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Spatial and temporal patterns of NDVI response to precipitation in Mongolian Steppe

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時空間 NDVI データを用いたモンゴル草原植生の降水応答

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1. Introduction

Nomadic livestock husbandry is a traditional sector of Mongolia and plays an important role in Mongolian economy. Livestock husbandry is very sensitive and vulnerable to weather and climate and therefore greatly depends on pasture condition.

Intensity and frequency of natural disasters, including droughts and dzuds are increasing significantly during the last few years because of climate change. These phenomena cause significant economic damages and losses. Recent studies are show that changes in climate of Mongolia manifest significantly in winter season.[1)]

According to climate change studies conducted in Mongolia, during the period between 1940 and 2005, the annual average temperature in Mongolia has increased by about 1.9℃ and winter temperature changes were even greater in the mountainous areas (2.0–3.7℃).

The annual precipitation has been observed to decrease from the 1940's to about the mid-1980's, but has since shown signs of increasing in all areas except the Gobi desert area. Annual mean precipitation has been decreasing in central Mongolia, but has been increasing in both the eastern and western regions of country. Seasonally, both winter and spring precipitation has decreased, while summer and autumn have registered no changes.[2)]

There is a significant change not only in precipitation amount, but also in its type (synoptic-cyclone related or convective rain), frequency and coverage area.

Between 1960 and 1998, precipitation varied greatly, both increasing and decreasing in Mongolia. The frequency of relatively heavy rainfall events increased in the eastern Gobi desert and Altay Mountains in Mongolia.[3)]

Meteorological data of the Hustai National Park shows that seasonal dynamics of the precipitation follows the general trend that characterizes the forest-steppe belt of Mongolia. About 85 percent of the annual precipitation falls as rain during the summer, of which about 188.8 mm falls in May and August. Seasonal maximum precipitation (60.6 mm) is recorded in July. Seasonal minimum precipitation (2.8 mm) is recorded in January (Fig. 1).

Mongolian pasture's growth dynamic and its correlation with weather and climate conditions were studied using meteorological and agro-meteorological regular observation data[4)], various maps and digital data of satellite NOAA/AVHRR data[5)].

However, spatial and temporal patterns of NDVI in response to precipitation in Mongolian Steppe still aren't well interpreted. Therefore it

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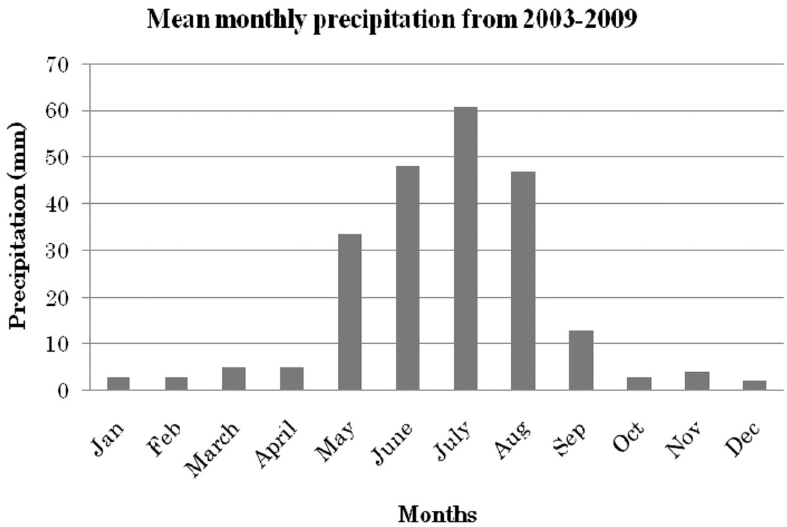

Fig. 1 Mean monthly precipitation amount during 2003-2009 at Hustai National Park.

is necessary to study the relation between vegetation cover and precipitation. Remote sensing technology and methods have proved to be very useful for monitoring of vegetation cover.

2. Materials and methods

2.1 Site description and materials

Study sites are (Hustai National Park (HNP), 47°35′N-47°52′N, 105°23′E-106°00′E elevation 1100-1840 m) situated in the steppe zone in the southwest part of Mongolia, characterized by the pale and dark brown soil, *Stipa klemenzii*, *Convolvulus ammanii*, *Caragana* sp., *Poa* sp. steppe community (Fig. 2).

