Assessment of the global population size of the Mongolian gazelle *Procapra gutturosa*

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Abstract The Mongolian gazelle *Procapra gutturosa* is a wild ungulate ubiquitous across the largest remaining temperate grasslands of Mongolia, Russia and China. The species is nomadic and ranges over long distances, resulting in widely fluctuating abundance in any given location. Therefore, a comprehensive and range-wide survey is required to accurately estimate its global population size, but challenges are posed by the expansive geographical distribution and the political boundaries across the species' vast range. To obtain an estimate of the total population, we compiled data from recent range-wide surveys. During 2019–2020, we estimated the population size in Mongolia by conducting line transect distance surveys and total counts, and by deriving numerical predictions for unsurveyed areas through data analysis. The gazelle's population in Russia was surveyed in 2020 across its summer range using simultaneous counts, transect surveys and expert knowledge. The distance sampling surveys in Mongolia revealed that slightly more than half of the gazelles along the transects were detected. Our assessment of the gazelle population, although probably an underestimate, suggests there are c. 2.14 million individuals in Mongolia and c. 30,000 in Russia. These results confirm that the Mongolian gazelle is the most abundant nomadic ungulate in the open plains across its range. However, to obtain more accurate estimates across all range states and effectively monitor the gazelle's population status, it is essential to implement standardized survey protocols that correct for imperfect detection. At present, the management of the Mongolian gazelle is inadequate, as there is a lack of regular monitoring to identify any adverse population changes that could necessitate conservation interventions.

Keywords Density estimates, distance sampling, Mongolia, Mongolian gazelle, population size, *Procapra gutturosa*, Russia, temperate grassland

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Introduction

The Mongolian gazelle *Procapra gutturosa* (hereafter 'gazelle') is one of the few remaining open-plains long-distance migrant ungulates in the grasslands of Mongolia and adjacent areas of Russia and China. Globally, the species is categorized as Least Concern on the IUCN Red List (IUCN SSC Antelope Specialist Group, 2016b). However, the population in Russia was extirpated in the early 1970s and the species only returned to the country in the 2000s as a result of conservation interventions and transboundary movements from Mongolia. The gazelle's core habitat in Mongolia is one of the largest remaining intact temperate grasslands (Batsaikhan et al., 2014). The gazelles are remarkable for their long-distance nomadic movements across the landscape, often in large groups (Olson et al., 2009a; Joly et al., 2019; Nandintsetseg et al., 2019). These movements are driven by dynamic forage resources whose availability is determined by unpredictable precipitation patterns (Mueller et al., 2008; Ito et al., 2013b). The major threats documented for the species include habitat fragmentation and conversion, displacement by livestock, unsustainable hunting and disease spill-over from livestock (Wingard & Zahler, 2006; Yoshihara et al., 2008; Bolortsetseg et al., 2012; Ito et al., 2013a).

Accurate and precise population size estimates are necessary to prioritize management and conservation actions for the gazelle. They often occur in large groups, with up to 250,000 individuals (Olson et al., 2009a). This, together with their distribution over vast geographical areas and long-distance nomadic movements creates logistical and analytical challenges for deploying robust monitoring programmes. Aerial surveys involving well-defined statistical methods and analyses are ideal to overcome these difficulties (Singh & Milner-Gulland, 2011). However, lack of suitable aircraft, capacity and funds make this methodology infeasible for regular monitoring. Surveys using ground-based distance sampling offer an established, cost-effective alternative for monitoring gazelle populations (Olson et al., 2005). The most recent reliable estimates of 1.13 million gazelles (95% CI = 843,410–1,504,500) inhabiting 220,000 km² of grassland habitat to the east of the Trans Mongolian Railway in Mongolia were obtained from distance sampling line transect surveys conducted in 2005 (Olson et al., 2011).

Here we present the first near-range-wide estimate of the gazelle population obtained from ground-based surveys across Mongolia and Russia. In addition, we provide anecdotal accounts of the gazelle's status in China. The surveys in Mongolia used distance sampling line transect methods (Olson et al., 2011; Buuveibaatar et al., 2017), except for the isolated population in western Mongolia, for which total count methods were deployed. The population size in Russia was estimated using a range of methods that have been implemented previously by local rangers: simultaneous counts, line transects and accounts of recent observations by local experts. Density and abundance estimates derived from data collected across the species' entire range are useful for assessing the effectiveness of conservation efforts, prioritizing threats and supporting the development of future management goals.

Study area

The estimated global range of the gazelle is 746,281 km², of which 91% (681,863 km²) is in Mongolia, 5% in China (34,718 km²) and 4% in Russia (29,700 km²; Fig. 1). Fencing along the 1,359 km national border between Mongolia and China impedes gazelle movement and effectively separates these populations. In contrast, transboundary movements can occur across the 524 km border between Mongolia and Russia as fences are either absent or were laid down during periods when large numbers of gazelles were observed in the border area. The gazelle range within Mongolia is mostly continuous; however, the population in and around Khomiin Tal National Park in western Mongolia is isolated (c. 600 km from the main range; Fig. 1). In Russia, gazelles are known to occur in five distinct areas during the summer, which are divided by natural (rivers and mountains) and anthropogenic (railways) barriers.

The climate across the region is continental, with an extreme temperature range of −45 to +42 °C. Precipitation decreases from the north-east to the south-west, mainly falling during a few months in summer (June–August). There are ponds, lakes and rivers scattered throughout the region, especially in the Daurian Steppe that stretches across north-eastern Mongolia and the southern Siberian region of Russia. Availability of resources such as vegetation cover and surface water is highly dynamic, driven by spatio-temporal variation in precipitation patterns (Vandandorj et al., 2015; Payne et al., 2020). There is an elevational gradient from 600 m in the east to 2,500 m in the west.

