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Satellite tracking of Mongolian gazelles (*Procapra gutturosa*) and habitat shifts in their seasonal ranges

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Abstract

Conservation and management are urgently required for Mongolian gazelles *Procapra gutturosa* inhabiting the Mongolian steppe. We captured and satellite-collared two adult females in Dornogobi Province and two adult females in Omnogobi Province and examined whether their seasonal migration corresponded to shifts in the normalized difference vegetation index (NDVI) in their habitat. The mean NDVI values of their annual, summer and winter ranges were calculated based on data acquired by the moderate-resolution imaging spectrometer (MODIS) onboard the Terra satellite. Satellite tracking of gazelles proved their ability to move long distances and provided details of their migration routes. In Omnogobi, the NDVI of the summer range was higher than those of annual and winter ranges during summer, but from October to November the NDVI of the summer range was lower than annual or winter ranges. The shift in NDVI values between summer and winter ranges corresponded with seasonal migrations of gazelles. In contrast, NDVI values were higher in the winter ranges than in both the summer and annual ranges throughout the year in Dornogobi. The results showed that the NDVI is a good indicator of gazelle habitat, but the NDVI alone cannot the explain seasonal migration of gazelles. It is important to evaluate the effectiveness and limitations of the NDVI as an indicator of habitat quality.

Introduction

Mongolian gazelles *Procapra gutturosa*, which inhabit the steppes of Mongolia, northern China and southern Russia, were listed in the *IUCN Red List of threatened animals* as a near-threatened species (IUCN, 1996). Conservation and management of gazelles are urgently required (Jiang *et al*., 1998; Reading *et al*., 1998), as the total population has decreased from about 1.5 million head in the 1940s to 300 000–800 000 at present (Lhagvasuren & Milner-Gulland, 1997; Jiang *et al*., 1998; Olson *et al*., 2005). The Mongolian gazelle migrates hundreds or thousands of kilometers seasonally, but details of the migration routes are still unknown (Berger, 2004), because continuous tracking is difficult.

To conserve animals that migrate long distances, it is necessary to know their migration routes and reasons for migrating (Berger, 2004). Over the last decade, the advent of reliable satellite tracking technology has enabled the study of such long-distance movements (Gillespie, 2001; Akesson, 2002; Webster *et al*., 2002; Nathan *et al*., 2003). In addition, satellite imagery and remote sensing technology are now commonly used to assess habitat extent and quality in ungulate studies (e.g. Unsworth *et al*., 1998; Bowyer *et al*., 1999; Leimgruber *et al*., 2001).

For ungulates inhabiting grasslands, aboveground net primary productivity is strongly correlated with habitat quality (McNaughton, 1985, 1993; Frank & McNaughton, 1992). Therefore, it is possible to use the normalized difference vegetation index (NDVI; Eidenshink & Faundeen, 1994; Lillesand, Kiefer & Chipman, 2003) calculated from satellite imagery as an index of habitat quality. Strong statistical relationships have been proven between the NDVI and biomass and/or productivity (Cihlar, St-Laurent & Dyer, 1991; Paruelo & Lauenroth, 1995; Paruelo *et al*., 1997), and the NDVI has been used to estimate the habitat quality of the Mongolian gazelle (Leimgruber *et al*., 2001; Ito *et al*., 2005) and other wild and domestic ungulates (e.g. Verlinden & Masogo, 1997; Oesterheld, RiBella & Kerdiles, 1998; Serneels & Lambin, 2001).

Leimgruber *et al*. (2001) showed that winter and calving grounds had the highest NDVI scores during the period of use by gazelles in eastern Mongolia, suggesting that gazelle movements track shifts in primary productivity across the steppe. However, they could not detect shifts between summer and winter grounds. It may be caused by their classification method of gazelle ranges. In that study they simply delineated the habitat types within the gazelle range (i.e. winter, summer and calving grounds) according to the literature and expert knowledge, not by actual migration data (Leimgruber *et al*., 2001), because data on migration routes and habitat selection of gazelles were lacking.