The annual (mean) air temperature at the Hustai National Park is 3.5℃ to 0.3℃. The annual monthly average temperature of the coldest month, January, is −20.2℃ to −27.4℃ in the steppe zone. July is the warmest month. The average air temperature in July is 17.1℃ to 20.9℃. About 80% of annual precipitation occurs in June, July and August (126.7-279 mm). The driest

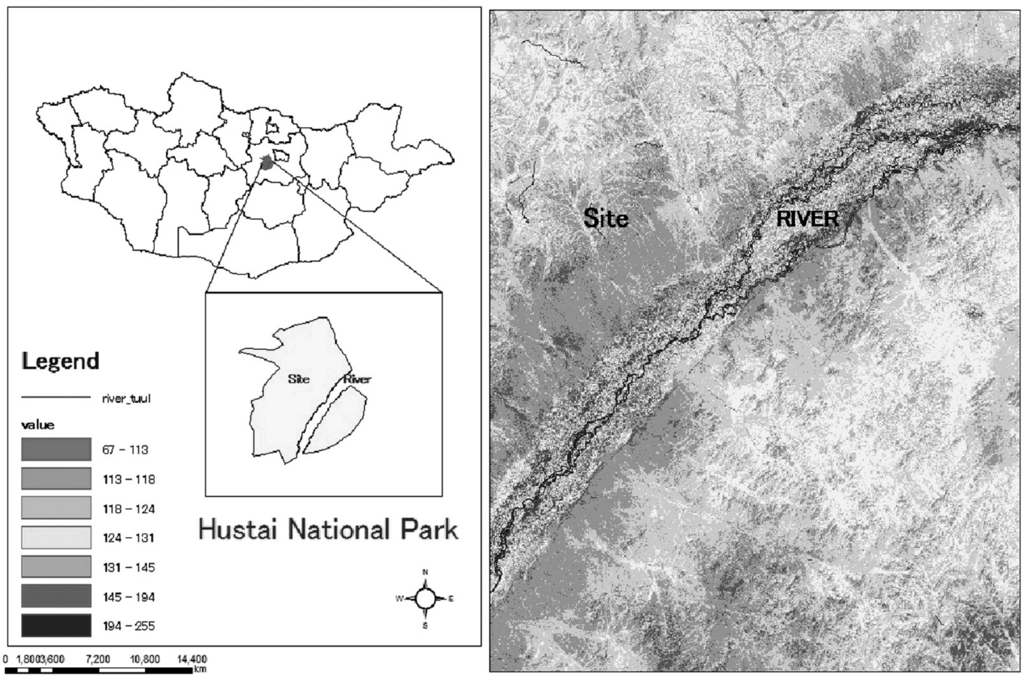

Fig. 2 Location of the study area.

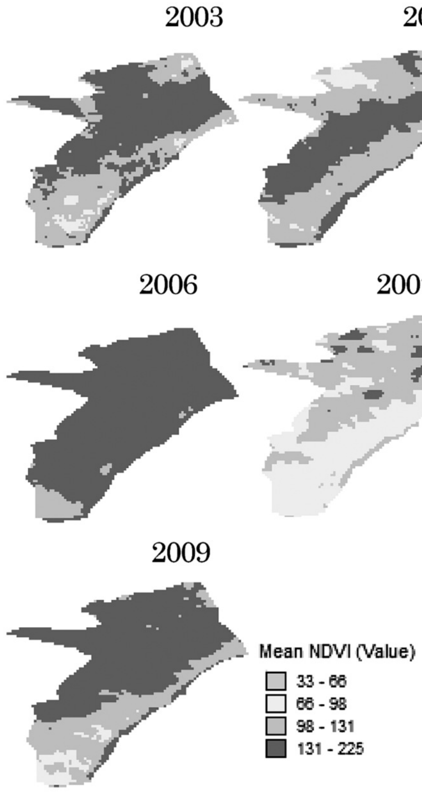

Fig. 3 Spatial distribution of the mean NDVI changes in HNP during August (1st 10 day) of 2003-2009

months are from November to March (1.2-31.5 mm). In general, the amount of precipitation in Mongolia is low and varies from 131.1mm to 291.2 mm in this region.[6)]

