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A comparative study of pasture degradation of Inner Mongolian fenced and unfenced land based on remotely sensed data

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リモートセンシングを用いた内モンゴルの草原における柵内・外の土地の退化に関する比較研究

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1. Introduction

The China's natural desert ecosystems have a complex geological history and existed for at least one million years. However, in recent times, the natural borders for deserts are greatly expanding due to the increasing human population pressure combined with an expansion of crop and livestock production, and resulted in loss of vegetation and acceleration of desertification processes (FAO, 2003).

Inner Mongolia became the destination of millions of Han Chinese peasants, and it consequently turned from natural grasslands to urban settlements and agricultural field. In recent years, increasing density of settlements has led to severe ecological degradation, forcing many nomadic Mongols to leave their deserted homeland, thereby destroying their traditional way of life.

The grassland ecosystems in Inner Mongolia used for a number of purposes such as livestock grazing, wildlife habitat, and recreation. Most types of grassland in China can be found in Inner Mongolia. Approximately 35% belong to typical steppe, 21% to desert steppe, 10% to meadow steppe, 10% to eco-tone of desert to grassland, 6.8% to transition area of grassland to desert, and 11% to lowland meadow, respectively (Liu M. Z., et al., 2004,). Three major zonal grassland categories, i.e., meadow steppe, typical (dry) steppe and desert steppe are distributed along the northeast to the southwest in Inner Mongolia.

Beginning from the Qing Dynasty, during last 150years period the Eastern District of Inner Mongolia (Horqin area) became semi-nomadic, semi-agricultural region where inhabitants are practice both agriculture and livestock breeding. One half of the income of local people comes from the production of crops and the remaining half from animal husbandry. The cultivated land is in lowland meadow (oasis) and surrounding sand dunes are used as pastures for livestock. To protect crops from livestock the plantations are fenced. However, during thousand of years the grassland in Xilingol has been used by nomadic pastorals only and the level of hard Calcium remained stable. In conditions of the typical dry steppes, the layer of hard Ca is situated 5 to 10 cm from the soil surface, and not tree but grasses are could be grown (Wulantuya, 2000, 2002).

Pasture fencing became the problem because this is restricts movement of nomads and they are forced to use the same kind of pasture all year around. Crowded pastures are quickly overgrazed and grassland is turned into desert. Grassland ecosystems in Inner Mongolia are very fragile, not well suited for agriculture, and its productivity is largely dependent on annual precipitation. Continuous long-term usage of grassland

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for agriculture causes degradation and resulted in desertification (Dee Mack Williams, 1996).

The purpose of this research is to investigate effect of pasture fencing on grassland productivity in Sunite steppe that situated near the new outbreak focuses of Asian dust storm in heart of inland Asia. Soil structure, moisture, vegetation cover of pastures, and other characteristics, including dry matter productivity (DMP) were studied in fenced and open pastures. Comparisons are made to understand effect of fencing on environmental conditions (K. Kawamura, et al., 2005).

2. Materials and methods

2.1 Site description

Sunite steppe, Xilingol Aimag, Inner Mongolia, China. Latitude (N42046'-N43048') ; Longitude (E113042'-E115035'). Soil is 5 to 25cm thick, 10cm in average. Annual precipitation is 110-310mm, those in 2006year were 209mm (see Table 1). The average altitude is 1,100m, vegetation cover is 3%-26%. Typical soil types are chestnut and brown chestnut soil. Dominant plant communities consist of *Aneurolepidium chinense*, *Stipa grandis*, *S. krylovii* and *S. klemenzii*.

Historical remarks: The land cultivation began in 1950's, and has been greatly enhanced during following four stages. During the first one (early 50's), the immigrants from continental China has settled in southern part of Xilingol Province. The second stage (1958-1961) is "The big land cultivation" campaign (one stage of the so called "Da-Yue-Jin"− political campaign). The third campaign (1966 to 1976) was so called "Cultural Revolution" during which the militarized construction corps made cultivation of the 12million ha of grassland. The fourth campaign has been conducted in the last half of 1980's and named as "Reform and opening-up" and "Development Zone rush". Implementation of four campaigns, the land cultivation that continued for more than 50years seriously affected grassland in Xilingol steppe, almost one half of the Province has been turned into deserts and lost its productivity. (Sara Brogaard and Zhao X., 2002 ; George C. et al., 2003)