In arid areas including the Mongolian steppe, annual variation in climate is great. This variation affects distributions of plant availability (Yu *et al*., 2004) and areas used by wild herbivores in large scale. Therefore, analyses between animal movements and their habitat conditions in the same periods are necessary to evaluate actual relationships between them. If gazelles migrate from summer ranges to winter ranges as typical migrant species, NDVI values in the summer ranges should be higher than those in the winter ranges during summer, but lower during winter. Analyses between animal movements and their habitat conditions in the same periods may be able to detect such crossing of NDVI values between the summer and winter ranges. On the other hand, if gazelles move nomadically and/or distribute proportionally with the food availability according to the ideal free distribution (Fretwell & Lucas, 1970), relationships between movements of the tracked gazelle and NDVI values in their seasonal ranges may not be clear.

Such analyses are necessary to understand the mechanisms of gazelle migration, allowing us to devise conservation and management plans. Therefore, we undertook the first trial of satellite tracking of Mongolian gazelles. Our objectives were to describe the migration routes of Mongolian gazelles on the basis of satellite tracking and to examine the relationships between their seasonal migrations and shifts in NDVI in their summer and winter habitat.

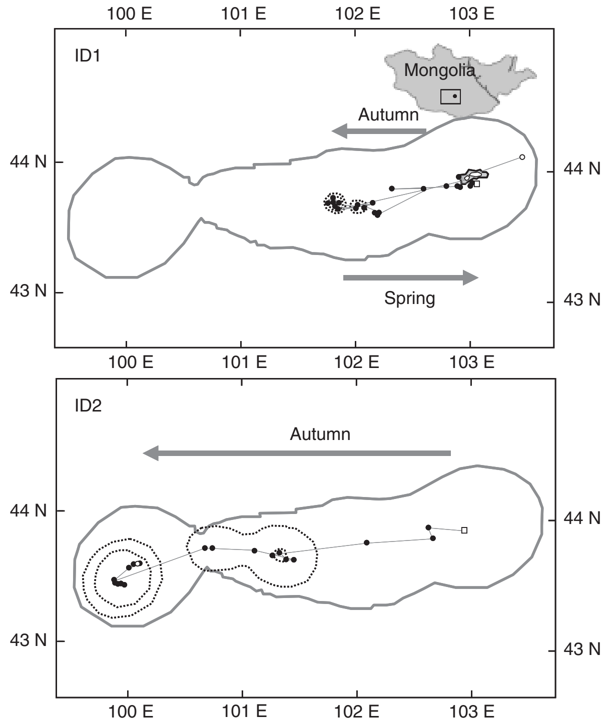

Figure 1 Gazelle locations (solid circle) and annual (gray polygon), summer (solid polygon) and winter ranges (dashed polygon) of ID1 and ID2 in Omnogobi from October 2002 until October 2003. Location intervals are 1 week. Open squares and open circles indicate the sites of capture and the last location points, respectively. Outside and inside polygons of the summer and winter ranges indicate 80 and 50% core areas, respectively. Core areas in summer ranges are shown as gray (80%) and white (50%) polygons without a location point, because most gazelle locations are concentrated in a small area. No summer range is indicated for ID2 because she died in February 2003.

Methods

Study area

The region is characterized as high upland (*c*. 1000 m). The climate is strongly continental and arid, characterized by a cold winter (to −35 °C), dry, windy springs, and relatively wet, hot summers (to 40 °C). Annual precipitation increases from about 100 to 600 mm from the western desert to typical steppe (Ni, 2003). Fine-leafed grasses and onions dominate in the Gobi steppe, and semi-shrubs, shrubs and some grasses dominate in the semi-desert regions. An international railroad between China and Russia bisects the habitat of the Mongolian gazelle. The nearly linear railroad runs north-west to south-east through Mongolia (Figs 1 and 2) and barbed-wire fences were built alongside it to avoid accidents involving livestock (Ito *et al*., 2005).

Gazelle tracking

We captured and collared two adult female gazelles in Dornogobi Province, Mongolia, on 18 October 2002 and two adult females in Omnogobi Province on 26 and 29 October 2002 (Figs 1 and 2). The gazelles were captured using two cars and a net measuring 300 m long and 1.5 m high. The cars pushed the herd of gazelles slowly toward the net and chased the gazelles into it when they came close. The body weights of captured gazelles were 27.0–31.5 kg. Each gazelle was collared with a satellite transmitter (platform terminal transmitter or PTT; model ST-18, Telonics Inc., Mesa, AZ, USA). The weight of a PTT with collar was 550 g. The PTTs were programmed to transmit radio signals for an 8-h period each week, that is, to obtain location data 1 day per week. The location data were received through computer communications and computer disks sent from the Collecte Localisation Satellites Service in France.