2.2 Data and methods

2.2a. Meteorological variables or ten-day precipitation data sets for June 2003 to August 2009, were obtained from HNP meteorological station.
2.2b. Pasture plant biomass has been measured with standard methods at the test plots located in the HNP from June 2003 to August 2009.
2.3.1 Satellite data

NDVI data includes a 10-day composite SPOT VEGETATION (VGT) data set (with 1 km resolution) from June of 2003 to August of 2009 (http://free.vgt.vito.be/home.php).
NOAA NDVI data (with 8 km resolution and 15 day) used in this study were processed by in the GIMMS group at NASA.
Many experiments have shown that several mathematical combinations of the 0.55-0.68 μm and 0.725-1.10 μm wavelength data on pasture vegetation provide important information on pasture vegetation condition. The parameter is called "Normalized Difference Vegetation Index" (NDVI), which is derived from the visible red (RED) and near-infrared (NIR) spectral bands: NDVI＝(NIR-RED) / (NIR＋RED)[7)]

The NDVI was calculated from SPOT VGT data by using the combinations of bands 2 (0.61-0.68 μm) and 3 (0.78-0.89 μm) NDVI＝(Band3-Band2) / (Band3＋Band2).

Then, a yearly NDVI anomaly during the warming season (June to August) was calculated as follows: $NDVI_{\sigma}=\{((NDVI_{\alpha}) / (NDVI_{\mu})-1)100\}$ where NDVI[8)] are the respective (June to August) percent anomalies, $NDVI_{\alpha}$ are individual seasonal (June to August) means, and $NDVI_{\mu}$ is the long term (June to August) mean.

3. Results

3.1 Spatial distribution of NDVI in Hustai National Park.

We have analyzed the distribution and long terms vegetation dynamics. The mean NDVI values in HNP's were highest during 2003, 2006, 2009, and lowest in 2005, 2007 (Fig. 3). The first decrease in mean NDVI registered in 2004 and lowest was in 2005. However, in 2006, again NDVI values were very high and comparable with those of 2003. So far, generally (from 2003 to 2005, and from 2007 to 2009) spatial distribution of NDVI has changed in accordance to values of precipitation. As it mentioned above, despite very low precipitation uncharacteristically high NDVI values registered in 2006.

In general, the precipitation has been continuosly decreasing from 2003 until 2007, however that trend was not followed with means of NDVI (Fig. 4). Especially in 2006, despite low amount of precipitation uncharacteristically high mean NDVI was registered.

Considering average precipitation level, 2003, 2004 and 2009 were recognized as wet years (172 mm, 158.8 mm and 243.8 mm, respectively), while the dry year period continued from 2005 to 2008 (138.2 mm 2005, 125.6 mm in 2006, 90.1 mm in 2007) (Fig. 4b)

3.2 Relationship between NDVI and precipitation

Fig. 5 shows that due to the rain the NDVI values slowly increased with 10 and 20 days time lag. (Fig. 5b, 5c). However, cortelation values were low.

In the wet year of 2003, positive correlation between amount of precipitation and NDVI was observed at 10 days time lag base (Fig. 6b). However, during 2007 period the correlation coefficient was higher at the 20 days time lag (Fig. 7c).

3.3 Monthly and10 day time series patterns

Fig. 8 Shows mean NDVI changes of average 10 days NDVI during 2003-2009. Maximum NDVI value (175.4) was recorded in August and minimal NDVI (66.9) recorded in June.

Fig. 9 and Fig. 10 shows seasonnal in the average of monthly NDVI for HNP's during 2003-2009. NDVI value in July showed a increase trend.

3.4 Trends in spatial variations of NDVI.

Fig. 11a, 11b shows the Hovmöller diagram of NDVI patterns during 2005-2006 year. We also have analyzed the NDVI change. The HNP's NDVI maximum value was 0.8, and minimum