2.2 Methods

2.2.1 Satellite data.

The satellite data come from Landsat MSS, TM images taken in June 19, 1977 ; September 24, 1993 ; October 3, 1999, and September 28, 2006. The digital numbers were corrected on atmospheric effect and been converted into reflectance, and the ground field survey was performed to detect changes in land cover and land uses. The reflectance images were used for NDVI calculation, and further to estimate the dry matter productivity. The normalized difference of the vegetation index (NDVI) is a non-linear transformation of the visible(Red)and near-infrared (NIR) bands of satellite reflectance. NDVI is defined as the difference between the visible (Red) and NIR bands, over their sum. The NDVI is an alternative measure of vegetation amount and condition, and is associated with vegetation canopy characteristics such as biomass, leaf area index and percentage of vegetation cover.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The NDVI is also calculated from LANDSAT-TM data by using the combinations of bands 3 (0.63-0.69mm) and 4 (0.76-0.90mm) [(Band-4−Band-3)/(Band-4+Band-3)]. Healthy vegetation will have a high NDVI value. Bare soil and rock reflect similar levels of near-infrared and red and so will have NDVI values near zero. Clouds, water, and snow are the opposite of vegetation in that they reflect more visible energy than infrared energy, and so they yield negative NDVI values. In this study, the land covers classification by the using NDVI values and ground measurement data (Tucker, 1979 ; Huete, A. R., 1988).

Table 1 Average monthly temperatures, Sunite steppe (2006)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature	−18.9	−12.1	−3.5	7.5	15	21.1	24	21.4	15.6	4.1	−7.7	−16.5

2.2.2 Ground survey data

Vegetation survey methods: sites for vegetation survey were selected in both inside and outside of fenced pastures. Using Quadrate method the flora, dominant plant species, their height, cover value data, DMP and etc. were investigated on 5m×5m plots. Soil water content has been measured using a Hydrosensec soil moisture and water detection system at 12 and 20cm soil horizons. The plant species spectrums were measured using spectroradiometric measurements system Handheld FieldSpec equipment. Question and interview survey was conducted to know the types and changes in land uses, livestock density, income of local livestock breeders and etc. (Bastin, G. N., 1995 ; K. Kawamura, et al., 2005)

3. Results and discussion

Today, Inner Mongolia (Inner Mongolia Autonomous Region of China), once a land of nomadic pastorals for thousand of years quickly becomes densely populated agricultural area. Sharmuruun (Xi-Liao-He, the Western Liao River)region in Tong-Liao is a mosaic land where oases alternates with sand dunes and has a 130year history of oasis cultivation. Now, the territory of oases is greatly reduced, more than half of its territory is replaced with sand desert and no longer serve for agricultural purposes. The present study site in Xilingol steppe characterized by its unfitness to agriculture, because the soil calcium horizon is covered with few centimeters of sand or sandy soil (chestnut soil) and hardly can used for cultivation. Any kind of settlement in this area would increase the environmental stress and lead to grassland degradation and as result to a land desertification.

3.1 Changes in vegetation coverage inside and outside of fences

The ground survey location is shown on Fig. 1. Analysis of the satellite data clearly showed that in 2006 despite good precipitation levels the entire pastures were severely degraded. Results from ground survey indicated that plant communities in the selected area are greatly changed. Once dominant populations of *Aneurolepidium chinense*