Location classes (LCs) ranged from 0 to 3. The higher the LC, the more accurate the location data. Less accurate data are also provided as LC A and B (Service Argos, 1988). Keating, Brewster & Key (1991) calculated the accuracy of LC 1, 2 and 3 data from the PTTs. Their one-standard-deviation accuracy results, compared with the accuracies reported by Service Argos (1988), were 1188 versus 1000 m for LC 1, 903 versus 350 m for LC 2 and 361 versus 150 m for LC 3.

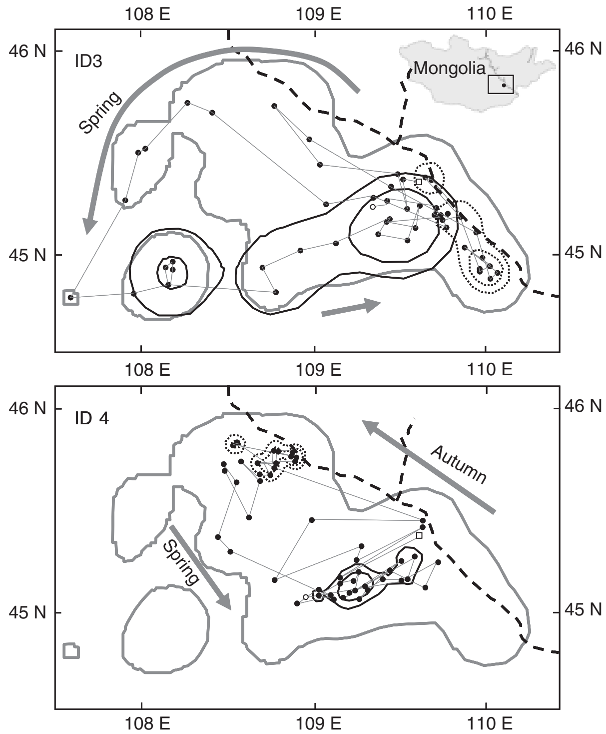

Figure 2 Gazelle locations (solid circle) and annual (gray polygon), summer (solid polygon) and winter ranges (dashed polygon) of ID3 and ID4 in Dornogobi from October 2002 until October 2003. Location intervals are 1 week. Open squares and open circles indicate the sites of capture and the last location points, respectively. Outside and inside polygons of the summer and winter ranges indicate 80 and 50% core areas, respectively. Bold dashed lines indicate the international railroad.

We obtained location data for the four gazelles for a year. We selected the best data in each day according to the LC to plot gazelle migration routes. When there were several data of the best LC in a day, the last location data of the LC were selected. 96.0% of the total number of the best location data in a day fell into LC 3, 2 or 1 (LC 3, 51.1%; LC 2, 27.3%; LC 1, 17.6%), with 2.8% falling into LC 0 and 1.2% into LC A and B. We avoided location data of LC A and B in analyses.

We categorized the home range into annual, summer and winter ranges. The annual range in each province was defined as the 95% core area on the basis of data from October 2002 until October 2003. Summer and winter ranges of each gazelle were defined as core areas on the basis of data from 1 June to 31 August and from 1 December to 28 February, respectively. These home ranges were calculated by the kernel method (Worton, 1989) using ArcInfo/ArcView (Environmental System Research Institute Inc., Redlands, CA, USA) with the animal movement extension (Hooge & Eichenlaub, 2000). For summer and winter ranges, we calculated 95, 80, 70, 60 and 50% core area to determine the most suitable core area to evaluate environmental conditions in their seasonal home ranges.

