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Identifying Trends in the Distribution of Vegetation in Mongolia in the Decade after its Transition to a Market Economy

Akira HIRANO[1]* and Bayaraa BATBILEG[2]

[1] Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)
[2] Mongolian State University of Agriculture (MSUA) (Ulaanbaatar, Mongolia)

Abstract

The spatial distribution of vegetation trends identified by time series analysis of the normalized difference vegetation index (NDVI) for the Mongolian grasslands was cross-referenced with the recently obtained land use/cover data and socioeconomic information in the geographic domain. Global Inventory Modeling and Mapping Studies (GIMMS) dataset with an 8-km resolution provided by the Global Land Cover Facility (GLCF) of the United States were used to compute the vegetation trends. We cross-referenced the vegetation trends obtained from the land use/cover information as of 2005 extracted from the European Space Agency's (ESA) GlobCover land cover dataset and the Mongolian livestock statistics. We found that vegetation or pasture degradation prevailed in the decade after 1990. Results indicated that 21.1% of the vegetation degradation occurred in croplands, mainly in the northcentral part of the country, which may be linked to the abandonment of large-scale state-operated farmland after 1990 when Mongolia made the transition to a market economy. A decline in the vigor of vegetation was also commonly observed in provinces where livestock numbers surged, and may be attributable to the over-exploitation of pasture resources. However, a greening belt was observed around the mountain areas along 45°N. The number of livestock remained relatively constant and no major land use/cover change was observed in these areas, suggesting that the improved vegetation vigor was attributable to the recent global climate change.

Discipline: Agricultural environment / Grassland / Information technology
Additional key words: grasslands, land cover, livestock, remote sensing

Introduction

Mongolia is the world's second largest landlocked country, located between Russia and China. The country has a total area of over 1.56 million km^2 and is located on the high Mongolian plateau that ranges from 900 to 1500 m in elevation. Most precipitation comes during the summer's short rainy season, when sudden torrential thunderstorms and more prolonged gentle showers occur. Annual rainfall seldom exceeds 400 mm in the northern mountains and 100 mm in the southern areas[4] (Fig. 1). The Mongolian territory is characterized by rocky deserts and grassy semi-arid temperate steppes. Forests, which are limited to mountainous areas, cover only about 7% of the entire country. Grasslands have great importance in Mongolia. It is particularly unique in that more than 99% of its agricultural area is comprised of grasslands: permanent meadows and pastures. Changes in this vast agricultural area, which totals 1.15 million km^2, may impact on the country's future economic prospects and regional environmental changes.

Reports exist suggesting large-scale desertification caused by recent climate changes and other anthropogenic causes[1,14]. However, Suttie[11] reported that despite intensive grazing, Mongolian grasslands remain in good condition. In an attempt to examine the magnitude and spatial extent of vegetation changes, Hirano[5,6] used the

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*Corresponding author: e-mail akhirano@jircas.affrc.go.jp
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Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) dataset to compute long-term vegetation trends and extract only statistically significant vegetation trends throughout the Mongolian territory. After statistical filtering, Hirano[5,6] concluded that meaningful degradation of vegetation during the decade after 1990 was limited to only 6.4% of the entire country.

The objective of this study is to characterize the Mongolian grasslands by spatially examining the changes in vegetation during the 1990's in connection with recent land cover and the number of livestock grazed.

Data and Methods

1. GIMMS NDVI Dataset

We obtained the GIMMS NDVI dataset with an 8-km resolution from the Global Land Cover Facility (GLCF) of the United States to compute the vegetation trends in Mongolia between 1991 and 2000. The GIMMS dataset was originally constructed from the NOAA Advanced Very High Resolution Radiometer (AVHRR) measurements. The data were corrected for calibration, viewing geometry, volcanic aerosols, and other effects unrelated to actual vegetation change[13]. Previous efforts suggested that NDVI data was among the best of the proposed types of vegetation indices used to estimate the actual vegetation condition when no location-specific soil characteristics and vegetation densities were available[8]. Examples of other indices considered are the soil-adjusted vegetation index (SAVI) and the modified and transformed SAVI (MSAVI and TSAVI).

