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Shifts in vegetation growth in response to multiple factors on the Mongolian Plateau from 1982 to 2011

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ABSTRACT

The Mongolian Plateau (MP) steppe is one of the largest steppe environments in the world. To monitor the terrestrial vegetation dynamics on the MP and to ascertain what the driving forces, this study examined the vegetation dynamics in Republic of Mongolia (M) and the Inner Mongolia Autonomous Region (IM) of China from the period 1982 to 2011, based on the satellite-derived GIMMS NDVI3g (Normalized Difference Vegetation Index) data across three biomes (desert, grassland and forest). The results are as followed: (1) Vegetation coverage in IM was generally greater than that in M. Before 2002, time series of NDVI over the MP increased at an average rate of 0.05% yr^{-1}. Additionally, after 2002, the NDVI increased at a rate of 0.21% yr^{-1}. From 1982 to 2011, the area of IM and M with positive anomalies in the NDVI increased at a separate rate of 1.82% yr^{-1} and 1.76% yr^{-1}, respectively. (2) At the biome scale, the inter-annual forest NDVI variation in IM and desert NDVI for the entire MP had a significant increasing trend (0.06% yr^{-1} and 0.04% yr^{-1}, respectively). (3) Climate forcing was a dominant controlling factor affecting the vegetation, and the anthropogenic behavior exhibited no significant value in the whole region. However, overgrazing was the most important reason for the regional degradation, particularly in IM. (4) In the future, the forest biome will go to recovery, whereas both the grassland and desert biomes are predicted to degrade continuously.

1. Introduction

Global warming and extreme climatic events are major threats for terrestrial ecosystems, particularly in arid and semi-arid regions (Jiménez et al., 2011; Lloret et al., 2012). Vegetation growth has received considerable attention due to its ecological vulnerability, its high sensitivity to climate change, external disturbances (Fensholt et al., 2009; Judger et al., 2011; Lioubimtseva et al., 2005; Liu et al., 2008; Van Keulen and Breman, 1990) and its important role in the global carbon cycle (Still et al., 2003). In particular, as predominately demonstrated by population growth and by anthropogenic climate change (i.e., the growth rate of atmospheric CO_2), vegetation growth is altered even more directly and drastically worldwide (Cook et al., 2013; Walther et al., 2002; Zhen et al., 2010a). According to the latest IPCC AR5 summary for policymakers, historical temperatures have presented a warming of 0.85 (0.65–1.06) °C over the period from 1880 to 2012 (Buckle and Mactavish). Therefore, there is an increasing requirement for detecting, understanding, and predicting ecosystem variations in arid and semi-arid regions, and these variations can provide early warnings of ecosystem degradation (Cao et al., 2013; Pettorelli et al., 2005).

International research has focused more attention on the Mongolian Plateau in recent years (John et al., 2013; Sneath, 1998, 2000). One significant mark of this global concern has been the increasing number of scientific studies regarding natural and social-economic aspects focused on the MP (Sneath, 1998, 2000). Natural disasters, such as *dzuds*, dust storms, desertification and soil erosion, more frequently threaten its pastoralists' and herds' survival and influence the land surface via hydrological, biogeochemical processes directly and timely in this region (Cao and Woodward, 1998; John et al., 2013; Mu et al., 2013; Tietjen et al., 2010), the climate system in eastern Mongolia and in northeastern China was shown to be getting warmer and drier (Li et al., 2008). Harsh droughts occurred over the plateau from 1999 to 2001, in 2005 and in 2009 over most of the country, resulting in devastating

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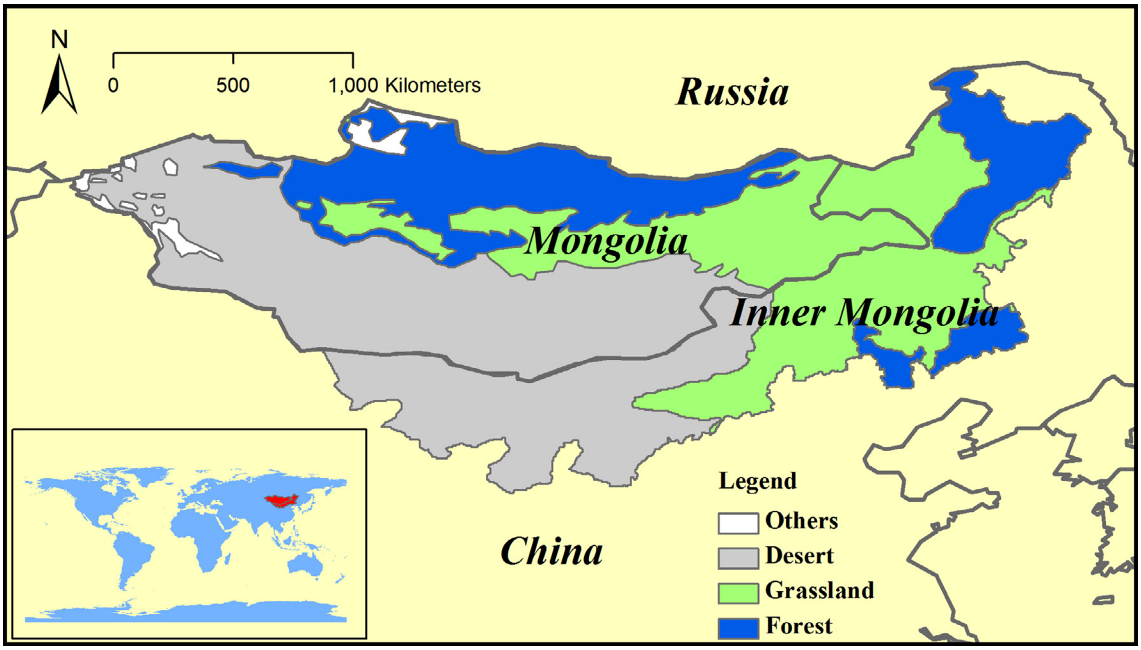