Analysis of environmental conditions

NDVI values were calculated using imagery from the moderate-resolution imaging spectrometer (MODIS, Raytheon Co., Waltham, MA, USA; Huete *et al*., 2002) on the Terra satellite. NDVI values ranged between -1.0 and $+1.0$. Positive values indicated the existence of plants and were positively related to plant biomass, whereas negative values generally represented non-vegetated surfaces such as barren lands, rock, water or ice. We downloaded NDVI data of a 16-day composite and 250-m resolution for the distribution area of Mongolian gazelle (tile numbers: h24v04, h25v03, h25v04 and h26v04) from NASA's Earth Observing System Data Gateway via the internet (http://redhook.gsfc.nasa.gov/~imswww/pub/imswelcome/plain.html, MODIS vegetation indices, MOD13Q1 Product; NDVI, 250 m). We used 23 time series of NDVI imageries from 16 October 2002 to 30 September 2003 (the first date of the 16-day composite) for analyses.

The mean NDVI of each range was calculated using Erdas Imagine (Leica Geosystems GIS & Mapping, LLC, Heerburgg, Switzerland) for every time interval. According to the methods in Leimgruber *et al*. (2001), we subtracted the mean NDVI in the annual ranges from each of the values for the summer and winter ranges for every time interval to obtain an index of relative quality in the different ranges within the annual ranges, and used Wilcoxon signed rank tests to examine differences in relative NDVI values between the seasonal ranges during winter and summer. In the test, we defined seven time intervals from 17 November 2002 to 18 February 2003 and another seven intervals from 25 May to 29 August as winter and summer, respectively.

Results

Gazelle migrations

The two gazelles in Omnogobi (ID1 and ID2) moved west in November along the southern mountains (Fig. 1). Both arrived in the western area in late December. In late March, ID1 went back east to the area near the site of capture, but ID2 did not move after February. We found ID2 dead during our field survey in the summer of 2003. Annual, winter and summer ranges are shown in Fig. 1.

The two gazelles in Dornogobi (ID3 and ID4) used the area alongside the railroad from October to April (Fig. 2). In early April, both gazelles were located in the northern part of their annual range. In mid-April ID3 went south-west and stayed there until June, moved east in July and went back to the area where they were captured in September. ID4 moved 100 km south-east in mid-April and stayed there until the end of the study. Throughout the year, neither gazelle crossed the railroad (Fig. 2). Their winter ranges were located near the railroad and summer ranges were in western areas away from the railroad (Fig. 2).

For all the gazelles, the maximum distance moved per week was about 80 km and the maximum linear distance moved per

Table 1 Distances moved per week and per year by each gazelle, and tracked periods

		Distance moved per week (km)				Distance moved per year (km)		
ID	Province	Mean	SD	Maximum	Minimum	Maximum linear	Cumulative	Tracked period
1	Omnogobi	12.9	15.5	71.7	0.6	161.7	658.7	21 Oct. 2002–14 Oct. 2003
2[a]	Omnogobi	22.5	25.4	81.2	2.1	285.4	383.2	29 Oct. 2002–25 Feb. 2003
3	Dornogobi	21.4	16.5	79.9	0.4	200.8	1111.5	18 Oct. 2002–13 Oct. 2003
4	Dornogobi	19.4	16.3	78.8	2.0	129.7	1011.1	18 Oct. 2002–13 Oct. 2003

[a]ID2 was tracked for only 5 months because she died in February 2003.

year was 285 km (Table 1). Cumulative distances for the year reached more than 1000 km for ID3 and ID4 (Table 1).

Seasonal patterns of NDVI in the summer and winter ranges

Mean NDVI values in the different percentages of core areas showed similar seasonal changes in each seasonal range, and differences among the different percentages of core areas were not so large (Fig. 3). However, NDVI values in the 50% core area were highest in the season when gazelle used these in the ID2 winter range, ID1 summer range and ID3 summer range, although they were lowest in the ID1 winter range (Fig. 3). In summer, NDVI values in the 50% core area in the winter ranges were lowest in all individuals (Fig. 3). These results mean that the value in 50% core areas is the best indicator of the environmental conditions in their seasonal ranges from 95 to 50% core areas. Therefore, we used the value in 50% core areas to compare NDVI values between the summer and winter ranges.

NDVI values in each range changed seasonally, being highest between June and September and lowest between December and February in both provinces (Fig. 4). During winter, NDVI decreased to near or below zero, except for the winter range of ID4.