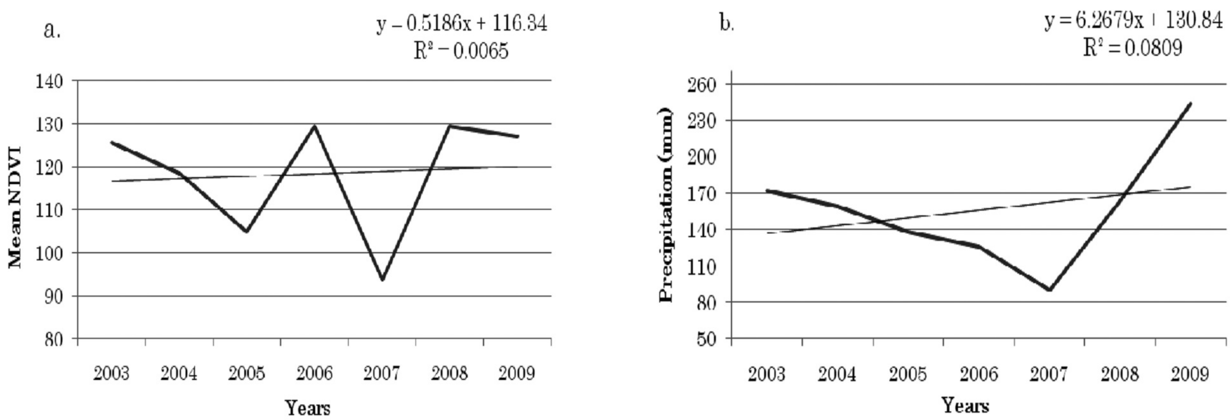

Fig. 4 Changes in mean NDVI (Fig. 4a) and precipitation (Fig. 4b) in Hustai National Park during 2003-2009

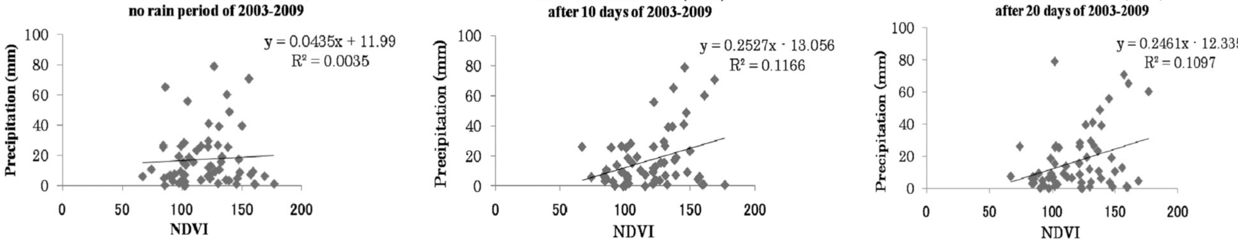

Fig. 5 Relations between NDVI and precipitation during 7 year period.

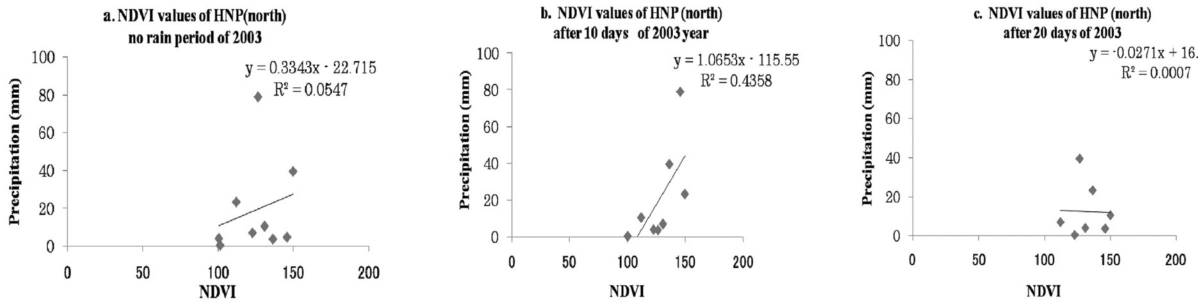

Fig. 6 Relations between NDVI and precipitation in 2003 year (a-2003, no time lag, b-2003, 10 days lag, c-2003, 20 days lag).