In Mongolia, the gazelle range falls within 13 *aimags* (provinces or states) and 128 *soums* (regional districts), where c. 32 million livestock were held in 2020 (46% sheep, 42% goats, 6% horses, 5% cattle and 1% camels; National Statistics Office, 2020). The Trans Mongolian

Fig. 1 Mongolian gazelle range and the population survey regions (central and eastern Mongolia, southern Gobi and Khomiin Tal National Park) during 2019–2020 in Mongolia. The 2020 gazelle population survey region in Russia comprises five zones (areas) including (I) Daursky Protected Area, (II) Dzeren Valley Protected Area, (III) west Krasnokamensk, (IV) north Onon River and (V) Sokhondinsky Nature Reserve and north Daursky.

Railway bisects the gazelle range in Mongolia along a north-west/south-east axis (Fig. 1). In Russia, there are c. 115 villages within the gazelle's range, primarily located along railroads, and the town of Borzya with a population of > 30,000 people. There are c. 0.4 million livestock (mostly cattle) in the Russian range of the gazelle, and < 3% of the steppe is converted to croplands. Existing linear infrastructure in Russia, apart from 125 km of border sections with strong fences, is relatively permeable, enabling the gazelles to move across the landscape within the country and across its borders (Kirilyuk, 2021).

Methods

Population surveys in Mongolia

Gazelle population surveys were conducted during May–June in 2019 and 2020, prior to the calving season, across three regions: central and eastern Mongolia (steppe and mountain steppe ecosystems), southern Gobi, and Khomiin Tal National Park (Fig. 1). The total extent of the three survey regions is 535,575 km² (81% central and eastern Mongolia, 18% southern Gobi and 1% Khomiin Tal National Park), which represents 79% of the gazelle range in Mongolia. The remaining 146,288 km² (21%) of known gazelle range in south-western Mongolia were not surveyed as the region is generally unsuitable for driving line transects and gazelles are only documented occasionally and in small numbers. However, by utilizing distance sampling data from the neighbouring regions, we generated an approximate estimate of the gazelle population in this region.

Gazelle numbers were recorded by driving line transects and using distance sampling protocols in the central, eastern and southern regions of Mongolia (Buckland et al., 2001, 2015; Young et al., 2010; Olson et al., 2011; Buuveibaatar et al., 2017). This method accurately estimates the mean density of ungulate groups as it accounts for detectability and considers the proportion of groups not seen by observers in the area sampled by fitting a detection function to the distances measured to the centre of the observed groups. Estimated group density (groups per unit area) together with the expected group size allows for the estimation of individual density (individuals per unit area), which in turn provides the population size when combined with the area of the survey region. We designed the survey and analysed the data using the programme *Distance* (Strindberg et al., 2004; Thomas et al., 2010).

We conducted the distance sampling surveys in May and June in 2019 and 2020 across 98,216 km² and in the southern Gobi and 433,245 km² in the central and eastern steppe regions (Fig. 1). In 2019, we drove 64 transects of 4–205 km in length (total effort of 3,464 km; Table 1) in three teams (each consisting of four observers). In 2020, we drove an additional 40 transects of 33–587 km in length (total effort of 13,895 km) in six teams simultaneously. Each team received training in distance sampling survey protocols prior to the field surveys. The spacing between the survey transects was 20 km for the southern Gobi and 30 km for central and eastern Mongolia (Fig. 1). We orientated the transects for both surveys in a north–south direction, to systematically cover the different habitats within the heterogeneous landscape (e.g. mountain forest, steppe and Gobi Desert). Whilst driving at 20–40 km/h, following the transect lines as closely as possible, observers searched for gazelle groups. We recorded radial distance from the transect line to the centre of the group, the compass bearing to the centre of the group and group size using a handheld laser range finder (maximum range c. 2,500 m), compass, binoculars and GPS units.

We estimated the gazelle population in Khomiin Tal National Park from total counts because the Park is relatively small (4,114 km²) compared to the other two survey regions and gazelle movement outside the area is restricted by lakes, sand dunes and mountains. We conducted this survey in May 2020, with 11 rangers simultaneously driving along c. 656 km of survey routes covering the entire National Park. The rangers counted gazelle groups encountered along the routes using binoculars and spotting scopes.

TABLE 1 Survey details and observation statistics from line transect surveys for the Mongolian gazelle *Procapra gutturosa* in the southern Gobi in 2019 and central and eastern Mongolia in 2020 (Fig. 1). The table shows, for the different strata and overall, the survey year, area and effort, numbers of observed groups and individuals, and the mean, median and range of the number of individuals per group.

Stratum	Year	Area (km²)	Effort (km)	Groups	Individuals	Mean	Median	Range
Southern Gobi	2019	98,216	3,462	58	1,719	29.6	6.0	1–600
Central & eastern Mongolia								
West	2020	138,912	4,220	226	5,081	22.5	7.0	1–221
Central	2020	76,516	2,345	303	34,921	115.3	25.0	1–2,850
North Kherlen	2020	83,194	3,310	179	79,277	442.9	63.0	1–16,200
South-west	2020	108,941	3,297	208	9,136	43.9	12.5	1–950
Menen	2020	25,682	723	131	23,276	177.7	12.0	1–8,400
Overall (central & eastern Mongolia)	2020	433,245	13,895	1,047	151,691	160.4	16.0	1–16,200

Population surveys in Russia

We surveyed the gazelle population in five Russian sites covering 10,089 km^2 (Fig. 1; Supplementary Table 1). We did not survey the remainder of the Russian gazelle range (19,611 km^2) as gazelles use this area exclusively in the winter and would have been absent during the summer survey months. The surveys in the Daursky and Dzeren Valley protected areas (the core range of the species in Russia) used total counts within 1,643 grid cells (each 2×2 km) systematically placed across an area of 6,572 km^2. Eight experienced teams carried out the survey simultaneously during 10–12 June 2020 to minimize double counting of groups. The teams counted gazelle groups from vantage points as they covered the entire area of each grid cell by car. When they encountered gazelles, the teams photographed the large herds using a quadcopter for subsequent accurate estimation of group size. In addition, to determine the accuracy of the method, the teams repeated the surveys twice (within the same day or the next day) in the same control zone, determining the number, sex and age of gazelles in each group. We also conducted transect surveys for the west Krasnokamensk (766 km^2) and north Onon River (1,320 km^2) areas during 12–20 June 2020. It was not feasible to drive along a systematic array of transects in these areas because of the rugged landscape, and thus vehicles mainly followed existing dirt tracks. We surveyed along six road transect lines for each area (527 km for west Krasnokamensk and 451 km for north Onon River). Finally, we sought expert opinion to estimate the population size of gazelles around the Sokhondinsky Nature Reserve (962 km^2) and north Daursky areas (469 km^2).