In Omnogobi, NDVI of the summer range was higher than those of annual and winter ranges during summer, and even during winter for the summer range of ID1 (Table 2, Fig. 5a). From October to November, NDVI of the summer range was lower than annual or winter ranges (Fig. 5a). In contrast, NDVI of the winter range was lower than that of the annual range throughout most of the year, although it was higher from October to December (Fig. 5a).

In Dornogobi, NDVI of the winter range was higher than those of summer and annual ranges throughout most of the year (Table 2, Fig. 5b). Seasonal changes of relative NDVI of the summer ranges were slight, with NDVI values being higher than the annual range during summer and lower during winter (Fig. 5b).

Discussion

This is the first trial to show the migration routes of Mongolian gazelles using satellite tracking. The cumulative distance moved by some gazelles was more than 1000 km. Satellite tracking proved their ability to move long distances and provided details of their migration routes, which can be used to examine the reasons for their long-distance migrations and to devise habitat conservation plans.

We tracked only four gazelles. However, Mongolian gazelles are gregarious and often form large groups, some as large as 80 000 animals, during spring and autumn migrations (Lhagvasuren & Milner-Gulland, 1997; Jiang *et al*., 1998). In fact, the tracked gazelles belonged to large herds of hundreds of animals when they were captured. We also found larger herds in their home range the following summer. Therefore, it is likely that several hundred gazelles moved together with the tracked gazelles.

Tracked gazelles changed their range seasonally, although the summer and winter ranges of ID3 were partially overlapped. NDVI values in the 50% core area of their seasonal ranges were higher than those in larger percentage core areas or not so different during the seasons when they were used. This suggests that Mongolian gazelles have the ability to select better sites among their potential home range, and the satellite tracking and core area analysis are useful in evaluating the preferred habitat.

Shifts in NDVI values between summer and winter ranges corresponded with seasonal migrations of gazelles in Omnogobi. In the summer range, NDVI values were higher than those in the annual range during summer, but lower from October to November. In the winter range, in contrast, NDVI values were lower than those in the annual range during summer, but higher from November to December. These shifts in habitat quality explain well why the gazelles migrated seasonally. The shift in relative NDVI values between the summer and winter ranges corresponds to the autumn migration period of gazelles. During midwinter, however, NDVI values in winter ranges were not higher than that in the summer range. This shift in plant biomass would be an important migration trigger.

Leimgruber *et al*. (2001) divided the Mongolian gazelle habitat into three categories – winter, summer and calving grounds – and noted the seasonal shift of NDVI values between calving and winter grounds in eastern Mongolia. In the present study, a similar shift of NDVI values was shown without separating calving grounds from summer range in Omnogobi. The difference in our findings is because Leimgruber *et al*. (2001) delineated the gazelle habitat on the basis of information in the literature and expert knowledge, whereas we used actual location data of gazelles and analyzed relationships between location and NDVI in the same period. Annual variability in climate may affect which habitats and migration routes are used by gazelles