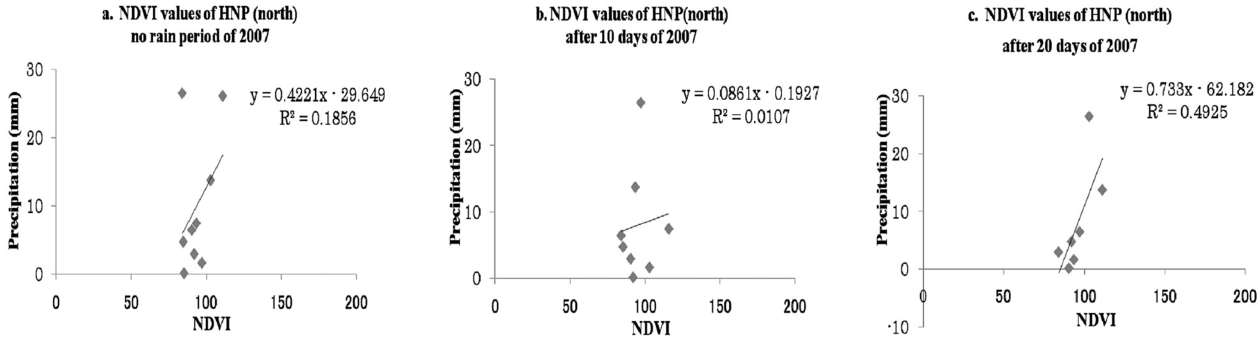

Fig. 7 Relations between NDVI and precipitation in 2007 year (a-2007, no time lag, b-2007, 10 days lag, c-2007, 20 days lag).

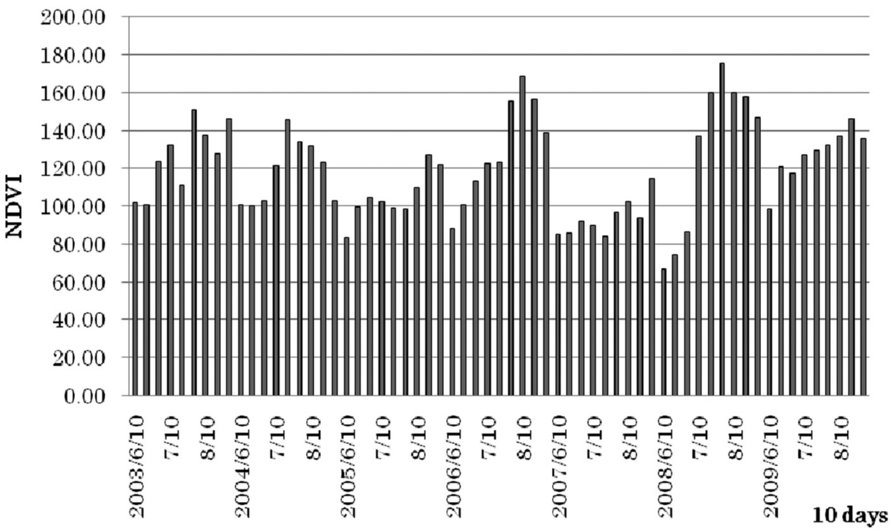

Fig. 8 NDVI changes between June-August, 2003-2009 (10 days)

Fig. 9 NDVI value between June-August, 2003-2009

value was 0.08. NDVI higher values ranging 0.4-0.8 were distributed over the north-west of the NHP. Lower values of 0.08-0.1 dominate in middle part and south.

3.5 NDVI anomaly index.

While the period from 2003 to 2009 was dominated by above normal conditions with 71% of the