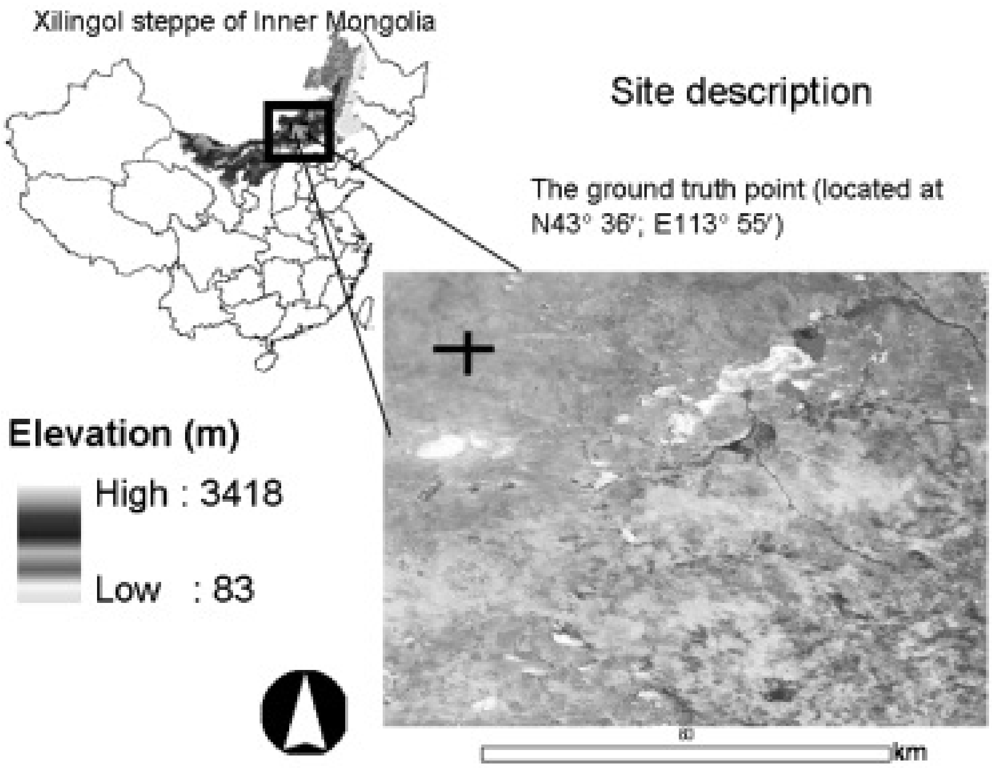

Fig. 1 Location map of study area

Table 2 Pasture degradation and desertification is caused by many natural and anthropogenic factors (Unit: km²).

	Sep. 24, 1993	Oct. 03, 1999	Sep. 28, 2006
Water bodies (dependent on natural factors)	78.31	67.67	76.75
Water blighted area (dependent on natural factors)	91.16	478.62	210.68
Degraded grassland (caused by both natural and anthropogenic factors)	5118.82	9449.23	9176.27
Non-degraded grassland outside of fenced area	11548.27	6227.54	7114.66
Non-degraded grassland inside fenced area (dependent on anthropogenic factors)	846.15	1459.65	1104.35

and *Stipa grandis* were replaced with *Artemisia frigida* and *Potentilla acaulis*. Besides changes in composition of communities, values for the vegetation coverage, height and DMP (g/m2) were greatly varied between fenced and unfenced pastures (Table 2). During both the dry and wet years the plant communities inside the fenced area characterized by taller and dense grasses, DMP values were 2.75 to 5.26 times higher than those outside fence (Table 2 and Fig. 2). However, the community height and vegetation coverage values in protected area did not increased in favorable conditions of 2006 wet year, and the total plant coverage even decreased despite high rainfall that is essential for the plant growth in desert steppes. As for unfenced area, the plant community height decreased from 7.3cm to 5.3cm, and vegetation coverage is also decreased from 8.6 to 7.2% in average. This is indicated that unfenced area is degraded due to overgrazing effect and could not recover in favorable conditions. Also, biomass of such highly valuable pasture plant species as *Aneurolepidium chinense* have been decreased, and the less valuable plants (*Artemisia frigida*, etc.) became dominant species. NDVI values obtained from the satellite data corresponding to the ground survey results and show that along with general degradation of pastures, desertification tendency is registered for the fenced area in 2006. Fences are could serve only for the temporary protection from livestock and seemed to be non effective in the long term (see Fig. 2).