2. GlobCover Land Cover Dataset

The GlobCover initiative of the European Space Agency (ESA) resulted in the generation of a 300-m global land cover map based on Envisat MERIS Fine Resolution data acquired during 2005 and 2006. The land cover classification system adopted in the GlobCover land cover product is that of the United Nations Land Cover Classification System (LCCS) that guarantees compatibility with other global land cover datasets. The GlobCover dataset was officially tested worldwide for classification accuracy (67.1% agreement with classification and validation)[2]. We also considered the use of other land cover information, namely the Global Land Cover Characteristics (GLCC) by the United States Geological Survey (USGS), that should have better represented the ground conditions during the 1990's. However, we found a significant shortfall in the GLCC area estimate for the croplands class for the year 1992/93. In addition, the GLCC dataset failed to provide a conclusive accuracy statement[10]. The GlobCover classification agreed better when overlaid onto the historical Landsat Thematic Mapper (TM) images captured in 1989. For these reasons, we concluded that the GlobCover Land Cover dataset was more reliable and used it throughout our vegetation trend analysis.

3. Vegetation Trend Analysis

The vegetation trend for each pixel location was calculated using a series of maximum GIMMS NDVI values

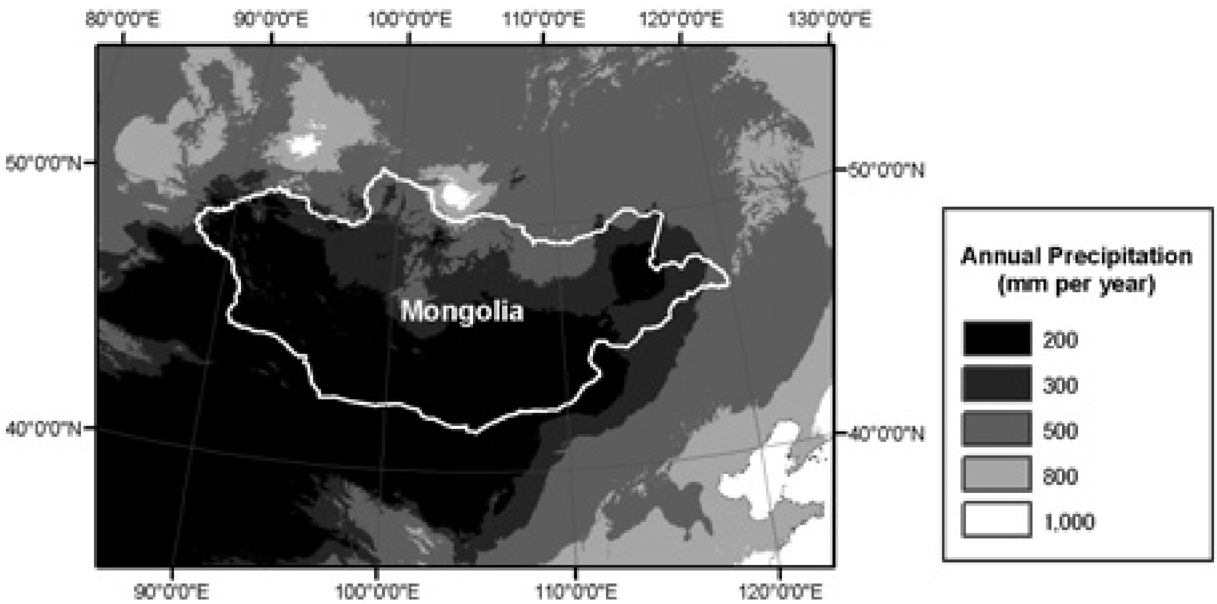

Fig. 1. Location of Mongolia and the distribution of its annual precipitation

for each year based on the simple time series regression model. The process of selecting the annual maximum NDVI for each pixel disregards the seasonal timing of the NDVI values[9]. The calculation resulted in a collection of slopes at each pixel location. For example, all nationwide locations in Mongolia are assigned a coefficient that represents some degree of degradation or improvement of the vegetation over the study period. Hirano[5,6] selected only pixels with statistically significant increases or decreases ($P < 0.05$) to assess the spatiotemporal pattern in vegetation vigor and the same approach was used in this study.