Fig. 1. Location map of the study area (including national boundaries Russia, Republic of Mongolia and China; Ecological zonings: desert, grassland and forest).

livestock losses (Davi et al., 2013; John et al., 2013). Sneath reported an overview of state policies and land degradation statuses in Inner Asia, primarily focusing on Russia, Republic of Mongolia (M) and on Inner Mongolia (IM), and noted different land degradation degree changes under entirely different political and economic policies (Sneath, 1998). Above all, monitoring the vegetation changes in the steppe areas will be crucial to indigenous pastoralists who rely on stock farming.

Several studies have explored the relation between vegetation, human activity and climate factors in the entire plateau, and vegetation variation was primarily attributed to the eastern Asia monsoon system and to the total annual precipitation (Bao et al., 2013; Cao et al., 2013; Chen and Wang, 2009; Schimel, 1995), whereas Yang et al. (2011) thought the NDVI and temperature were the closest factors, followed by precipitation, sunshine hours and relative humidity (Yang et al., 2011). In addition to natural factors, according to Hilker's study, 80% of the decline in grassland in M was due to overgrazing induced by increases in livestock from 2002 to 2012 (Hilker et al., 2013). However, most of the studies focused on one single aspect (temperature, precipitation or human activity) affecting a single temporal trend or spatial trend and lacked long-term data. To our knowledge, few studies attempted to separate the pressure from climate and population on the local people's environment and on conditions on this plateau. To gain a better understanding of vegetation dynamics in dry areas with different land management practices, it is essential to analyze the land use, climate, human activity and national policy to overcome this shortcoming.

Understanding how the vegetation of arid and semiarid ecosystems responds to multiple factors is crucial for regional sustainable development of environment and economy. In this research, the newest global vegetation dataset GIMMS NDVI3g and CRU (Climatic Research Unit) grid data are applied to examine the spatiotemporal information concerning vegetation activity dynamics from 1982 to 2011 over the MP. Then, we present how the vegetation response to climate change and to anthropogenic activity varies between M and IM. Using Mann–Kendall trend tests, greenness anomalies, and the Hurst exponent and linear regression methods, our study investigates the following issues: (1) Has the vegetation decreased or increased in spatiotemporal distribution across different ecosystem biomes in recent years? (2) Are there any different effects of climate and anthropogenic factors on the vegetation between the two political units: IM and M? (3) What will be the vegetation status in the immediate future?

2. Material and methods

2.1. Study area

The entire area of the MP constitutes of the M (relatively small population: 2.9 million in 2013) and IM (relatively large population: 25 million in 2013) in the eastern part of the Eurasian continent, with an average elevation of 1600 m (Fig. 1) (Miao et al., 2014b). The areas of IM and M are 1.18 billion sq. km and 1.56 billion sq. km, respectively. The vegetation could be divided into three biomes with obvious boundaries, according to Olson's global terrestrial ecoregions (Gobi desert in the west, grassland in the middle and forest in the northern and eastern part) (Olson et al., 2001). The MP steppe is one of the largest remaining grassland ecosystems controlled by the continental climate (Li et al., 2008; Mason et al., 1999). Climate is extremely cold in the winter and hot in the summer with an average precipitation of 200 mm yearly. Livelihoods in M and in IM are primarily based on livestock and grassland resources, with most of the region covered by desert along with sparse vegetation and grasslands (Olson et al., 2001). The MP provided an entirely new area for understanding how pastoral peoples interact with these northern, interior, and steppe-desert environments (John et al., 2013; McColl, 2002). Both IM and M experienced a similar arid and semi-arid climate but had different anthropological influences via their separate social and economic development histories (Sneath, 1998, 2000).

2.2. Material

NDVI is a common indicator to track vegetation productivity and vegetation growth at regional or global scales (Fensholt and Proud, 2012; Fensholt et al., 2009; Peng et al., 2011; Piao et al., 2006). Global satellite-derived data have been widely applied in vegetation diagnosis in regional areas (GIMMS/AVHRR, MODIS, SPOT, etc.) (Jiang et al., 2013; Mu et al., 2013; Wang and Li,