LETTER

Death by a thousand huts? Effects of household presence on density and distribution of Mongolian gazelles

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Abstract

In late spring 2005, we surveyed Mongolian gazelle (*Procapra gutturosa*) populations in a 275,000-km^2 portion the eastern steppe of Mongolia to estimate their population size and assess their distribution with respect to forage and human households. We estimated a total population of 1.126 million (95% CI, 843,000–1,500,000), and found that gazelle distribution could be accurately predicted by a Normalized Difference Vegetation Index (NDVI) as an approximated measurement of vegetation productivity, and thus habitat quality. However, the presence of households had a considerable impact on gazelle density; in most regions, density was 76–98% lower than in survey blocks where no households were found. We show that in addition to large regional differences in gazelle density throughout their range, the presence of herding households had a negative impact on gazelle density in selected habitat. The conservation of ungulates that depend on the ability to make long-distance nomadic movements requires not only that access to habitat is unimpeded but also that the subtle impacts of activities associated with the presence of people need to be considered.

Introduction

Habitat conflicts between free-ranging wild ungulate populations and infrastructure development are being increasingly documented (Berger 2004; Harris *et al.* 2009). Physical barriers such as fences, pipelines, or structures can influence habitat selection, displacing animals even though the forage quality of the habitat surrounding these areas remains suitable. For example, infrastructure associated with natural gas extraction in the Great Basin of North America threatens to block migratory routes and wintering grounds for a population of pronghorn antelope (*Antilocapra americana*) (Berger 2004). Oil field development on the North Slope of Alaska has contributed to displacement of caribou (*Rangifer tarandus*) from the area at calving (Dau & Cameron 1986; Noel *et al.* 2004). Elk (*Cervus elaphus*) have been displaced in the Rocky Mountains of Colorado from their range as a result of a ski resort's expansion (Morrison *et al.* 1995). Veterinary cordon fences in southern Botswana resulted in major declines of several populations of migratory ungulates (Mbaiwa & Mbaiwa 2006) and contradictory policies toward livestock production and grassland conservation have led to fencing of portions of the Tibetan Plateau, thus setting the stage for conflict (Fox *et al.* 2009). Saiga antelope (*Saiga tartarica*) calving site selection in central Asia is increasingly driven by human disturbance (Singh *et al.* 2010). Reversing the issue, kiang (*Equus kiang*) in the Indian Himalayas are perceived by pastoralists to be overabundant and grazing on prime pastures for livestock leading to the fencing of prime pastures to exclude kiang from consuming forage that livestock are expected to eat (Bhatnagar *et al.* 2006).

Even in the absence of physical barriers that restrict mobility or access to grazing resources, the influence of livestock grazing on pasture condition can still affect wildlife populations. Guanacos (*Lama guanacoe*) compete for forage with sheep in Patagonia (Baldi *et al.* 2001), Himalayan ibex (*Capra sibirica*) densities in the Trans-Himalayan mountains were negatively correlated with sheep/goat densities (Bagchi *et al.* 2004), and Tibetan argali (*Ovis ammon*) were pushed into grazing more marginal habitat and spent more time avoiding dogs and livestock (Namgail *et al.* 2007).

Mongolian gazelles (*Procapra gutturosa*) are nomadic migrants (Olson *et al.* 2010a) whose population and range both within and outside of Mongolia have been reduced by perhaps 75% (Lhagvasuren & Milner-Gulland 1997; Wang *et al.* 1997; Milner-Gulland & Lhagvasuren 1998). This range contraction has been attributed to unsustainable hunting (Reading *et al.* 1998; Wingard & Zahler 2006), habitat conversion or degradation in Russia and Inner Mongolia, China (Wang *et al.* 1997; Humphrey & Sneath 1999), increases in human density (Milner-Gulland & Lhagvasuren 1998) and, more recently, competition with livestock (Campos-Arceiz *et al.* 2004; Yoshihara *et al.* 2008). The man-made barriers to movement (a railway fence that runs north–south between Ulaanbaatar and Beijing, the parallel Russian–Mongolian border fences, and the Chinese–Mongolian border fence) appear not always to be absolute barriers, as gazelles are sometimes found between fences and on both sides of fences when moving or migrating (Ito *et al.* 2008; Olson *et al.* 2009a).