4. Vegetation Trends according to Land Cover Classes

We examined the spatial distribution of per-pixel vegetation trends by land cover in the GlobCover land cover product. Areas corresponding to the three vegetation trend classes—namely degraded, improved, unchanged—were summarized by different land cover classes.

5. Vegetation Trends with the Provincial Livestock Statistics

The statistics obtained from the Mongolian government for the number of livestock indicated an overall and constant increase during the 1990's until a major winter disaster (locally called "Dzud") affected the country in 1999, resulting in a major loss of livestock[4]. Since the increase in grazing pressure is considered to be one of the major anthropogenic causes of vegetation degradation, we computed the ratio in terms of the number of livestock per unit grazing area[7] in 1999 over that of 1991 to illustrate the changes according to province. The livestock statistics of 2000 were excluded because the sharp decline in the number of livestock in 2000 could distort efforts to determine overall trends for the decade. We then spatially cross-referenced these statistics with the vegetation trends.

Results and Discussion

Decadal vegetation trends with statistical significance are shown in Fig. 2. As reported by Hirano[5,6], we confirmed that only 6.4% of the entire Mongolian territory depicted statistically significant vegetation trends of any kind. Fig. 3 shows the GlobCover dataset of Mongolia, with the original 50 land cover classes being aggregated to 8 classes to represent the major land cover classes in the country.

An obvious concentration of negative trends in NDVI is observed in the northcentral part of the nation,