Data analysis for the surveys in Mongolia

We analysed distance data as exact distances and in distance intervals, the latter to address the challenges associated with locating the centre of a group that is not uniform with respect to both the distribution of individuals within the group and the shape of the group (Buckland et al., 2001, 2015). We examined the data to check that the assumptions of the method were met (i.e. distances had been recorded accurately and all groups on or close to the centrelines had been observed). We modelled detection probability of gazelles using a hazard rate function (without and with simple polynomial adjustment terms for the 2019 and 2020 data, respectively) to account for any potential evasive movement (Supplementary Figs 1 & 2). We binned the 2019 and 2020 perpendicular distance data into four and seven equal intervals of up to 350 m (24% right truncation to improve model fit) and 1,221 m (5% right truncation), respectively, to account for the difficulty of locating the centre of groups when taking the radial distance and compass bearing measurements.

To address any bias that may have occurred during the estimation of group size, we used the expected rather than mean group size when the regression line fit to the natural logarithm of group size vs detectability was significant at the 15% α-level. During the 2020 survey, we classed group sizes as either 'counted' (observers attempted to count all individuals in the group) or 'estimated' (observers estimated group sizes, mostly for larger groups). To limit the error introduced by the estimated group sizes, we aimed for at least 95% of the group size data used in the analysis to be from counted groups. To achieve this, we replaced estimated group sizes recorded for sightings furthest from the observers (which were likely to be the least accurate) falling within the right truncation distance with the closest counted group sizes recorded for sightings beyond the truncation distance. We post-stratified the 2020 survey data into five strata (Fig. 2) to facilitate comparison of our results with those from previous surveys (Olson et al., 2011).

To obtain a comprehensive estimate of the gazelle population in Mongolia, we extrapolated the density estimates obtained from distance sampling surveys to the unsurveyed region of south-western Mongolia. This involved calculating the mean gazelle density for the southern Gobi and west survey strata within the central and eastern Mongolia survey region, which border the south-western Mongolia survey region. By multiplying the area of the south-western Mongolia survey region by the mean gazelle density derived from the two surveyed regions, we obtained an approximate estimate of the gazelle population in the target area.

Data analysis for the surveys in Russia

To improve the accuracy of the counts for the Daursky and Dzeren Valley protected areas, we eliminated duplicate observations by excluding groups that had been previously counted and subsequently moved to an adjacent survey plot and were counted again; such duplicates were identified based on group size and composition. We assessed the accuracy of group size estimates through repeated counting of individuals in larger herds (usually > 100–200 individuals) as well as control counting based on photographs of the largest herds obtained from the quadcopter. In the final calculations, we accounted for missed observations by increasing the mean by the proportion of groups missed and adjusting the group size estimate. The population assessment for the remainder of the Russian surveys in west Krasnokamensk, north Onon River, Sokhondinsky Nature Reserve and north Daursky assumed 100% detectability of gazelles during the counts.

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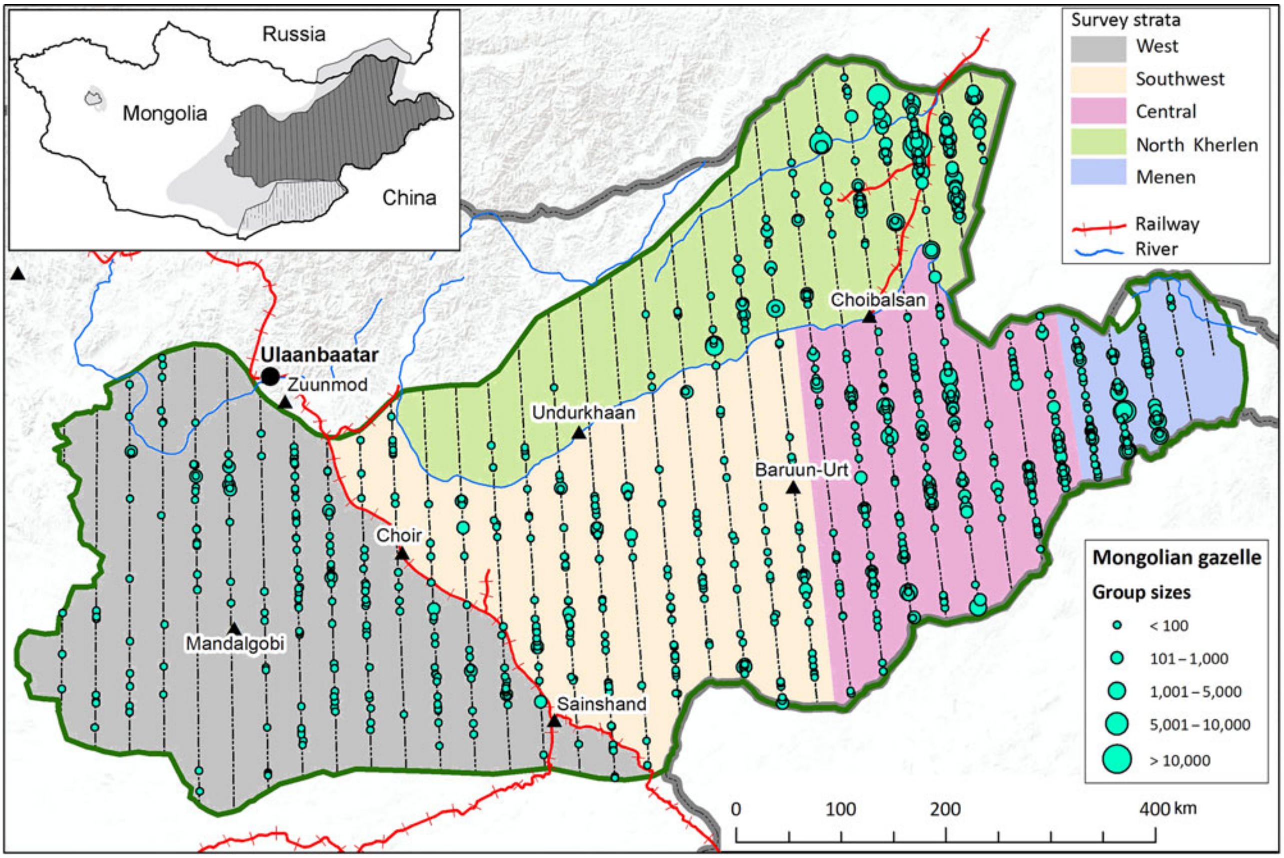