For the future conservation of this wide-ranging species, quantitative identification of factors that influence or limit gazelle movements and distribution within their current range is essential. Potential alternative land-use changes, increased development, and human population expansion need to be planned for in light of the relatively unpredictable nature of gazelle movements. Thus, in late spring 2005, we surveyed Mongolian gazelle populations to estimate abundance and distribution and assess their relationships to habitat quality and household presence. Based on earlier findings (Mueller *et al.* 2008), we expected that gazelle distribution largely could be predicted using satellite imagery (mid-range Normalized Difference Vegetation Index [NDVI] as in Pettorelli *et al.* 2005) data as an approximated measurement of vegetation productivity. However, that model was not able to account for lack of gazelle use of some apparently high-quality habitat on the steppe. Recognizing that these regions often included nomadic livestock herders, we collected additional data to assess if gazelles avoid human presence (i.e., household distribution), even where vegetative productivity is high.

Methods

Habitat

Mongolia's eastern steppes consist of portions of the Daurian steppe and Mongolian-Manchurian steppe Global 200 Ecoregions (Olson & Dinerstein 2002) and is an approximately 275,000-km^2 portion of a much larger (~1.5 million km^2) grazing ecosystem that until recently had experienced low human disturbance. Once contiguous, the grasslands of Inner Mongolia and Manchuria, China, and the Daursky region of Russia have largely been degraded due to intensive overgrazing and land conversion (Hu *et al.* 1992; Yang *et al.* 2005).

The regional climate is continental consisting of extreme temperatures that range between -40 and $+40$ °C. Precipitation is highly variable averaging 228 ± 67 mm year^{-1} with lows of 100 mm occurring in the drier regions adjacent to the desert steppe ecotone to the west and 40 cm along the forest steppe ecotone in the north and east. The southern region of the steppe is bordered by China and consists of mostly degraded or intensively used habitat. In Mongolia, elevations range between 600 and 1,700 m above sea level and typical steppe vegetation is dominated by grasses, forbs, and few shrubs. Trees occur along the boundaries between forest and steppe and along drainages and rocky outcroppings trees. For detailed descriptions of the steppe vegetation and ecological processes, see Hu *et al.* (1992), Gunin *et al.* (2000), Mueller *et al.* (2008), and Olson *et al.* (2010b).

Human dimensions

Pastoralists live throughout large portions of the steppe and tend mixed herds of sheep, goats, horses, cows, and camels. The herding culture is seminomadic with household locations tied to locations of functioning wells and fresh water springs. Dogs are commonly kept primarily for personal protection and to guard against wolves. Within the eastern steppe, there are three regional capitals with populations between 16,000 and 35,000 people, and several dozen smaller village centers usually consisting of several hundred families. The entire region is inhabited by about 200,000 people (WWF Mongolia 2010). The land tenure system consists of communal grazing lands with individual ownership of winter and spring shelters allowed (Fernandez-Gimenez 2006; Upton 2009). Following the discovery of deposits of coal, oil, and uranium, the region is experiencing development pressures from both private and government sectors (UNDP 2003). Gazelles serve as an important subsistence source of protein for Mongolian herders; 46% of 156 herding family households interviewed in the area reported killing an average of >7 gazelles each in the previous 12 months (Olson 2008).

Field surveys

We conducted a line transect survey in the portion of the Mongolian steppe east of the Ulaanbaatar—Beijing railway and in the north and south bounded by the Russian and Chinese borders (Figure 1). Due to the presence of border fences and fencing paralleling the railway, the population of gazelles is more or less restricted to this region, even though the barriers are not absolute (Ito *et al.* 2005; Olson *et al.* 2009a).