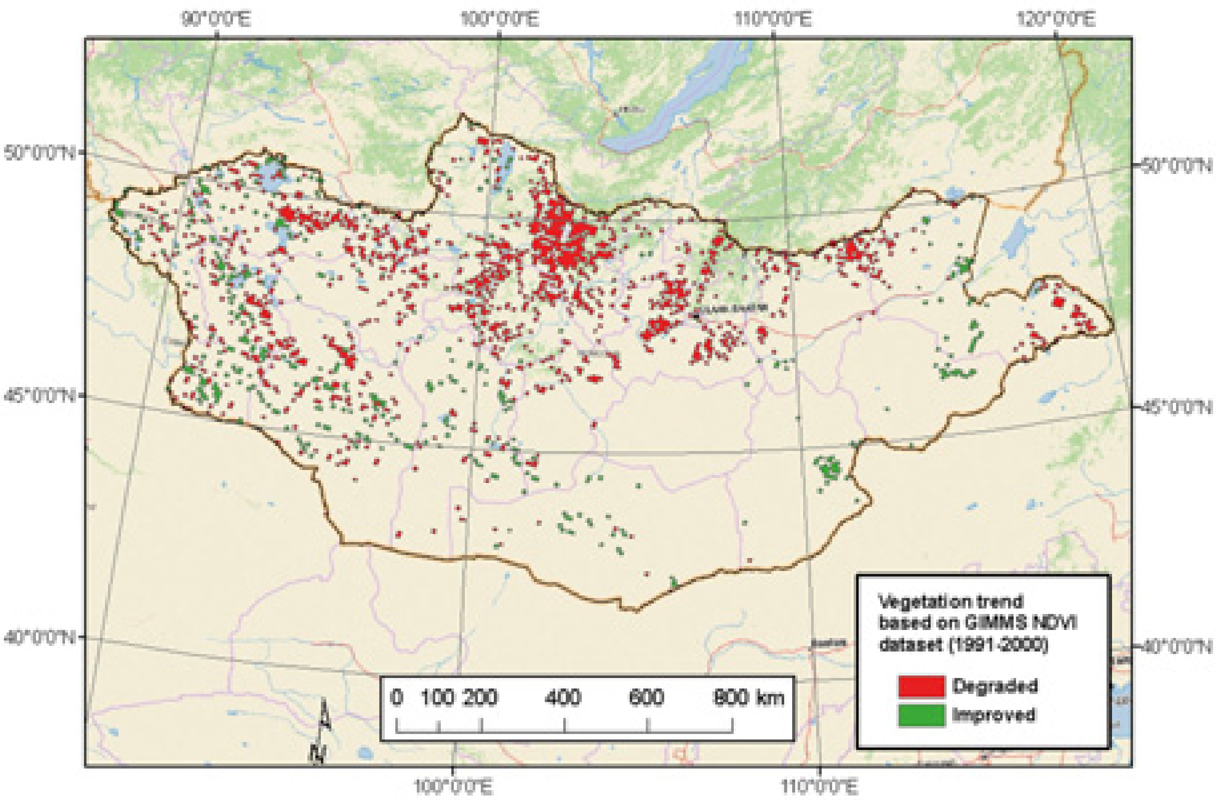

Fig. 2. Spatial distribution of statistically significant vegetation trends in Mongolia (1991–2000)

which is the only region with sufficient precipitation for irrigated cultivation. Consequently, large-scale farming was practiced during the planned economy under the then-Soviet influence before 1990. Following the transition to a market economy, the large-scale croplands experienced a sharp decline and the majority were abandoned.

Cross-referencing the vegetation trends with the land cover revealed that about half (47.9%) of the degraded areas were categorized as grasslands, followed by bare land (21.9%) and croplands (21.1%) (Table 1). It is noteworthy that a significant portion (22,400 km^2) of the degraded areas corresponds with the croplands class while only 500 km^2 of the croplands showed vegetation improvement. These figures indicate that much of the vegetation degradation took place in current and former cropland areas. The most likely cause of such degradation could be the soil degradation commonly observed in the abandoned croplands[12]. Other spatial concentrations of