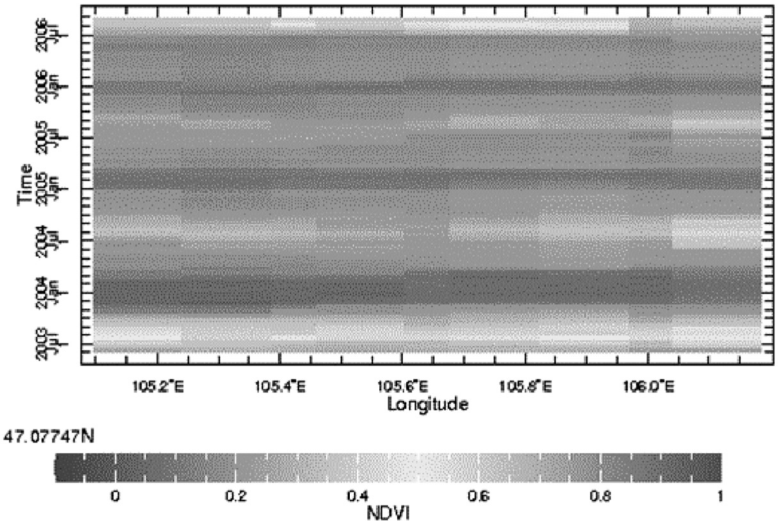

Fig. 10 Time-Longitude section of monthly NDVI from Jan-Dec, 2003-2006

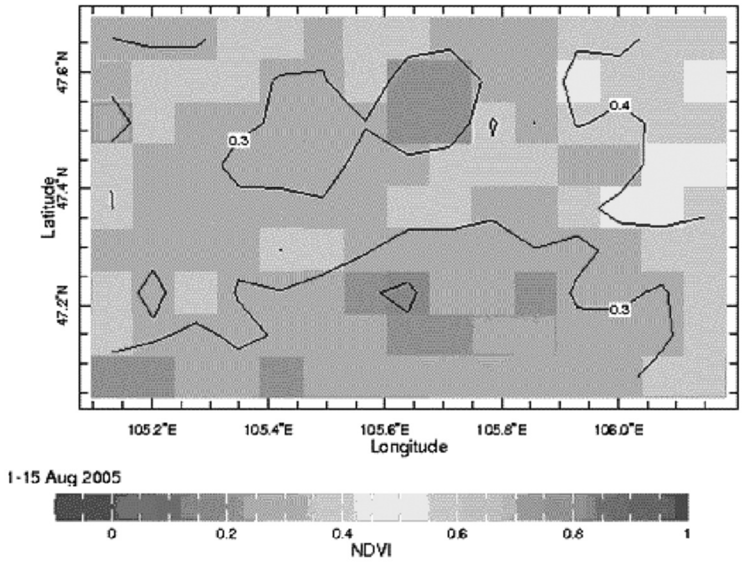

Fig. 11a Spatial distributions of NDVI in dry year (Aug, 2005)

years showing above normal NDVI conditions, the severest departures in NDVI occurred in 2003-2004, 2006 and 2008-2009.

Fig. 12, (Table. 1) NDVI anomaly stores (−/+) showing persistence patterns of below normal or above normal vegetation conditions

4. Summary and Conclusion

Understanding of recent trends of vegetetion cover changes and its relationship with climate change will help acquire a more accurate prediction of vegetation cover changes. The accurate prediction of vegetation cover is essential in reducing loss and damages to the economy of the country. Vegetation cover activity appears to control rainfall.

Both precipitation and mean NDVI were very variable between 2003-2008 in the HNP. The highest amount of precipatation observed in 2003, lowest in 2005 and 2007. And highest value of NDVI observed in 2006 and 2008, lowest in 2005 and 2007. (Fig. 4a, 4b).

The correlation observed between NDVI and precipitation in 10 to 20 days, highest was lag in 10 to 20 days observation in 2007. And 20 days lag happened to be the best predictor in this case. The correlation observed between NDVI and precipitation in 2003 and 2009 was insignificant.

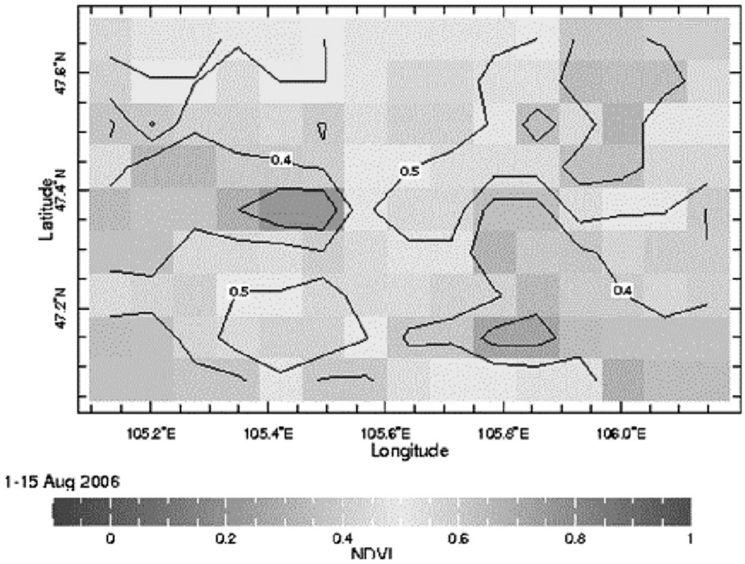

Fig. 11b Spatial distributions of the trends in NDVI from Aug, 2006

Iwasaki[9] observed strong relationship between precipitation and NDVI. He has found that during 1993-2000, 10-30 days lag correlations was between precipitation and NDVI in the steppe vegetation zone of Mongolia.