FIG. 2 Distance sampling line transects (survey effort = 13,895 km), survey strata and locations of Mongolian gazelle groups encountered in the central and eastern Mongolia survey region during the May–June 2020 survey. (Readers of the print journal are referred to the online article for a colour version of this figure.)

Results

Population surveys in Mongolia

The 2019 and 2020 survey data included 58 and 1,047 group observations (totalling 1,719 and 151,691 individuals), respectively. Mean group size was 30 (range = 1–600) in 2019 and 160 (range = 1–16,200) in 2020 (Table 1). Detection probabilities were 0.57 (95% CI = 0.39–0.85) and 0.34 (95% CI = 0.30–0.38; Fig. 3), with effective strip widths of 200 m (95% CI = 136–296 m) and 412 m (95% CI = 370–459 m) for the 2019 and 2020 surveys, respectively; the differences are in large part because of the different right truncation regimes. There was an indication of size bias in estimations of mean group size for the 2020 survey data but not for the 2019 survey data because of the more severe right truncation of these earlier survey data.

The gazelle group encounter rates during the 2020 survey were highest in the south-west followed by the north Kherlen, west, Menen and central strata, and the lowest encounter rate was in 2019 in the southern Gobi (Table 2). Overall, the encounter rate in the central and eastern steppe regions of Mongolia was substantially higher than in the southern Gobi (0.71 vs 0.01 groups/km^2). In all cases the expected group size estimates were smaller than the mean group size estimates (in north Kherlen and Menen, the expected group size was less than half the mean group size), indicating that a greater proportion of larger groups tended to be seen farther from the transect line, with smaller groups more likely to be missed with increasing distance from the observers (Table 2).

For the 2020 survey, estimated group density was highest in the Menen stratum and estimated individual density was highest in the central stratum, whereas the highest abundance estimates were obtained for the central and north Kherlen strata. In contrast, the 2019 survey in southern Gobi yielded the lowest estimates for all of the parameters; individual density, for instance, was approximately one order of magnitude lower than the overall density for the 2020 survey (Table 3).

Overall individual density estimates from the 2019 and 2020 surveys were 0.52 and 4.72 gazelles/km^2, respectively, with total population estimates of 40,899 (95% CI = 16,307–102,580) individuals in southern Gobi and 1,991,300 (95% CI = 1,464,900–2,706,700) in central and eastern Mongolia (Table 3). In 2019, most of the variance in the abundance

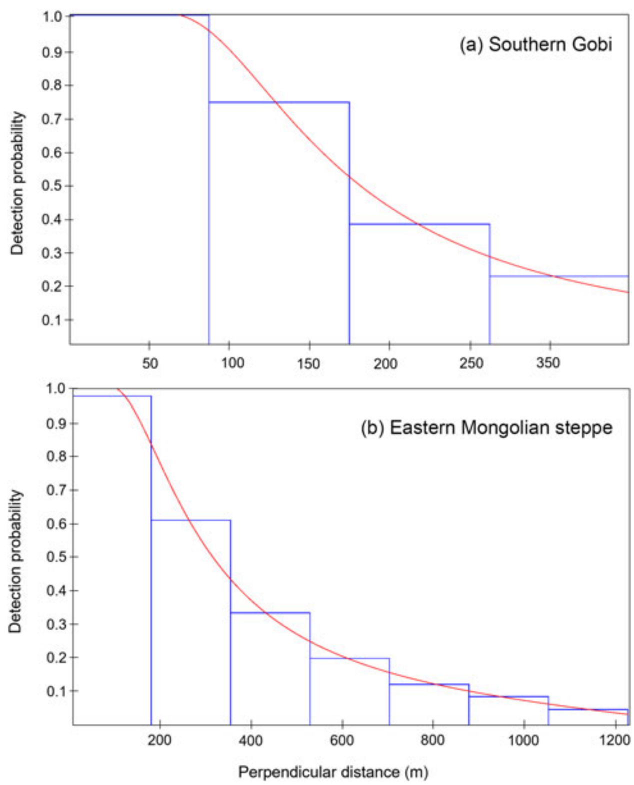

FIG. 3 Detection probability functions for Mongolian gazelle groups in (a) the southern Gobi in 2019 and (b) the eastern Mongolian Steppe in 2020. The curved line represents the best-fit model describing how the detection probability changes with distance.

estimates was attributable to group size (53%), whereas encounter rate and detection probability contributed 31% and 16% of the variance, respectively. In contrast, uncertainty in the abundance estimates for the 2020 survey was mostly because of encounter rate (54% of the variance), followed by group size (41%) and detection probability (5%).