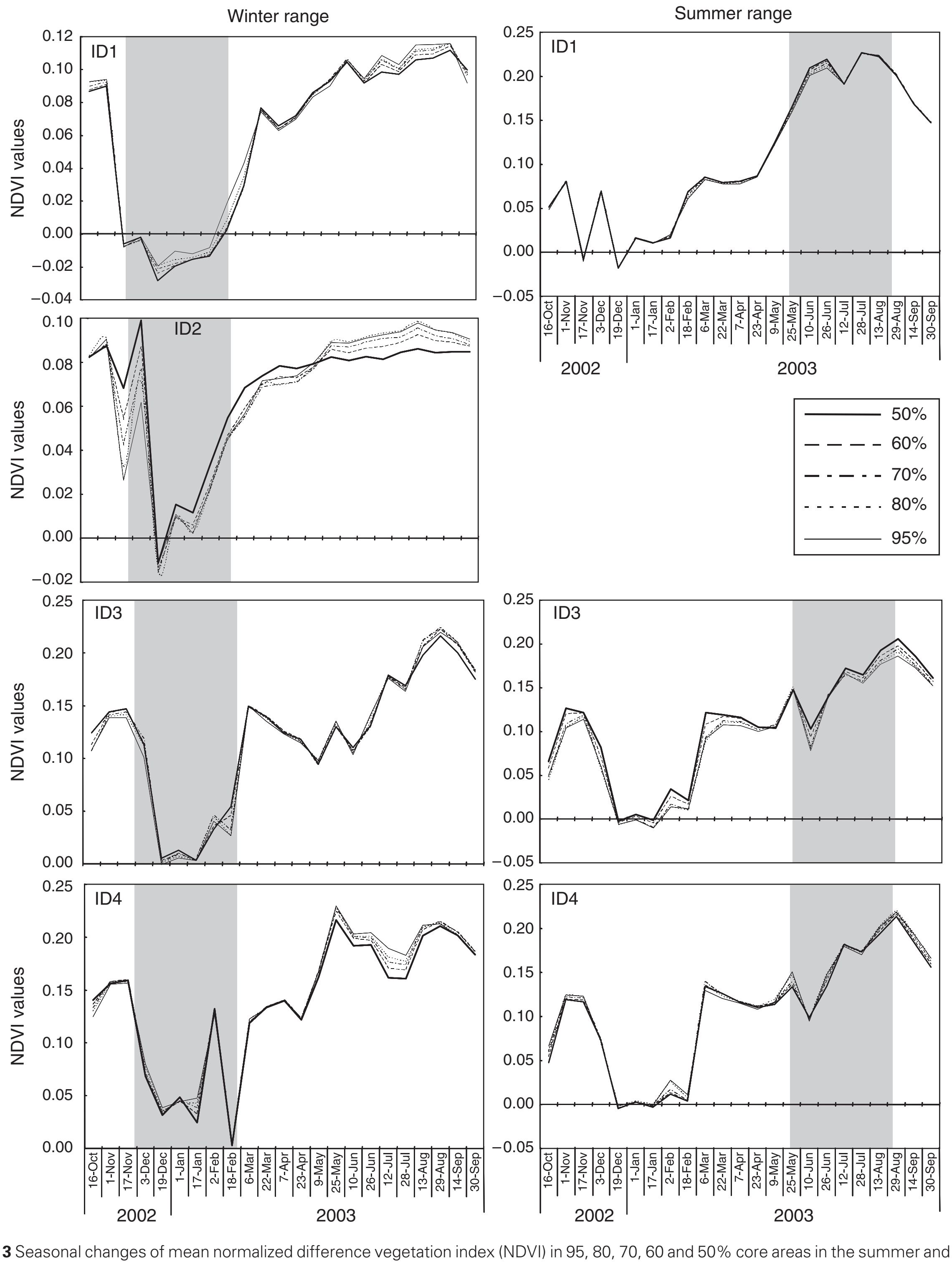

Figure 3 Seasonal changes of mean normalized difference vegetation index (NDVI) in 95, 80, 70, 60 and 50% core areas in the summer and winter ranges. The periods when gazelles used these seasonal ranges are highlighted.

each year, because inter-annual and spatial variability of precipitation in this region is great and results in great inter-annual and spatial variability of vegetation conditions (Yu *et al*., 2004). Thus, not only is it important to analyze gazelle movements and habitat characteristics in the same period, but also long-term studies are needed as well. Such analyses are important for other herbivore species inhabiting arid environments.

The pattern of NDVI values between summer and winter ranges was different in Dornogobi. NDVI values were higher in the winter ranges than in both the summer and annual ranges throughout the year, although NDVI values in summer ranges were higher during summer and lower during winter than in the annual range. Several factors may explain why gazelles did not use areas where the NDVI was higher.

First, the herds of tracked gazelles might move according to an ideal free distribution (Fretwell & Lucas, 1970). Food availability in the winter range may be greater than in other areas even during summer; if gazelle density were also higher in the range, some gazelles would benefit by moving to other areas. Thus, the tracked gazelles may have selected areas where food availability was lower but gazelle density was also lower than in the winter range, because there were enough plants in other areas during summer. To examine whether gazelles distribute according to the ideal free distribution or not, the sample size is very limited. More samples of gazelle locations are needed at the same periods using more satellite transmitters and/or aerial surveys, and distribution patterns of gazelles and of plant availabilities should be compared. However, collecting location data of animals moving long distances is still difficult and costly. Therefore, approaches to gathering expert knowledge and delineating important sites for animals would also be effective in comparing environmental conditions.