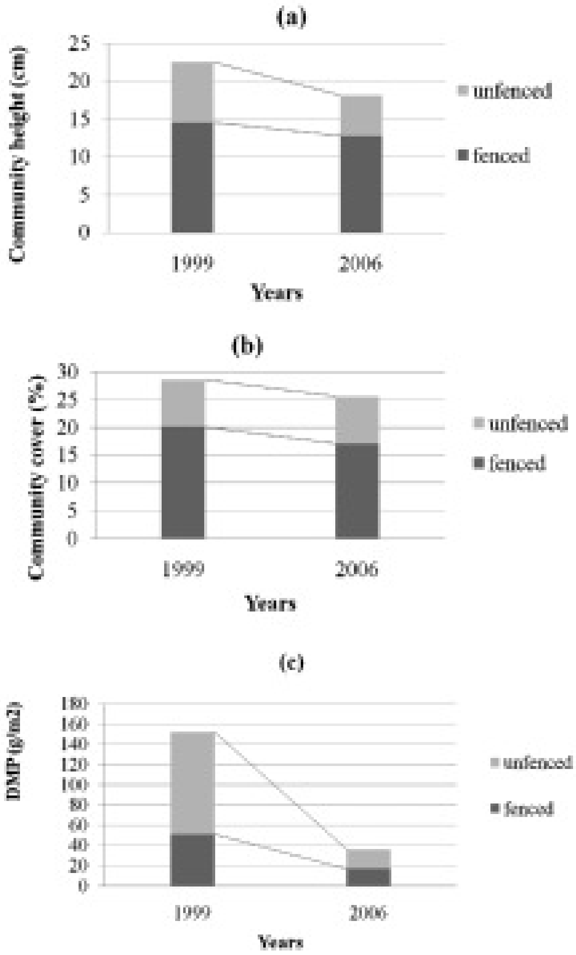

Fig. 2 Comparison of vegetation community of inside and outside of the fences (located in N43° 36'; E113° 55')
(Were, (a) the community height (cm); (b) the community cover (%); and (c) Dry matter productivity (DMP) (g/m2))

3.2 Land degradation in 1993, 1999, 2006

Inland climate is warming and drying trend is in on the increase (Buhe et al, 2006). Due to global warming the influence of monsoon in Eurasian continent is weakened; humid air masses from Indian, Pacific and Arctic Oceans reach only coastal area resulting in heavy rains and inland territories becomes more arid. In addition, increased human activity further, accelerating the process of land degradation.

Fig. 3 shows two kind of land degradation caused by different factors. Land outside of fence is degraded due to overgrazing, while that inside fence is due to changing climate (environmental factors) and human activity. However, overgrazing of unfenced pastures is directly caused by the fencing, because the latter is decreased pasture territory and restricted movement of livestock. Another interesting fact is that the territories surrounding the fenced area used more intensively because sheep and goats are attracted by vegetation inside fences. So far, fencing the pastures could not control land degradation and desertification too (Fig. 3-4). Both the satellite data and ground survey data shows that fence surrounding area is heavily used by livestock and land over there is seriously degraded.

The years surveyed were different in total precipitation rate, 1993 was dry and has been hit by drought, 1996 was normal and 2006 was a wet year. In normal years, during June to September, average precipitation totaled 210mm. This rate for dry year was only 150mm and for wet year 310mm. The herbaceous plants distributed in desert steppes of Xilingol characterized by ability to survive in even harsh years with low precipitation (minimum 50mm per season) (Changzhen, Y., et al., 2005 ; Sara Brogaarda, et al., 2005 ; Le K., et al., 2007). Desert steppe plants could utilize and do rapid growth even after one rainfall. So far, decrease in vegetation coverage, forage yield and community height in condition of 1996 and 2006year with total precipitation exceeding 200mm during vegetation season could be explained by degradation and desertification of pastures. NDVI values calculated from Landsat-TM data (Fig. 5) for 1993 to 2006a surveyed shows that pastures did not recover and total degraded area increased by 22%. NDVI value : (−0.89- −0.15 are water bodies; blighted water area are NDVI (−0.14- −0.01) ; the barren soils NDVI (−0.009-0.09) ; desert grasslands NDVI (0.10-0.21) and Grasslands (dense) NDVI (0.22-0.65).