During the census in Khomiin Tal National Park, the rangers observed 1,134 individual gazelles in 37 groups (mean = 30.7 ± SD 40.9 gazelles). Density was 0.27 gazelles/km^2 for this small and isolated population across the 4,114 km^2 study area (Supplementary Table 1).

The density estimate for the southern Gobi was 0.52 gazelles/km^2, and for the west stratum 0.97 gazelles/km^2, giving a mean density of 0.75 gazelles/km^2. The study area of south-western Mongolia was estimated to be 146,288 km^2. Based on these figures, the estimated gazelle population size in the south-western Mongolia region was c. 109,716 gazelles (Supplementary Table 1).

Population surveys in Russia

During the survey in the Daursky and Dzeren Valley protected areas, we observed 18,898 individuals in 475 groups. During the repeated counts, we recorded 1,020 animals in 27 groups at the first count and 1,097 animals in 29 groups at the second count. During the first of the repeated counts, the team missed two gazelle groups that were seen during the second count; similarly, the team missed a single group

TABLE 2 Mongolian gazelle encounter rate (groups/km), mean group size and expected group size, all with 95% CIs, for the southern Gobi in 2019 and central and eastern Mongolia in 2020.

Stratum	Year	Encounter rate (95% CI)	Mean group size (95% CI)	Expected group size (95% CI)
Southern Gobi	2019	0.01 (0.007–0.02)	16.4 (8.1–33.0)	11.5 (6.1–16.9)
Central & eastern Mongolia				
West	2020	0.50 (0.35–0.72)	22.2 (17.6–28.0)	15.7 (12.6–19.5)
Central	2020	0.11 (0.74–0.16)	97.0 (70.7–133.2)	75.8 (56.3–102.0)
North Kherlen	2020	0.55 (0.36–0.83)	241.0 (163.8–354.6)	117.1 (71.5–191.8)
South-west	2020	0.60 (0.49–0.73)	42.3 (30.7–58.3)	30.8 (22.8–41.8)
Menen	2020	0.18 (0.81–0.41)	82.7 (41.7–164.3)	41.4 (24.3–70.4)
Overall (central & eastern Mongolia)	2020	0.71 (0.58–0.86)	91.3 (73.5–113.3)	48.6 (41.3–57.3)

TABLE 3 Estimates of gazelle group density (groups/km^2), individual density (individuals/km^2) and abundance, with 95% CIs, and overall percentage coefficient of variation (%CV) for the southern Gobi in 2019 and central and eastern Mongolia in 2020.

Stratum	Year	Group density (95% CI)	Individual density (95% CI)	Abundance (95% CI)	%CV
Southern Gobi	2019	0.03 (0.02–0.06)	0.52 (0.21–1.30)	40,899 (16,307–102,580)	49.04
Central & eastern Mongolia					
West	2020	0.06 (0.04–0.08)	0.97 (0.63–1.47)	132,010 (86,940–200,440)	20.98
Central	2020	0.13 (0.09–0.20)	10.30 (6.31–16.81)	765,350 (469,040–1,248,800)	24.27
North Kherlen	2020	0.06 (0.04–0.10)	7.86 (4.19–14.76)	636,890 (339,460–1,194,900)	32.56
South-west	2020	0.07 (0.05–0.09)	2.26 (1.57–3.25)	240,970 (167,260–347,160)	18.65
Menen	2020	0.22 (0.09–0.50)	9.21 (3.94–21.53)	216,060 (92,415–505,130)	41.04
Overall (central & eastern Mongolia)	2020	0.08 (0.07–0.11)	4.72 (3.47–6.41)	1,991,300 (1,464,900–2,706,700)	15.63

during the second count that had been observed in the first count. When summing up, taking into account the newly identified groups, the total number in the repeated count zone was 1,197 individuals (i.e. 15% more than the minimum survey value). Thus, based on the results from the double counting method, the number of gazelles that we counted increased by 15% to account for the groups that we missed. The inaccuracy associated with group size estimation was < 5%. Gazelle density was 3.30 gazelles/km^2, producing an estimate of 21,701 gazelles (95% CI = 20,616–22,785 individuals) across a 6,572 km^2 area. We counted 4,214 (n = 61 groups) and 485 (n = 28 groups) individuals during the transect surveys in the west Krasnokamensk and north Onon River areas, with resulting density estimates of 5.50 and 0.37 gazelles/km^2, respectively. Experts estimated that c. 3,300 gazelles occupy Sokhondinsky Nature Reserve and 350 gazelles the north Daursky area. These findings suggest that there are a total of 30,050 gazelles across a 10,089 km^2 region in Russia (Supplementary Table 1).

Discussion

We combined results from various surveys conducted in Mongolia and Russia, covering almost the entire global range of the Mongolian gazelle, with the exception of 5% of its range in China. This represents the first attempt to produce a near-range-wide estimate of the gazelle population. Our estimated total population size is c. 2.14 million individuals (Supplementary Table 1), which is probably an underestimate. These results confirm that the gazelle is one of the most numerous open-plains ungulates globally. Other abundant species that are comparable with respect to their ecology and life history are wildebeest *Connochaetes taurinus* and *Connochaetes gnou* on the Serengeti plain of Africa (c. 1,560,000 individuals; Estes & East 2009), saiga antelope *Saiga tatarica* in Central Asia (c. 1,318,800 individuals; ACBK, 2022) and pronghorn antelope *Antilocapra americana* in North America (c. 1,000,000 individuals; IUCN, 2016a). However, some of these estimates are not recent and require updating.