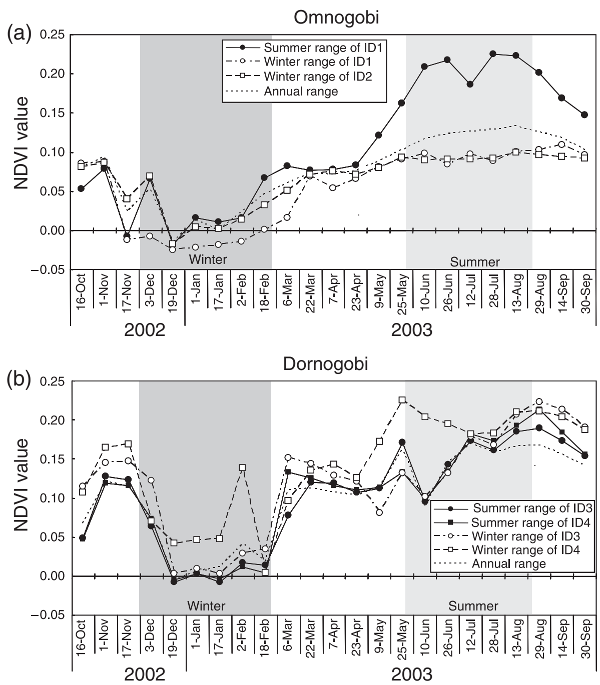

Figure 4 Seasonal changes of normalized difference vegetation index (NDVI) in the summer, winter and annual ranges. Dates indicate the first day of each 16-day composite of the satellite images. No summer range is indicated for ID2 because she died in February 2003.

Second, a higher NDVI may not directly reflect a better site for gazelles. Wildebeest *Connochaetes taurinus* in the Serengeti prefer short- and intermediate-height grass of moderate greenness during both the dry and wet seasons, consistent with the model prediction that large-scale movements by wildebeest are motivated by an energy-maximizing strategy (Wilmshurst *et al*., 1999). Dry matter intake rate is positively related to sward biomass (Gross *et al*., 1993), yet energy digestibility declines along the same gradient. Hence, it is generally predicted that, for grazing ruminants, the daily energy intake rate will be highest on intermediate biomass swards, where the grazer can optimize dry-matter intake rate and energy digestibility (Fryxell, 1991). Seasonal migrations over an elevation gradient by other ungulates, such as red deer *Cervus elaphus* (Albon & Langvatn, 1992) and bighorn sheep *Ovis canadensis* (Festa-Bianchet, 1988), suggest that migrants benefit nutritionally by migrating to sites of fresh green growth emerging as the snow cover retreats.

In Mongolia, precipitation increases from south-west to north-east (Ni, 2003). Omnogobi is drier than Dornogobi and eastern Mongolia. The vegetation in winter ranges in Omnogobi appears to be very poor: NDVI values were around 0.1 even in summer and lower than those in Dornogobi. In such areas, places with greater plant biomass – those with higher NDVI values – may be better for gazelles. In more humid areas such as central and eastern Mongolia, however, several vegetation types exist, for example, short grasslands, tall grasslands and shrublands. In these areas, when Mongolian gazelles prefer short or intermediate grasslands according to an energy-maximizing strategy, higher NDVI values might not indicate better habitat quality for gazelles.

Table 2 Two-tailed probabilities for differences in relative NDVI values between winter and summer ranges of each gazelle and higher NDVI ranges during winter and summer

		Winter season				Summer season			
Gazelle ID	Province	*n*	*Z*	*P*	Higher NDVI range	*n*	*Z*	*P*	Higher NDVI range
1	Omnogobi	7	−2.366	0.018	Summer range	7	−2.366	0.018	Summer range
2[a]	Omnogobi	7	−0.507	0.612	–	7	−2.366	0.018	Summer range
3	Dornogobi	7	−2.366	0.018	Winter range	7	−0.507	0.612	–
4	Dornogobi	7	−1.859	0.063	Winter range	7	−2.028	0.043	Winter range

[a]There are no data for the summer range of ID2 because she died in February 2003. The summer range of ID1 was used as that of ID2 for the test, because ID2 was captured quite close to the site of ID1's capture and the summer range of ID1. *n*, numbers of mean NDVI value during each period. NDVI, normalized difference vegetation index.