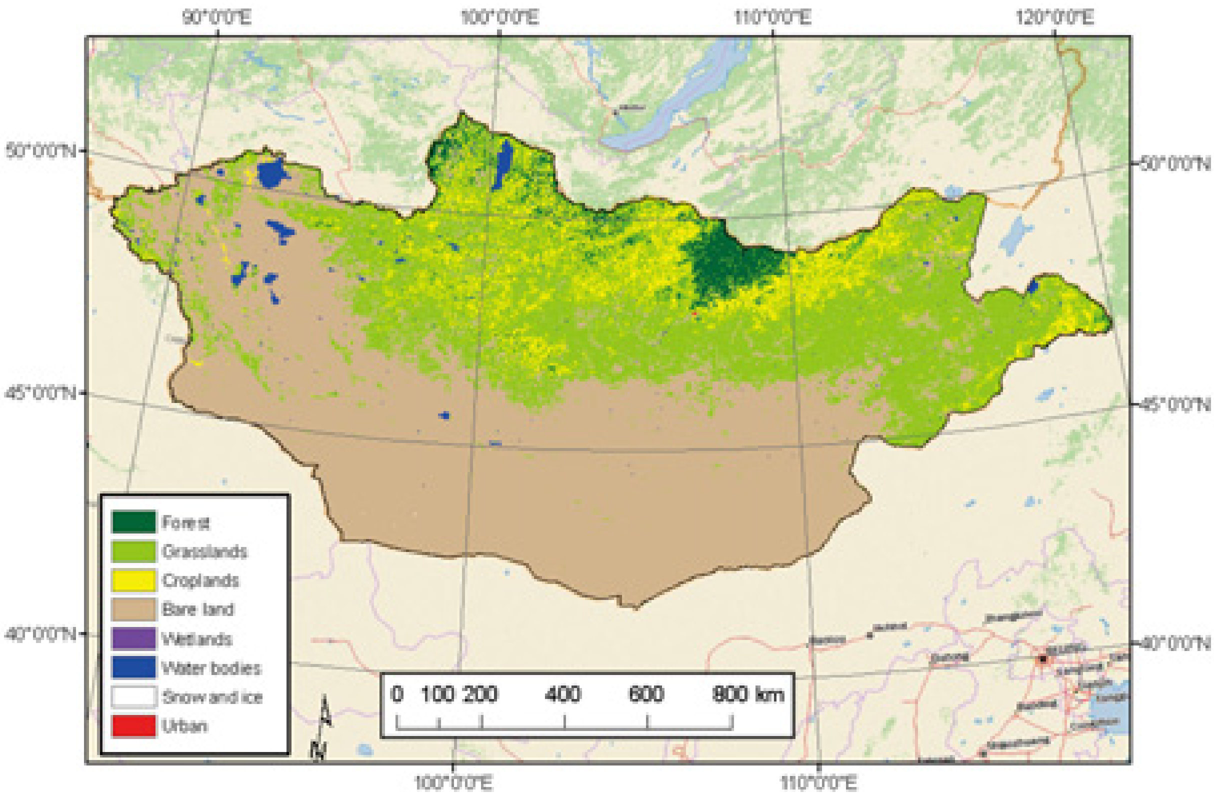

Fig. 3. GlobCover land cover map of Mongolia (2005/2006)

Table 1. Breakdown of the vegetation trends (1991–2000) by the GlobCover land cover

Area: thousand km^2 (percentage)

Land cover class	Degraded		Improved		Unchanged	
Croplands	22.4	(21.1)	0.5	(1.6)	0.0	(0.0)
Grasslands	50.8	(47.9)	6.0	(18.7)	0.0	(0.0)
Bare land	23.2	(21.9)	24.4	(75.6)	2.0	(100.0)
Forest	8.6	(8.1)	0.1	(0.2)	0.0	(0.0)
Wetlands	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Water bodies	1.0	(0.9)	1.2	(3.9)	0.0	(0.0)
Snow and ice	0.1	(0.1)	0.0	(0.0)	0.0	(0.0)
Urban	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Total	106.1	(100.0)	32.2	(100.0)	2.0	(100.0)

negative trends were observed in the northwestern part of the country, where most of such areas were categorized as grasslands. However, our spatial analysis is insufficient to determine the reason for the degradation.

Fig. 4 illustrates the spatial pattern of livestock dynamics—the percentage increase in the number of livestock per unit grazing area in 1999 over that of 1991—according to province during the 1990's. Statistically significant vegetation trends are superimposed on the livestock dynamics. Negative vegetation trends frequently emerged in provinces where the number of livestock per grazing area increased by 30% or more, as shown in Table 2. However, the same tendency could not be validated in the dry southern part of the nation, which is predominated by desert and where few animal traces to conduct the study were found.

Analysis of the spatial distribution of positive vegetation trends led us to identify a greening belt around the mountainous regions along 45° north. Since no particular land cover other than bare areas (in the mountains) corresponded to these positive vegetation trends and the number of livestock remained relatively constant (an increase of approximately 15% over the decade), other causes should be considered. The most likely reason for such trends is believed to be recent global climate changes, but no sufficient data currently exists to support this hypothesis. One potential factor supporting this hypothesis is the re-emergence of some surface water (rivers and lakes)