Amongst the range states, Mongolia holds the largest proportion (99%) of the global gazelle population and is thus the main stronghold for the species. Our estimates from Mongolia represent a 52% increase since the last attempt to estimate the population in 2005 (Olson et al., 2011). Comparisons of results from regions covered by both surveys indicate that density estimates from the 2005 (c. 1.12 million individuals) and 2020 (c. 1.99 million individuals) surveys were similar (5.14 gazelles/km^2 in 2005 and 4.72 gazelles/km^2 in 2020). This suggests that the population has at least remained stable across this important part of the species' range.

In Mongolia, gazelle densities are generally increasing from the more arid west towards the east, which experiences more precipitation. Density estimates west of the Trans Mongolian Railway, for instance, are the lowest (0.97 gazelles/km^2; 2.3–11.6 times less than regions east of the railway). Since the late 1950s, the Trans Mongolian Railway has become a nearly impenetrable barrier to the longitudinal movement of gazelle herds and a well-documented source of mortality (Ito et al., 2008, 2013a). It is likely that gazelle numbers west of the Trans Mongolian Railway are lower because this region is more extensively occupied by livestock and because the railway corridor fencing restricts gazelle mobility across this portion of the range (Ito et al., 2013a; Batsaikhan et al., 2014).

The c. 30,000 gazelles estimated to permanently occupy Russia are the result of a successful reintroduction that began in the 2000s, following the extirpation of the species from Russia in the 1970s (Kirilyuk, 2007). In recent decades the transboundary areas have become refuges for the gazelle, particularly for the herds emigrating from Mongolia during resource-poor months (e.g. summer droughts and harsh winters; Olson et al., 2009b; Kirilyuk, 2021). Since 2019, gazelle numbers in Russia sometimes exceed 100,000 individuals during winter when gazelles migrate north from Mongolia in search of better pasture and to escape deep snow (Kirilyuk, 2021). Access to the edges of the species' range is critical as these regions are more resilient to stochastic weather events and the impacts of the poorly understood effects of climate change on habitat quality.

Recent estimates from China are not available in the literature and experts from the country did not respond to our queries. In Hulunbuir prefecture, 522 individuals in 66 groups were observed during the winter of 2005–2006 (Luo et al., 2014). Historically gazelles were widespread across northern China, with as many as 500,000 individuals there prior to the 1950s (Gao et al., 1996). However, the population in that region was believed to be less than 8,000 individuals in 2000 and mostly to occur along the border region with Mongolia (c. 75,000 km^2 or 25% of the historical range) in eastern Inner Mongolia, Western Hulunbuir and around Dalai Lake (Wang et al., 1997; Jin & Ma, 2004). Because of a declining population and insufficient information regarding the current status of the species, it is crucial that China promptly implements measures that prioritize monitoring and conservation of the gazelle. Notably, the Chinese government has made significant efforts to conserve the Tibetan antelope *Pantholops hodgsonii* by effectively safeguarding the movement corridors of this species (Shi et al., 2018). Similar efforts should be extended towards researching and conserving the Mongolian gazelle within China.

The gazelle population remains large and widely distributed and continues to provide important ecosystem services such as redistribution of nutrients through the movements of the gazelles across the landscape, maintenance of forage diversity, and provision of prey for predators and carrion for

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scavengers (Olson, 2010; Genung et al., 2017). The cultural and economic values of the gazelle are also important, as the species has been hunted for subsistence primarily by rural populations for millennia and their presence on the steppes is a source of pride to many (Lhagvasuren & Milner-Gulland, 1997; Olson & Fuller, 2017). Additionally, the gazelles could generate income through eco-tourism.

The area forming the gazelle stronghold in Mongolia is subject to rapid human development, with increasing linear infrastructure and livestock herding (leading to forage quality degradation and disease spill-over risk), and there is a lack of effective control and management of hunting to ensure sustainability (Zahler et al., 2004; Bolortsetseg et al., 2012; Batsaikhan et al., 2014). Given the gazelle's large population size and extensive range, a broad range of options for the species' management remain viable, and resources should be dedicated to maintain and potentially further improve its status (Redford et al., 2013; Baker et al., 2019). The development and implementation of a comprehensive species management plan across its entire range are recommended (Mallon & Jiang, 2009).

Managing a species as abundant and geographically expansive as the Mongolian gazelle poses distinct challenges as it necessitates a comprehensive approach that considers the diverse range of stakeholders and resources involved. The viability of the gazelle population relies on its ability to freely traverse a vast mixed-use landscape that is subject to a multitude of competing interests and land uses. Small protected areas that are scattered throughout the landscape are not adequate because of the gazelle's long-distance nomadic movements, which require habitats between protected areas to also be of high quality (Nandintsetseg et al., 2019). To address these challenges, a holistic, landscape-scale approach is necessary. This approach should involve all relevant stakeholders, including local communities, government agencies, conservation organizations and researchers, collaboratively developing integrated land-use plans. Such plans should prioritize the maintenance and restoration of critical habitats, including both protected areas and functional connectivity across the wider landscape.

Mitigation of threats to the gazelle from linear infrastructure requires regional strategic planning to avoid further fragmentation of the landscape by barriers that would affect a large proportion of the population. In the case of structures associated with international boundaries such as border fences, high-level political engagement is required to facilitate transboundary gazelle movements (Linnell et al., 2016). For example, redesigning of the border fences between Mongolia, China and Russia to allow safe passage of gazelles could be considered with reference to the Daurian International Protected Area framework established in 1994. Existing fenced rail corridors require the enforcement of international conventions (e.g. the Convention on Migratory Species) and national laws, as well as constructive engagement with rail operators, to ensure that necessary changes are implemented effectively.