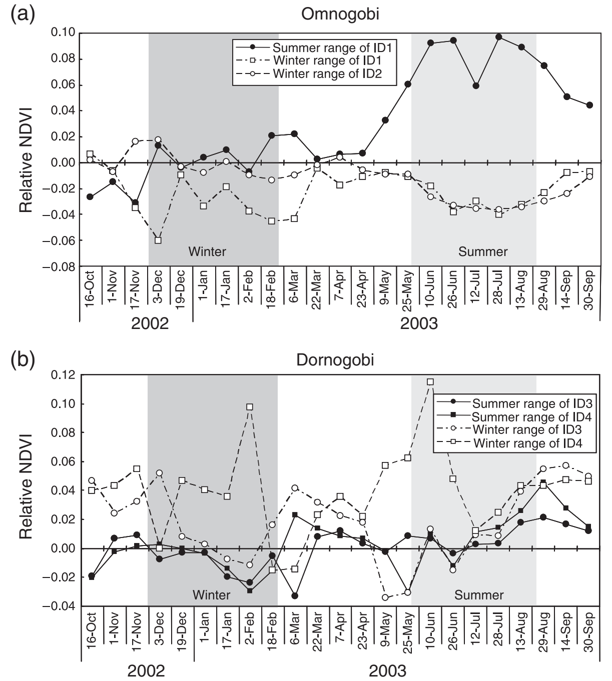

Figure 5 Seasonal changes of relative normalized difference vegetation index (NDVI) in the summer and winter ranges. Positive values and negative values mean higher and lower NDVI values than the average in the annual ranges, respectively. Dates indicate the first day of each 16-day composite of the satellite images. No summer range is indicated for ID2 because she died in February 2003.

Such climate and vegetation differences within the distribution area of Mongolian gazelles may course regional differences of gazelle movement patterns. It is unclear whether the movement patterns of Mongolian gazelles exhibit a regular migratory behavior or are more consistent with a nomadic behavior, and whether the movement patterns differ regionally. A combination of research on distributions and continuous tracking of gazelles for several years would be effective to answer these questions.

Barrier effects of the railroad (Ito *et al*., 2005) may also cause gazelles not to use higher NDVI areas. The tracked gazelles in Dornogobi did not cross the railroad. They used only the western side of the railroad through the year, despite their locations being close to the railroad during winter, and the NDVI when the gazelles moved the greatest distance in their autumn migrations was higher on the eastern than on the western side (Ito *et al*., 2005). In Omnogobi, the gazelles moved along the mountains. Topography and artificial barriers must be considered when studying gazelle habitat and migration route selection.

Even if higher NDVI values reflect better sites for gazelle, they may not have used these sites because of livestock and human activities. There are many livestock such as sheep, goats, horses, cattle and camels on the Mongolian steppe. Oesterheld *et al*. (1998) demonstrated that livestock stocking rate and NDVI were strongly related in the rangelands of Argentina. Livestock home ranges are regulated mainly by nomadic people, who select sites where they live and pasture livestock on the basis of grassland condition and water accessibility. Therefore, humans and livestock would use areas showing higher NDVI values. In addition, hunting is an important source of mortality for gazelles (Reading *et al*., 1998). If Mongolian gazelles tend to avoid areas where human activity is high to escape hunting and/or competition from livestock, areas selected by gazelles may not be coincident with areas showing the highest NDVI values.

The present study showed that the NDVI is a good indicator of gazelle habitat; however, the NDVI alone cannot explain all gazelle migration. This problem would exist in analyses targeting other animal species as well. To understand the migrations of Mongolian gazelle for conservation planning, it is important to evaluate the effectiveness and limitations of NDVI as an indicator and to analyze gazelle migrations on the basis of other factors, such as plant quality, topography, influences of livestock and human activity, and gazelle density at particular sites.

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