Sampling protocol for clustered populations along line transects followed distance-sampling methods and assumptions developed by Buckland *et al.* (2001). We partitioned the study area into four regions (North Kherlen—40,796 km^2; Southwest—99,709 km^2; Central—62,237 km^2; and Menin—16,338 km^2) and set out a stratified systematic line transect survey design consisting of 26 north–south transects spaced at 30- and 60-km intervals totaling over 5,000 km (Figure 1). We conducted the survey between 14 May and 12 June 2005 using two 4-wheel drive jeeps and followed the sampling protocol described in Olson *et al.* (2005).

Estimating population size

We detected 1,100 Mongolian gazelle groups (Olson *et al.* 2005, 2009b), ranging between 1 and 23,000 individuals (median group size = 11) (Table 1). In the exploratory analysis, we examined histograms to determine appropriate cutoff distances. We determined the number of intervals and their width by examining several different combinations and choosing the best fit between sighting data and the probability of sighting a group directly on the transect line [where $g(0) = 1$]. We selected the size bias regression method [ln(cluster size) vs. $g(x)$] to minimize any effects of increasing distance on detection probabilities, and used Akaike's information criterion in the final selection of models. We derived global density from the mean of 4 stratum estimates (North Kherlen, Southwest, Central, Menin) weighted by stratum area. For all analyses, we used *Distance* software version 5 using the conventional distance-sampling engine (Thomas *et al.* 2006).

Assessing the effect of household presence on gazelle density

We divided each north–south transect into 5 × 1.15 km intervals (5.75 km^2), then identified household presence/absence and gazelle density (gazelles/km^2) in each block. We estimated block width using the average sighting cutoff distance and length derived from a prior similar analysis, which was deemed reasonable given knowledge of daily gazelle movements (Mueller *et al.* 2008). We then assigned each block to one of four regions corresponding to stratum identified in the population size analysis.

During the surveys, we recorded perpendicular distances and locations of 818 households (traditional Mongolian felt tents [known as gers] or small single room wood cabins [mostly in the North Kherlen region]). To determine what the effect households have on gazelle density, we used a previously developed model of habitat use based on vegetation productivity (Mueller *et al.* 2008) comparing gazelle density across a gradient of habitat quality in blocks with households absent versus density with households present. To estimate habitat quality we used a NDVI, a satellite-based vegetation estimator that is good estimator of vegetation productivity in a diverse range of ecosystems including grasslands (reviewed by Pettorelli *et al.* 2005). We acquired NDVI data from the MODIS (Moderate-resolution imaging spectroradiometer) sensor on board the TERRA satellite. Corresponding to the time periods matching the survey (index composite 166 in 2005) we acquired a 16-day composite at 250-m resolution and reprojected the data to Lambert Azimuthal Equal Area coordinate system (central meridian 114, latitude of origin 47). For each segment, we calculated the average NDVI.

To analyze regional differences in the relationship between gazelles and the vegetation index, we first examined the overall effect of the vegetation index and household presence on the number of gazelles per km^2. We used a quasi-Poisson generalized linear mixed-effects model, accounting for the differences among regions with a random intercept (function lmer in library lme4, R Development Core Team 2009). We included the NDVI, its square, and household presence as fixed effects. We included the squared term of the vegetation index to allow for a humped-shape relationship between it and gazelle numbers: Mueller *et al.* (2008) demonstrated that while low vegetation-index areas might be limiting for gazelle because of too little vegetation, areas with a high vegetation index might be limited because of the low quality of tall grasses. We explicitly modeled spatial autocorrelation (Augustin *et al.* 1996) by including as an autocovariate the number (0, 1, or 2) of neighboring blocks (i.e., the adjacent 5-km blocks to the north and to the south)