4. Conclusion

The grassland degradation and desertification

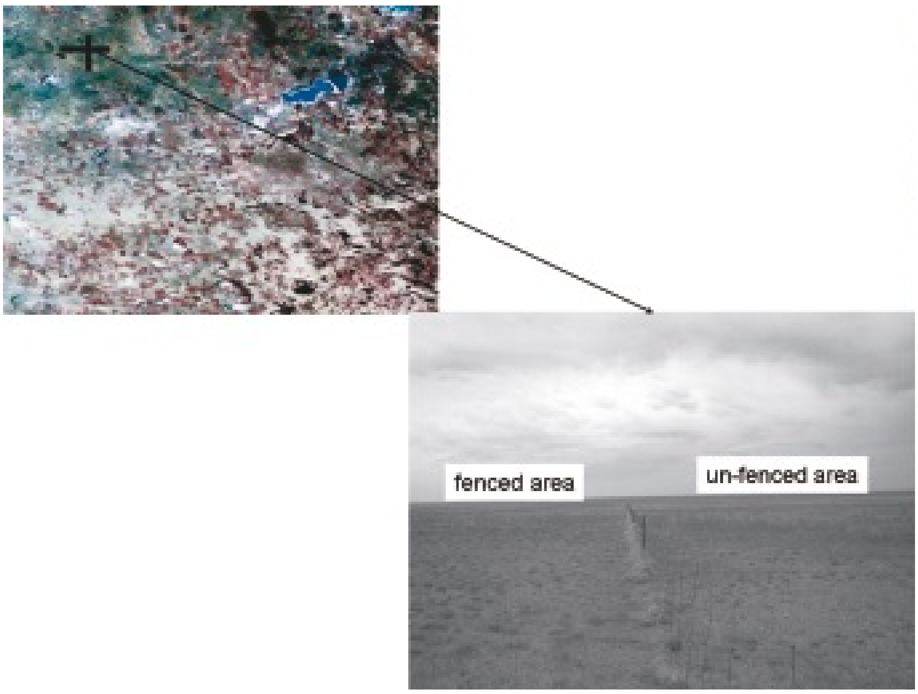

Fig. 3 Landscape of fenced (right) and unfenced (left) grassland of Inner Mongolia

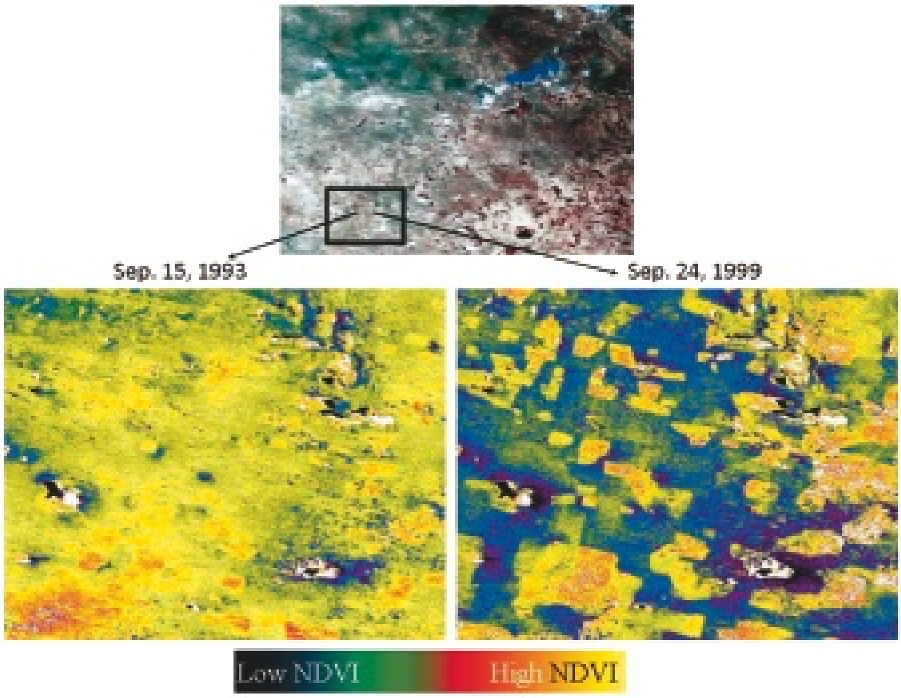

Fig. 4 Land cover change detection of fenced and unfenced area between 1993a and 1999a located in N42° 21' - N43° 07'; E114° 24' - E115° 31')