NDVI data alone with means of precipitation could not describe productivity of the pastures in condition of Mongolian steppes. For an accurate analysis we need more data on air and soil temperature and soil moisture. Also for the precise analysis, data on the pasture use by different kind of herbivores and in closures without grazing impact is required.

In this study the temporal and spatial response of 10 days of SPOT vegetation and precipitation was analyzed using data from June 2003 to August 2009 and the main results were as follows:

1. The maximum response of mean NDVI to precipitation had a lag of about 20 days.
2. In 2007 (dry) year, the response of mean NDVI to precipitation had lag of about 20 days.
3. In 2003 (wet) year, the response of mean NDVI to precipitation had lag of about 10 days.
4. Annual mean NDVI and precipitation increased on 0.65%, 0.8%, respectively.
5. Calculated NDVI anomaly indices were severest in 2005 and 2007.

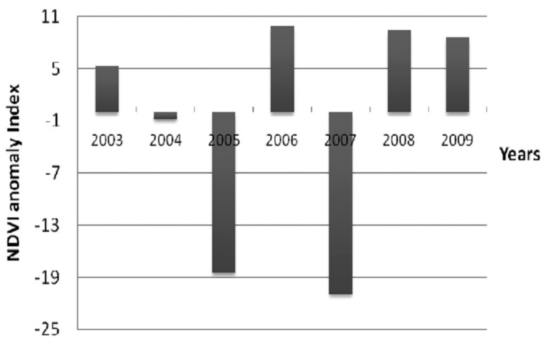

Fig. 12 Mean NDVI changes in Hustai National Park during 2003-2009

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Table. 1 Mean NDVI changes in Hustai National Park

Year	2003	2004	2005	2006	2007	2008	2009
Anomaly	+	−	−	+	−	+	+

Marie Samamukai and the staff of the Laboratory of Environmental Remote Sensing, Rakuno Gakuen University.

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要　約

降水量はモンゴル国の社会経済発展を制限する主な要因の一つである。従って，近年，モンゴルの気候変動，降水量の変化に対する植生生産力の応答の研究はほとんどない。本研究では，人間の影響が少ないモンゴル国のホスタイ国立公園を研究対象地にして，降水量と NDVI の時系列変化のパターンを解析した。時・空間的な変化は SPOT VEGETATION 衛星の NDVI データに基づいて分析した。その結果，全体的に，モンゴル国ホスタイ国立公園の北部の自然植生の降水量の変化に対する応答は，降水イベントが起きた後，時間的遅れ（delay）があり，10 日間と 20 日間後，最も相関があることが確認された。

Abstract

Rainfall is one of limiting factors of socio-economic development of Mongolia. Therefore, detailed studies of climate change and variability of precipitation and vegetation cover in Mongolia, using recent data is of fundamental importance. In this study, temporal patterns of normalized difference vegetation index (NDVI) in relation to precipitation in Hustai National Park of Mongolia are analyzed. The spatial and temporal changes have been analyzed based on the SPOT vegetation NDVI data.

NDVI from the SPOT vegetation data, at a spatial resolution of 1 km and 10 day intervals, are used to investigate the vegetation variations in Mongolia during the period from 2003 to 2009. Then, RS is used to examine the relationship and NDVI in Mongolia, and the value of NDVI is taken as a tool for drought monitoring. The results showed that in the study period, Mongolia vegetation cover tended to increase, with the annual mean NDVI having increased by 0.65%.

The results indicated the response of vegetation NDVI value to the variation of precipitation in northern part HNP. Vegetation NDVI value maximally responds to the variation of precipitation with a lag of about 10 days 20 days in vegetation period.

Examination of NDVI time serials reveals that during the period of 2003-2009 marked by low values below average NDVI, there was a persistence of drought with a signature drought during 2005 and 2007. The same period was marked by a wetter trend with HNP-wide high values above average NDVI and a maximum level occurring in 2006 and 2008.

If NDVI value and precipitation event were taken into account, then high correlation was observed in wet years and low or no correlation in dry years.