Hunting of gazelles occurs for both subsistence by herders and local markets. Setting realistic quotas to ensure sustainable hunting is hindered by the lack of adequate population monitoring, and much of the current gazelle hunting in the region is illegal because hunting permits are prohibitively expensive for many local people. However, hunting appears to have decreased according to the results of our survey. It is uncertain whether this is because of changes in socio-economic pressures, improved law enforcement or changing values. Harvesting of gazelles still occurs, and hunting management to support both local interests and trophy hunting is largely absent in Mongolia. Given the continued culture of hunting in Mongolia, the development of a sustainable programme that is based on maintaining the presently large numbers of gazelles would represent an important step in securing the long-term viability of this species.

Lastly, it is crucial to monitor the status of the gazelle population at regular intervals to facilitate proactive decision-making. Assessing the gazelle populations across Mongolia, Russia and China presents significant challenges because of the vast geographical area and the political boundaries of these countries. However, obtaining an accurate population estimate is vital for the conservation and management of this species. One approach that could be used in future would be to foster collaborations amongst range states to establish a coordinated approach to population assessments. This could involve developing standardized survey methods and sharing data to ensure consistency and accuracy of the gazelle population size estimates across these regions. Such collaboration would inform trends and provide the data necessary to determine the effectiveness of interventions or the urgency of preventative measures to avert population declines. Currently, such monitoring is not occurring, which allows threats to go unnoticed and hinders the implementation of actions to ensure the sustainable management of the gazelle.

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Conflict of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

Data availability The data supporting the findings of this study are available from the authors (BB for Mongolia and VEK for Russia) upon reasonable request.

References

ACBK (The Association for the Conservation of Biodiversity of Kazakhstan) (2022) Saiga numbers in Kazakhstan continue to grow. *Saiga News*, 28, 10.

Baker, D.J., Garnett, S.T., O'Connor, J., Ehmke, G., Clarke, R.H., Woinarski, J.C.Z. & McGeoch, M.A. (2019) Conserving the abundance of nonthreatened species. *Conservation Biology*, 33, 319–328.

Batsaikhan, N., Buuveibaatar, B., Chimed, B., Enkhtuya, O., Galdrakh, D., Ganbaatar, O. et al. (2014) Conserving the world's finest grassland amidst ambitious national development. *Conservation Biology*, 28, 1736–1739.

Bolortsetseg, S., Enkhtuvshin, S., Nyamsuren, D., Weisman, W., Fine, A., Yang, A. & Joly, D.O. (2012) Serosurveillance for foot-and-mouth disease in Mongolian gazelles and livestock on the eastern Steppe of Mongolia. *Journal of Wildlife Disease*, 48, 33–38.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001) *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford University Press, Oxford, UK.

Buckland, S.T., Rexstad, E.A., Marques, T.A. & Oedekoven, C.S. (2015) *Distance Sampling: Methods and Applications*. Springer, Cham, Switzerland.

Buuveibaatar, B., Strindberg, S., Kaczensky, P., Payne, J., Chimeddorj, B., Naranbaatar, G. et al. (2017) Mongolian Gobi supports the world's largest populations of khulan and goitered gazelles. *Oryx*, 51, 639–647.

Estes, R.D. & East, R. (2009) *Status of the Wildebeest (*Connochaetes taurinus*) in the Wild 1967–2005*. WCS Working Paper 37. Wildlife Conservation Society, New York, USA.

Gao, Z., Jin, K., Guan, D. & Bao, X. (1996) Ecological researches of Mongolian gazelle. *Journal of Northeast Forestry University*, 24, 37–42.

Genung, M.A., Fox, J., Williams, N.M., Kremen, C., Ascher, J., Gibbs, J. & Winfree, R. (2017) The relative importance of pollinator abundance and species richness for the temporal variance of pollination services. *Ecology*, 98, 1807–1816.

Ito, T.Y., Lhagvasuren, B., Tsunekawa, A., Shinoda, M., Takatsuki, M., Buuveibaatar, B. & Chimeddorj, B. (2013a) Fragmentation of the habitat of wild ungulates by anthropogenic barriers in Mongolia. *PLOS One*, 8, e56995.

Ito, T.Y., Okada, A., Buuveibaatar, B., Lhagvasuren, B., Takatsuki, S. & Tsunekawa, A. (2008) One sided barrier impact of an international railroad on Mongolian gazelles. *Journal of Wildlife Management*, 72, 940–943.

Ito, T.Y., Tsuge, M., Lhagvasuren, B., Buuveibaatar, B., Chimeddorj, B., Takatsuki, S. et al. (2013b) Effects of interannual variations in environmental conditions on seasonal range selection by Mongolian gazelles. *Journal of Arid Environments*, 91, 61–68.

IUCN SSC Antelope Specialist Group (2016a) *Antilocapra americana*. In *The IUCN Red List of Threatened Species* 2016. dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T1677A50181848.en.

IUCN SSC Antelope Specialist Group (2016b) *Procapra gutturosa* (errata version published in 2017). In *The IUCN Red List of Threatened Species* 2016. dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T18232A50193126.en.

Jin, K. & Ma, J. (2004) Distribution, quantity, threatening factors and protection of Mongolian gazelle. *Journal of Northeast Forestry University*, 32, 104–106.

Joly, K., Gurarie, E., Sorum, M.S., Kaczensky, P., Cameron, M.D., Jakes, A.F. et al. (2019) Longest terrestrial migrations and movements around the world. *Scientific Reports*, 9, 5333.

Kirilyuk, V.E. (2007) *The First Results and Prospects for the Restoration of the Mongolian Gazelle (*Procapra gutturosa*) in Russia*. Express-Publishing House, Chita, Russia. [In Russian]

Kirilyuk, V.E. (2021) Rapidly increasing migratory activity of Mongolian gazelle (*Procapra gutturosa*) and the sightings of goitered gazelle (*Gazella subgutturosa*) in Transbaikalia as an alarm. *Russian Journal Theriology*, 20, 25–30.

Lhagvasuren, B. & Milner-Gulland, E.J. (1997) The status and management of the Mongolian gazelle *Procapra gutturosa* population. *Oryx*, 31, 127–134.