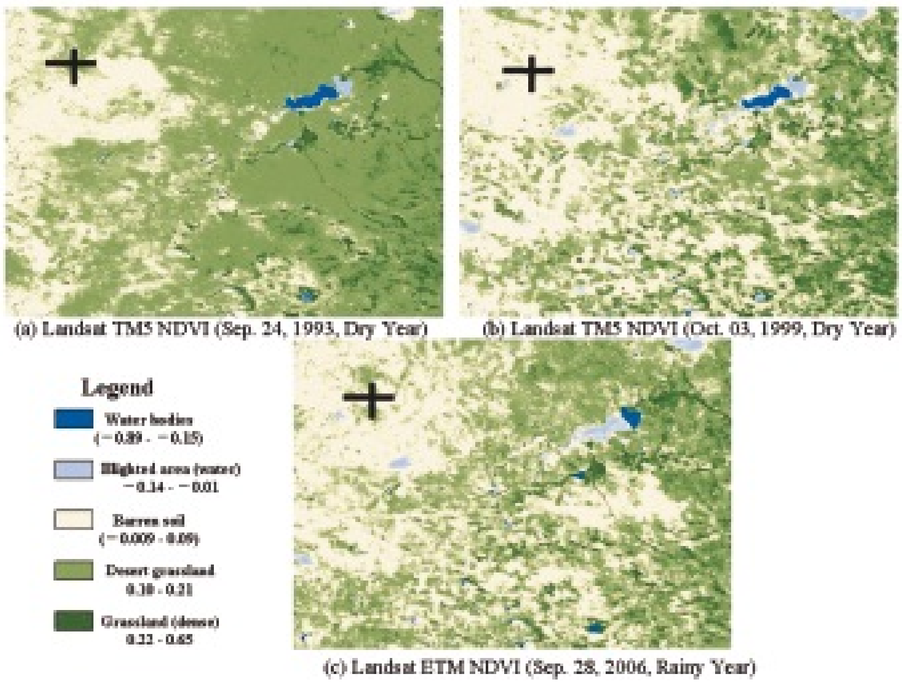

Fig. 5 Comparison of land degradation of grassland, with inside and outside of the fences in (a) Dry year: Sep. 24, 1993; (b) Very dry year: Oct. 03, 1999; and (c) rainy year: Sep. 28, 2006)

is caused by many natural and anthropogenic factors. The natural factors include wind and water erosion, global warming. However, in recent years, influence of anthropogenic factors, such as overgrazing is accelerating natural processes of land degradation and desertification.

Xilingol steppes of Inner Mongolia receive double pressure from human activities such as human settlement and overgrazing of pastures due to the increase in livestock numbers, and from the impact of global warming that resulted in long run dryness. A new method for the management of pastures using construction of fences and settlement of nomads appears not effective because that could not control degradation and spread of desertification. The emergence of fences has restricted livestock movement and contributed to heavy degradation of surrounding pastures because more greenery inside fences attracted animals searching grasses. Also, due to the settlement of nomads the number of livestock per unit pasture is sharply increased. The satellite data and field survey data shows that constructing fences in 1999 lead to spread of desertification and total degradation of pastures outside fences comparing with 1993. Moreover, the degradation processes did not stopped and spreading into protected by fences area in 2006. Analysis of the field data indicated that values of plant community height, vegetation coverage and DMP were significantly decreased from 1999 to 2006, and even favorable conditions could not recovered the degraded pastures. The grasslands in Inner Mongolia for thousand years used by nomadic pastorals presents extremely fragile environment and to protect them a new appropriate management style is needed. Degradation of pastures as resulting from the overgrazing and global warming is a common problem in the northern neighbor, Mongolia, too. However, the situation in that country is much better than in Inner Mongolia, because they are do not use pasture fencing and the livestock able to move freely in searching for better grazing.

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和 文 要 約

我々は７年に渡り，黄砂の新たな発生地である内モンゴル自治区のソニト（蘇尼特）左・右両旗（県）と，国境を挟んだモンゴル国側の南ゴビ，ドンドゴビ（中央ゴビ）に土壌水分，植生の計測，土地利用調査，家畜生産，農業政策，現地住民の聞き取り調査などを行い，同じ自然環境変動を背景に，遊牧と定住がモンゴル高原の生態系，生物多様性，土地被覆の変化,砂漠化と黄砂を引き起こす影響を比較し，柵によって草原の退化と砂漠化がもっと進行していることが確認された。

Abstract

This study is to evaluate an influence of overgrazing by livestock on pastures by comparing the changes in plant biomass and vegetation cover between the pasture within the fenced (closed) and unfenced (unclosed) pastures using method of satellite imagery. To protect grasslands from further overgrazing and desertification the Chinese government has prohibited the movements of nomadic cattle-breeders in some areas and takes measures to settle down the nomads in rural towns. However, despite that measures the degradation of pastures and desertification process is continues. The newly deserted areas were appeared between 1993a, 1999a and 2006a in Sunite and Uzhumqin steppe. The results of this study show that measures to fence grassland are not effective and even fenced pastures are degrading.