17
−5	76	85	55	66	42	53
−10	**100**	**100**	**97**	**99**	**90**	**95**
18-year monitoring programme						
1	24	32	18	25	15	22
5	**100**	**100**	**96**	**98**	**87**	**92**
10	**100**	**100**	**100**	**100**	**100**	**100**
−1	23	31	18	24	15	21
−5	**100**	**100**	**97**	**99**	**89**	**94**
−10	**100**	**100**	**100**	**100**	**100**	**100**

region (Wingard & Zahler, 2006), we believe that these low estimates were primarily attributable to a limited survey effort and non-standardized survey protocols. Thus the current higher estimates need to be interpreted as reflecting improved monitoring methods rather than an increase in population as a result of conservation interventions.

Our density estimates for khulan and gazelles are of the same order of magnitude but somewhat lower than those obtained in the Great Gobi 'B' Strictly Protected Area in south-western Mongolia (Ransom et al., 2012). Differences in population density and the ratio of khulan to gazelles probably reflect differences in habitat, human land use and protection. In particular, the khulan's range in south-western Mongolia falls largely within the Great Gobi 'B' Strictly Protected Area (c. 9,000 km²), where mining activities are illegal and infrastructure development is minimal. Furthermore, the presence of herders and livestock is seasonal, and resource (e.g. water and pasture) availability tends to be more predictable (D. Nandintsetseg, unpubl. data).

The precision of wildlife population surveys is generally low, and coefficients of variation of c. 30% are not uncommon (Kaczensky et al., 2015a). In this context, the estimates for the goitered gazelle, in particular, are good, with coefficients of variation < 15%. The precision of estimates for the khulan, at 18–27%, is also acceptable. However, improving the precision of population estimates for ungulates in the Southern Gobi would facilitate evaluation of the effectiveness of conservation measures, as wide confidence intervals make the detection of trends more challenging. Such evaluations also depend on the magnitude of fluctuations in population size in response to various environmental and anthropogenic factors, including unfavourable weather conditions (e.g. droughts and harsh winters) and poaching (Kaczensky et al., 2011a; Stubbe et al., 2012).

Power analyses indicate that it is difficult to detect change, even with a coefficient of variation of 15%. In 10 years an exponential decline of 1, 5 or 10% per year would result in losses of c. 10, 40 or 65% of the population, respectively (Table 4). Changes of this magnitude would be difficult to detect, in part because population changes are usually masked by process error (i.e. variation in true population size; Ahrestani et al., 2013). Moreover, the demographics of khulan and gazelles in Mongolia are not well studied. This highlights the need for a cautious management approach, as well as triangulation of results (i.e. considering the results from telemetry studies, habitat models and khulan carcass surveys), rather than relying solely on ground survey results to signal a statistically significant decline.

Three components contribute to the variance of the density or abundance estimate, namely the variance associated with the estimation of (1) the encounter rate, (2) the detection function, and (3) the expected group size (Buckland et al., 2001). The distribution of ungulates in the study area is closely related to seasonal variability in resources and anthropogenic disturbances. Thus, during the ground-based surveys, for both ungulate species, variance associated with encounter rate and expected group size were the largest contributors to the overall variance in density or abundance. Khulan and goitered gazelles formed smaller groups during the spring relative to the autumn survey, resulting in higher encounter rates, particularly for khulan. Consequently, surveys conducted in late spring would probably provide more precise and more accurate population estimates.

Photograph-based aerial surveys (c. USD 500,000) have certain advantages over the more cost-effective ground-based surveys (c. USD 50,000). Responsive movement of wildlife is generally less of a problem in aerial surveys, although this is a function of survey altitude and the characteristics of the aerial platform. Aerial photographs help to estimate group size accurately, even though species identification issues arose in terms of distinguishing Mongolian from goitered gazelles. Independent interpreters may be used to analyse digital photographs to ensure that animals are not missed or miscounted, and it is possible to test for biases caused by changing sightability with time of day, height and ambient light conditions. The aerial photographs also contain ancillary data on vegetation, vehicle tracks and other variables that may be valuable to future analyses. Our analyses show that the two survey methods produced comparable results for both khulan and goitered gazelles, indicating that ground-based distance sampling methods can provide sufficiently reliable and precise estimates. Thus, ground-based distance sampling can continue to be used to monitor plains ungulates in the region when funds are limited.

Given the rapid development of mining and other industries in the region, the uncertainty regarding their impact, and that the Southern Gobi supports c. 75% of the global khulan population, we make a number of recommendations. Firstly, landscape-scale monitoring of khulan and goitered gazelles should be implemented using ground-based distance sampling every 2 years. To obtain the best possible accuracy and precision through increased encounter rates and smaller group sizes, surveys should be conducted at the time of year when the ungulates are most widely distributed throughout the area. Secondly, aerial surveys should be repeated every 6 or 12 years, as they provide an important check on the ground survey estimates and provide valuable ancillary data at the landscape scale. Lastly, complementary studies that assess other vital population parameters, such as recruitment and mortality rates, are needed to provide a more complete picture of the status of these ungulate populations. Having reliable and multiple sources of information will support timely management actions to ensure the long-term survival of khulan and goitered gazelles in the Southern Gobi.

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Biographical sketches

Bayarbaatar Buuveibaatar is interested in the ecology and conservation of large ungulates inhabiting arid areas. Samantha Strindberg is a wildlife statistician and has a particular interest in the design and analysis of distance sampling surveys. Petra Kaczensky is a wildlife ecologist and has studied brown bears, lynx, wolves and wild equids. John Payne has experience in natural resource management and conservation. Buyanaa Chimeddorj is interested in threatened species and protected area management. Galsandorj Naranbaatar and Tserendorj Munkhzul are wildlife ecologists whose main research interests are the ecology and conservation of mammals. Saruul Amarsaikhan is an ecologist and is particularly interested is small mammals. Batsuuri Dashnyam and Tsolmonjav Purevsuren are interested in bird conservation. Dennis Hosack's area of interest is the management of threatened species. Todd Fuller is a wildlife biologist and is interested in the management and conservation of mammals.