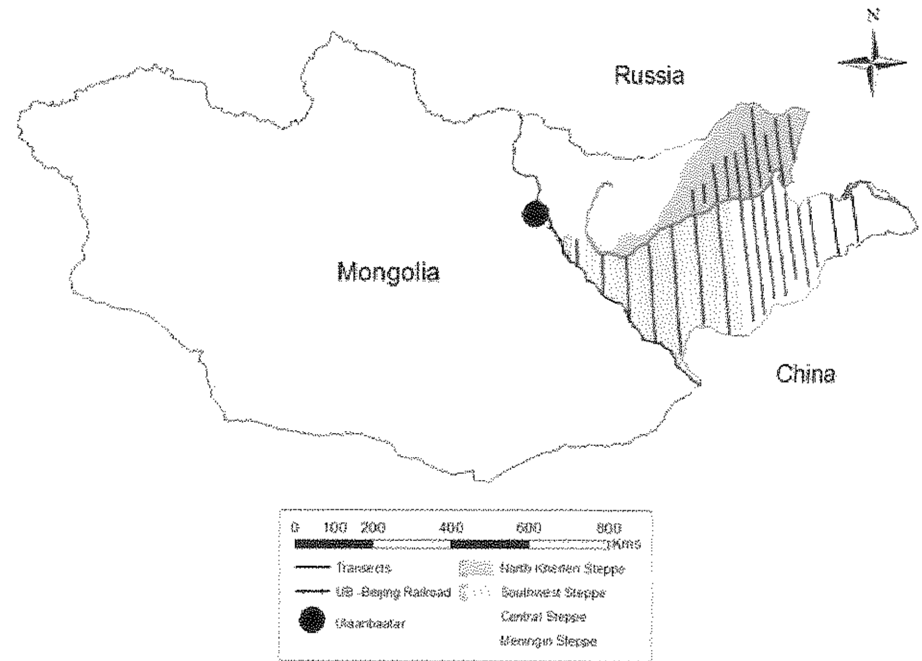

Figure 1 *Mongolia's Eastern Steppe region and survey area showing the transect lines that were driven during May and June 2005. Steppe names used in this survey are not based on ecological boundaries and are only for geographical referencing.*

where gazelles did occur as a fixed effect (Mueller *et al.* 2008). Since prior information about gazelle occurrence in adjacent areas is generally not available for predictive purposes, we also calculated a reduced model excluding the autoregressive term (Mueller *et al.* 2008).

Finally, we evaluated separate models for each stratum (excluding the Menin Steppe, because only one gazelle and no households were observed in that region) to assess the difference in magnitude of the effects of households and the vegetation index on gazelle numbers in the different areas.

Results

Global population density assessed throughout the survey region was 5.1 gazelles/km^2, ranging between 0.01 and 10.9 gazelles/km^2 at a regional level (Table 2). With the exception of the Menin region, we observed Mongolian gazelles in large numbers in all regions (Figure 2) with a total population estimate of 1.126 million (95% CI, 843,000–1,500,000). Gazelles were most abundant in the Central Steppe region (680,000); this point estimate was lower than previous estimates derived from the same

Table 1 Results of driving line transect surveys for groups of Mongolian gazelles in the Eastern Steppe of Mongolia during 14 May to 12 June 2005

		Transects			Group size[a]		
Stratum	Total area (km^2)	*N*	Total length (km)	No. of groups observed	Mean ± SD	Median	Range
Central	62,237	7	1,862	539	202 ± 1,310	12	1–23,000
North Kherlen	40,796	10	1,454	314	46 ± 131	10	1–1,650
Southwest	99,709	7	1,562	246	83 ± 412	10	1–5,800
Menin	16,338	2	268	1	1	1	1

[a]Data subsequently truncated for distance-sampling analysis (Buckland *et al.* 2001).