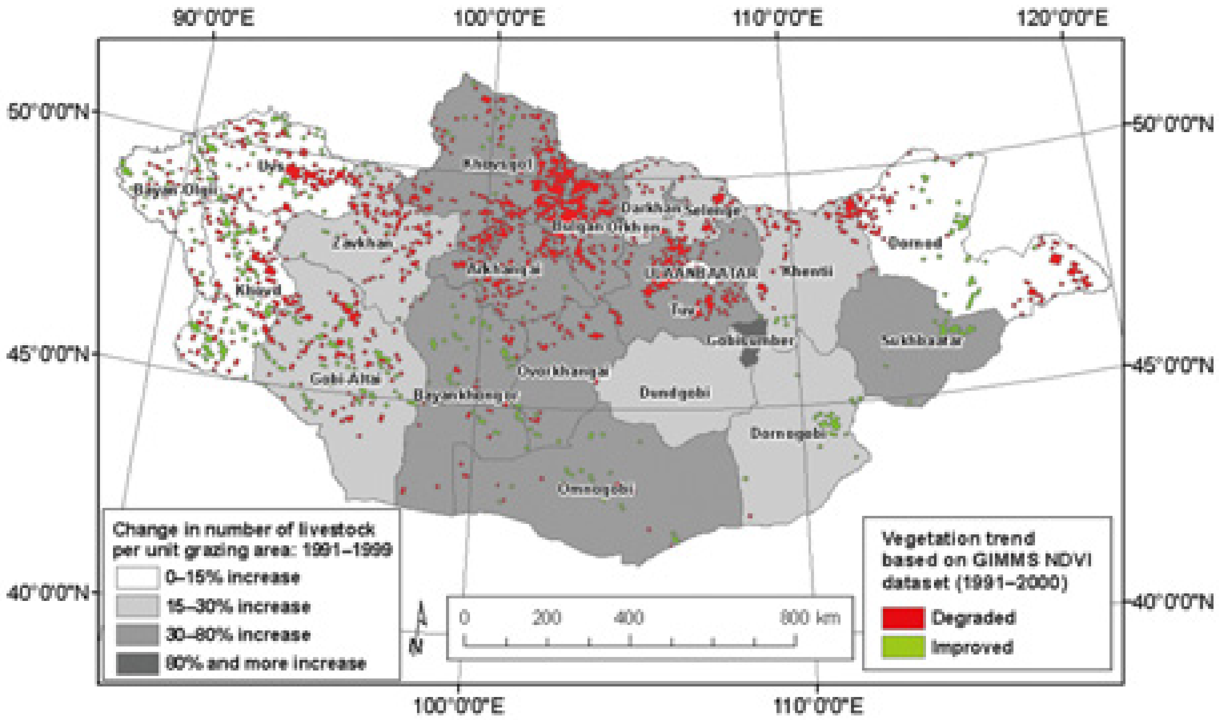

Fig. 4. Spatial distribution of statistically significant vegetation trends in Mongolia (1991–2000) superimposed on the percentage increase in the number of livestock per unit grazing area (1991–1999) by province

Table 2. Breakdown of the vegetation trends (1991–2000) by the percentage increase in the number of livestock per unit grazing area (1991–1999)

Area: thousand km^2 (percentage)

Ratio in number of livestock per unit grazing area (1991–1999)	Degraded		Improved		Unchanged	
0-15% increase	25.2	(24.8)	14.9	(48.8)	0.4	(25.7)
15-30% increase	23.1	(22.7)	7.9	(26.0)	0.2	(12.6)
30-80% increase	53.3	(52.5)	7.7	(25.2)	0.9	(61.8)

that had once dried up in these areas[1].

Summary and Conclusions

Satellite-based data provided us with tools to retrospectively examine the nationwide Mongolian vegetation dynamics and cross-reference these trends with land cover and livestock statistics in a geographic domain. We attempted to gain an overview of the spatiotemporal vegetation trends of the Mongolian grassland during the decade following its transition to a market economy in 1990. We analyzed the GIMMS NDVI time series to compute the vegetation trend and filtered per-pixel trends based on statistical significance. Although only 6.4% of the entire nation experienced vegetation changes of any kind, negative trends dominated those changes having occurred during the 1990's. Cross-references between these vegetation trends and recent land cover maps (2005/2006) revealed that a substantial portion (21.1%) of the negative trends occurred in the croplands class. From a spatial perspective, most of these negative trends were concentrated in the northcentral part of the nation. This degradation is likely to be linked to soil degradation due to the abandonment of large-scale farmland under the planned economy. Some areas that experienced sharp increases in the number of livestock per unit grazing area (30% or more) tended to present negative trends.

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