Linnell, J.D.C., Trouwborst, A., Boitani, L., Kaczensky, P., Huber, D., Reljic, S. et al. (2016) Border security fencing and wildlife: the end of the transboundary paradigm in Eurasia? *PLOS Biology*, 6, e1002483.

Luo, Z., Liu, B., Liu, S., Jiang, Z. & Halbrook, R.S. (2014) Influences of human and livestock density on winter habitat selection of Mongolian gazelle (*Procapra gutturosa*). *Zoological Science*, 31, 20–30.

Mallon, D.P. & Jiang, Z. (2009) Grazers on the plains: challenges and prospects for large herbivores in Central Asia. *Journal of Applied Ecology*, 46, 516–519.

Mueller, T., Olson, K.A., Fuller, T.K., Schaller, G.B., Murray, M.G. & Leimgruber, P. (2008) In search of forage: predicting dynamic habitats of Mongolian gazelles using satellite-based estimates of vegetation productivity. *Journal of Applied Ecology*, 42, 154–158.

Nandintsetseg, D., Bracis, C., Olson, K.A., Böhning-Gaese, K., Calabrese, J.M., Chimeddorj, B. et al. (2019) Challenges in the conservation of wide-ranging nomadic species. *Journal of Applied Ecology*, 56, 1916–1926.

National Statistics Office (2020) *Mongolian Statistical Information Service*. National Statistics Office of Mongolia, Ulan Bator, Mongolia. 1212.mn/en [accessed March 2024].

Olson, K.A. (2010) A literature review of Mongolian gazelle (*Procapra gutturosa*) ecology from 1998 to present. *Mongolian Journal of Biological Sciences*, 8, 15–24.

Olson, K.A. & Fuller, T.K. (2017) Wildlife hunting in eastern Mongolia: economic and demographic factors influencing hunting behavior of herding households. *Mongolian Journal of Biological Sciences*, 15, 37–46.

Olson, K.A., Fuller, T.K., Schaller, G.B., Odonkhuu, D. & Murray, M.G. (2005) Estimating the population density of Mongolian gazelles *Procapra gutturosa* by driving long distance line transects. *Oryx*, 39, 164–169.

Olson, K.A., Mueller, T., Bolortsetseg, S., Leimgruber, P., Fagan, W.F. & Fuller, T.K. (2009a) A mega-herd of more than 200,000 Mongolian gazelles *Procapra gutturosa*: a consequence of habitat quality. *Oryx*, 43, 149–153.

Olson, K.A., Mueller, T., Kerby, J.T., Bolortsetseg, S., Leimgruber, P., Nicolson, C. & Fuller, T.K. (2011) Death by a thousand huts? Effects of household presence on density and distribution of Mongolian gazelles. *Conservation Letters*, 4, 304–312.

Olson, K.A., Mueller, T., Leimgruber, P., Nicolson, C.R., Fuller, T.K., Bolortsetseg, S. et al. (2009b) Fences impede long-distance gazelle movements in drought-stricken landscapes. *Mongolian Journal of Biological Sciences*, 7, 45–50.

  doi:10.1017/S0030605323001515

Payne, J.C., Buuveibaatar, B., Bowler, D., Olson, K.A., Walzer, C. & Kaczensky, P. (2020) Hidden treasure of the Gobi: understanding how water limits range use of khulan in the Mongolian Gobi. *Scientific Reports*, 10, 2989.

Redford, K.H., Berger, J. & Zack, S. (2013) Abundance as a conservation value. *Oryx*, 47, 157–158.

Shi, J., Li, X., Dong, S., Zhuge, H. & Mu, Y. (2018) Trans-boundary conservation of Chiru by identifying its potential movement corridors in the alpine desert of Qinghai–Tibetan Plateau. *Global Ecology and Conservation*, 16, e00491.

Singh, N.J. & Milner-Gulland, E.J. (2011) Monitoring ungulates in Central Asia: current constraints and future potential. *Oryx*, 45, 38–49.

Strindberg, S., Buckland, S.T. & Thomas, L. (2004) Survey design and geographic information systems. In *Advanced Distance Sampling* (eds S.T. Buckland, D.R. Andersonm, K.P. Burnham, J.L. Laake, D.L. Borchers & L. Thomas), pp. 190–228. Oxford University Press, Oxford, UK.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L. et al. (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, 47, 5–14.

Vandandorj, S., Gantsetseg, B. & Boldgiv, B. (2015) Spatial and temporal variability in vegetation cover of Mongolia and its implications. *Journal of Arid Land*, 7, 450–461.

Wang, X., Sheng, H., Bi, J. & Li, M. (1997) Recent history and status of the Mongolian gazelle in Inner-Mongolia, China. *Oryx*, 31, 120–126.

Wingard, J.R. & Zahler, P. (2006) *Mongolia. Silent Steppe: The llegal Wildlife Trade Crisis.* Discussion Papers, East Asia and Pacific Environment and Social Development Department. World Bank. Washington, DC, USA.

Yoshihara, Y., Ito, T.Y., Lhagvasuren, B. & Takatsuki, S. (2008) A comparison of food resources used by Mongolian gazelles and sympatric livestock in three areas in Mongolia. *Journal of Arid Environments*, 72, 48–55.

Young, J.K., Murray, K.M., Strindberg, S., Buuveibaatar, B. & Berger, J. (2010) Population estimates of Endangered Mongolian saiga *Saiga tatarica mongolica*: implications for effective monitoring and population recovery. *Oryx*, 44, 285–292.

Zahler, P., Lhagvasuren, B., Reading, R., Wingard, J., Amgalanbaatar, S., Gombobaatar, S. et al. (2004) Illegal and unsustainable wildlife hunting and trade in Mongolia. *Mongolian Journal of Biological Sciences*, 2, 23–31.

  doi:10.1017/S0030605323001515