Table 2 Density and population size of Mongolian gazelles by region and pooled in the eastern steppe of Mongolia, as estimated using distance sampling (Buckland *et al.* 2001) and driving line transects

	Expected cluster[a] size			Density of clusters			Gazelle density (no./km^2)			Estimated population size	
Stratum[b]		% CV	95% CI		% CV	95% CI		% CV	95% CI		(95% CI)
Central	43.4	12.8	33.8–55.8	0.102	15.6	0.176–0.361	10.9	20.5	7.2–16.6	680,600	(447,940–1,034,100)
N. Kherlen	23.7	12.3	18.6–30.2	0.166	17.7	0.112–0.246	3.9	22.5	2.5–6.2	160,410	(102,260–251,620)
Southwest	28.0	15.6	20.7–38.0	0.012	21.1	0.649–0.161	2.9	26.2	1.7–4.9	285,420	(168,380–483,810)
Menin	1.0	–	–	–	–	–	0.01	–	–	25	–
Pooled estimate				0.149	10.8	0.12–0.19	5.14	14	3.8–6.9	1,126,455	(843,410–1,504,500)

[a]For distance analyses, a cluster is a group of gazelles.
[b]Key function + adjustment terms for each stratum: Central – Half-normal + Cosine; Kherlen – Half-normal + Cosine; Southwest – Uniform + Cosine; Menin – Uniform + Cosine.

region during 2000–2002 (803,000; Olson *et al.* 2005), but confidence limits overlapped.

Overall, gazelles were present in 44% of the surveyed area (436 of 990 sampled blocks [Southwest 33%, Central 49%, North Kherlen 58%, Menin 2%]) and households were present in 32% of all blocks (317 of 990 sampled blocks [Southwest 49%; Central 26%; Kherlen 27%; and Menin 0%]). Gazelle and households were both absent in 37% (367 of 990) of blocks (Central 29%, Menin 98%, North Kherlen 43%, Southwest 31%).

For the entire region, the model indicated strong influence of the NDVI and household presence on gazelle distribution independent of whether we accounted for spatial autocorrelation or not (Table 3). Overall, gazelle density in similar habitat blocks measured by the vegetation index was 7.5 times lower in habitat with at least one household present compared with no households (Figure 3). In the drier Southwest region, gazelle densities were higher in areas with slightly higher vegetation-index values than in the Central Steppe, while gazelles

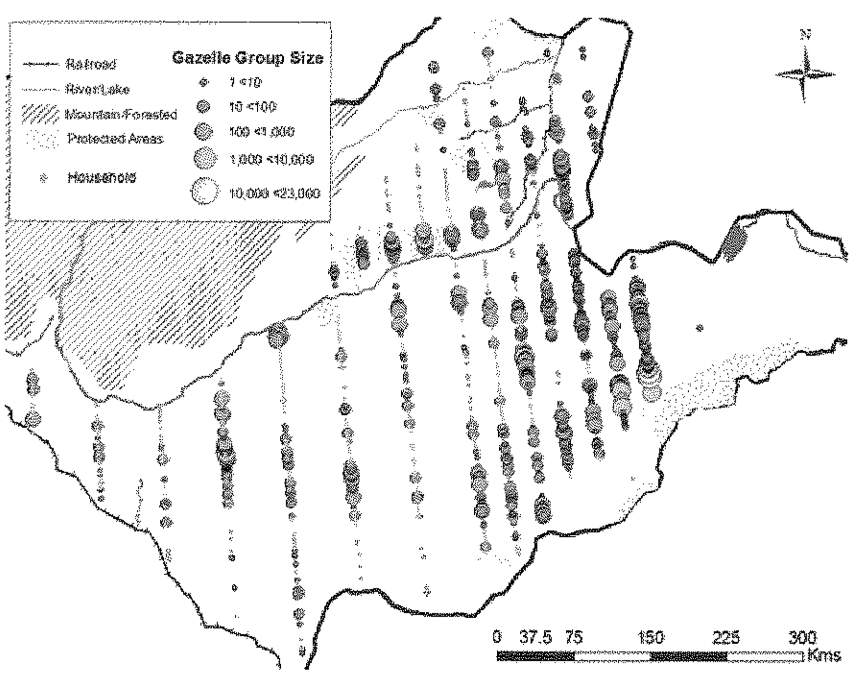

Figure 2 Household and gazelle group sightings along transects surveyed for Mongolian gazelles and households in eastern Mongolia during May and June 2005.

Table 3 Model results and performance of habitat coefficients (NDVI_5k = Normalized Difference Vegetation Index averaged for a 5 × 1.75 km block; household = household presence/absence; autocovariate = the number [0, 1, or 2] of neighboring blocks in which Mongolian gazelles were present [i.e., the adjacent 5-km blocks to the north and to the south]) for the entire range (survey area) comprising all four regions (including Menin, in which only a single gazelle was observed), and individual regions in the Eastern Steppe of Mongolia

Coefficients	Estimate	Standard error	*t*-Value	Deviance
Entire range with autocovariate term and random effects[a]				111,360
(Intercept)	−15.59033	13.59298	−1.147	
NDVI_5k	129.93522	16.17718	8.032	
(NDVI_5k)^2	−259.61067	35.96643	−7.218	
Household	−2.13637	0.27778	−7.691	
Autocovariate	1.18716	0.08553	13.881	
Entire range with random effects but excluding autocovariate term[b]				127,343
(Intercept)	−14.3706	19.0713	−0.754	
NDVI_5k	131.7667	17.7358	7.429	
(NDVI_5k)	−269.3011	39.6601	−6.790	
Household	−2.7979	0.3197	−8.752	
Central[c]				99,368
(Intercept)	−26.430	20.342	−1.299	
NDVI_5k	275.769	191.319	1.441	
(NDVI_5k)	−608.280	448.174	−1.357	
Household	−4.248	3.666	−1.159	
North Kherlen[d]				9,682
(Intercept)	−37.568	25.059	−1.499	
NDVI_5k	354.313	221.446	1.600	
(NDVI_5k)	−777.220	488.194	−1.592	
Household	−2.441	1.077	−2.266	
Southwest[e]				15,436
(Intercept)	−5.5817	3.3230	−1.680	
NDVI_5k	71.7942	31.0334	2.313	
(NDVI_5k)	−128.8387	68.1813	−1.890	
Household	−1.7780	0.6651	−2.673	

[a]Random effect: region, SD = 26.5341, [b]Random effect: region, SD = 37.4792, observations: 1,009, groups: 4, [c]DF = 369, [d]DF = 260, [e]DF = 308.

in the wetter North Kherlen region were found in greater densities in areas slightly lower than the median vegetation-index values (Figure 3).

Discussion

Our estimate of more than one million gazelles in Mongolia's eastern steppe is a positive sign that they remain relatively abundant, widespread, and ecologically important. This large population is an important prey base for predators such as wolves and eagles, and scavengers such as cinereous vultures (*Aegypius monachus*) or carrion beetles (Sylphidae). The movements across the landscape of large groups of gazelle redistribute nutrients through fecal and urine deposition and may play an important role in maintaining forage diversity, as well (Mazancourt *et al.* 1998).

Also, we confirmed (Mueller *et al.* 2008) that gazelle habitat use could accurately be predicted by a NDVI as an approximate measure of vegetation productivity (and thus habitat quality), and Mongolian gazelles selected habitat that fell within the middle ranges of vegetation productivity. However, including households in the analysis led to a difference in gazelle densities in similar habitats. We treated households first in terms of presence/absence and also tested regression models using the number of households per block. There was no clear trend in the response of gazelle numbers to households if we excluded the 0 data, but using presence/absence of households as a coefficient did reveal a notable difference in gazelle densities in the presence of human habitation for similar habitat. We surmise that this major effect is due to a variety of factors. Primarily, we note that gazelles serve as an important subsistence source of protein for Mongolian herders (Olson 2008), and thus, gazelles might be avoiding household hunters. Gazelles also might be avoiding free-ranging household dogs that are common (Buuveibaatar *et al.* 2009; Young *et al.* 2011), or grazing livestock that likely compete for forage around households (Campos-Arceiz *et al.* 2004; Yoshihara *et al.* 2008). Since our survey occurred in the month before gazelle calving (Odonkhuu *et al.* 2009), there is also the possibility that pregnant gazelles avoid disturbance by humans, as seems true for saiga antelope (Singh *et al.* 2010).

A growing human population (UNDP 2003) will inevitably reduce the range available for gazelles. Our results suggest that aggregations of households (e.g., around new wells or along new roads) can result in large regions that remain uninhabited by gazelles, even if the productivity in these regions is consistently high. Given that the areas of high-quality habitat differ from year to year, that areas of high gazelle density therefore exhibit interannual variability, and that human pressure on the range is increasing both in terms of households and new industrial development, the pressing conservation issue is to determine what kind of measures can be put in place to steward the Mongolian gazelle habitat and ensure that their population can thrive in future decades. Conventional conservation solutions would typically include a combination of land-use regulations that limit the number of herding households and their accompanying livestock that can occupy a region, development restrictions that prevent habitat fragmentation (through fencing, road location, pipeline construction), and designation of a mosaic of regions that are off limits to livestock grazing and successfully regulate gazelle hunting. All these are essentially protectionist and perhaps even punitive

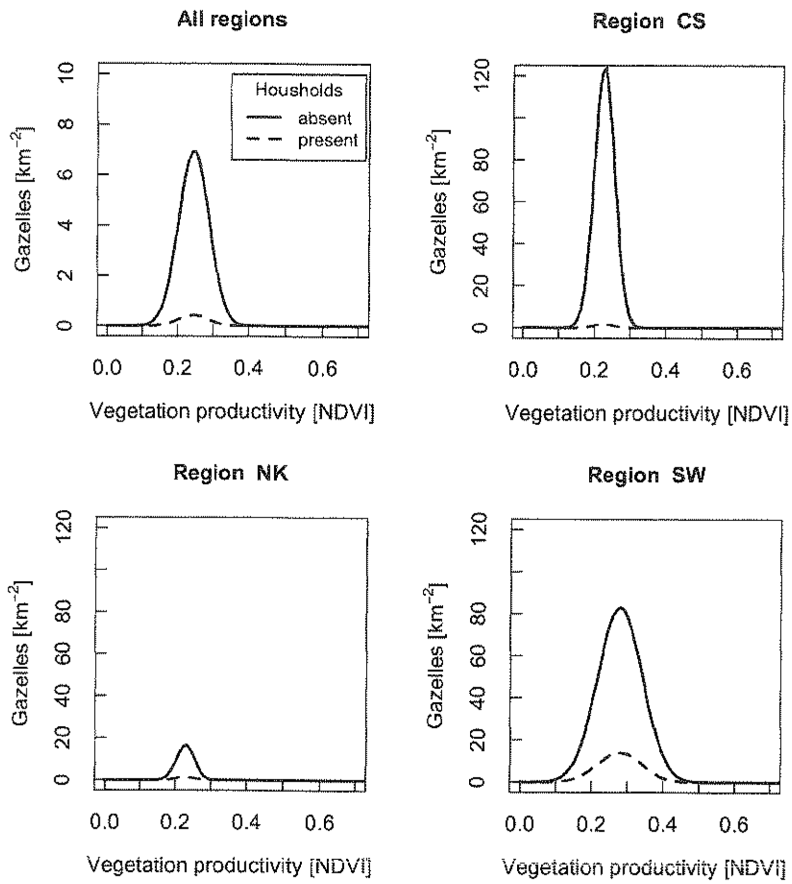

Figure 3 Effect of household presence on the number of gazelles along line transects in all regions of eastern Mongolia, and in subregions (CS, Central; NK, North Kerlen; SW, Southwest).

of the people who make their livelihood on the steppe, but they may be urgently necessary. An alternative approach could be the development of collaborative comanagement institutions in which the indigenous herders and the Ministry of the Environment share responsibility for developing and implementing conservation solutions; in current circumstances, however, such an approach is unlikely to be successful. If the value of a thriving gazelle population is clear to the residents of the steppe and if it is apparent that the long-term sustainability of the herd depends on changes in land-use policy, road closings at certain times of year, self-imposed hunting restrictions in selected areas, and further designation of protected areas may emerge and provide for a sustainable gazelle population.

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