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Research paper

Grassland degradation remote sensing monitoring and driving factors quantitative assessment in China from 1982 to 2010

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ABSTRACT

Remote sensing monitoring of grassland degradation will make a clear of the grassland degradation status of China. At the same time, quantitative assessment of the driving factors will benefit to the understanding of degradation mechanism and grassland degradation control. In this study, net primary productivity (NPP) and grass coverage were selected as indicators to analyze grassland degradation dynamics. And we designed a method to assess the driving force of grassland degradation based on NPP. Specifically, the potential NPP and LNPP (NPP loss because of human activities), which is the difference between potential NPP and actual NPP, were used to calculate the contribution of climate and human factors to grassland degradation, respectively. Results showed that grassland degradation area accounted for 22.7% of the total grassland area in China from 1982 to 2010. The contribution of climate change and human activities to grassland degradation was almost equilibrium (47.9% vs 46.4%). Overall, on the grassland restoration, human activities were the dominant driving factors, accounting for 78.1%, whereas the contribution of climate change was only 21.1%. However, there are obviously spatial heterogeneous on driving factors. And the contribution of climate change was larger than human activities. But for the grassland restoration, human activities were the dominant factors. Warm-dry climate was harmful to grass growth but useful restoration measurements were benefit to grassland restoration. Methods in this study can be widely used in other regions of grassland degradation evaluation. The probability distribution functions (pdfs) of habitat suitability were different for the 7 dominant grassland types. Among, the pdfs of *Imperata cylindrica* (*Linn.*) *Beauv.* and *Themeda japonica* (*Willd.*) *Tanaka* was uniform distribution and mainly distributed in the southeastern of China. The pdf of *Phragmites australis* (*Cav.*) *Trin. ex Steud.* was normal distribution and widely spread all over of China. The pdfs of the *Kobre siapygmaea C.B. Clarke* and *Stipa purpurea Griseb* were "leptokurtic shape" and concentrated in the Tibetan Plateau.

1. Introduction

Grasslands, one of the most common types of vegetation in the world, account for nearly 20% of the global land surface (Scurlock and Hall, 1998). Human food production and, to a lesser extent climate change, have profoundly influenced grasslands (Conant et al., 2001). China has 3.93 million km^2 of grasslands, which account for about 40% of China's total land area. However, approximately 866,700 km^2 of China's grassland is degraded (Bao et al., 1998). Recent studies have shown that nearly 90% of the grasslands in northern China are degraded to some extent (Nan, 2005). Grassland degradation is mostly attributed to overgrazing and conversion of grassland to cropland as well as unregulated collection of fuel and medicinal plants (Akiyama and Kawamura, 2007). Furthermore, drought, locust attacks and rodent activities as well as climate change contribute to grassland degradation (Liu et al., 2004).

Grassland degradation is related to relevant issues such as declining productivity, biodiversity loss, land degradation, and declining ecosystem services (Turner et al., 2001). Although the cause of grassland degradation is complex, overgrazing is regarded as the leading cause (Teague and Dowhower, 2003). Meanwhile, the changes in vegetation and soil because of overgrazing are accompanied by a decrease in primary production of vegetation (Snyman and Fouché, 1991). Furthermore, climate change especially water and temperature, will influenced the length of the growing season as well as physiological processes, primary productivity, community composition, and plant diversity is affected (Saleska et al., 1999; Levy et al., 2004; Lemmens et al., 2006). In fact, Climate drying that has occurred in recent decades in north

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China adds further stress to the ecosystem (Chen and Tang, 2005).

To alleviate the multi-faceted environmental degradation, the Chinese government has launched several ecological restoration programs. Especially the Grain to Green Program (GTGP) and Returning Grazing Land to Grassland Program (RGGP) have obtained considerable achievement and deeply affected the structure and function of grassland ecosystem (Liu et al., 2008; Wang et al., 2011). GTGP aims to convert cropland to forest and grassland in fragile areas, initiated since 1999(Ferraro and Kiss, 2002), whereas RGGP initiated since 2003, aims to alleviate grazing pressure in degraded grassland through forbidding grazing, rotational grazing (Tong et al., 2004). Long periods of forbidden grazing are expected to increase plant coverage (Wang et al., 2011), and previously degraded grasslands in Inner Mongolia (IM) have been restored to their 1960s level after three years of protection from grazing (Jiang et al., 2006).

Grassland degradation monitoring is traditionally studied by field investigation, through which contributing factors are identified (Li, 1997). This method is inefficient and costly because grassland usually covers a large spatial region (Asrar et al., 1986) and the results are unreliable. By contrast, remote sensing monitoring is much more efficient in assessing grassland degradation (Alfredo et al., 2002; Lu et al., 2007). However, the contribution of the two factors on grassland degradation is unclear at present. Therefore, a method to assess the driving contribution is crucial to monitor grassland degradation.

Recent studies have analyzed human-induced vegetation degradation based on rainfall use efficiency (RUE) method (Prince et al., 2004; Symeonakis and Drake, 2004). However, RUE is an oversimplified empirical indicator and provides results that are not very reliable. Several studies also have used vegetation dynamics to distinguish human-induced desertification from climate change (Wessels et al., 2007; Xu et al., 2010). As the vegetation dynamics are the most intuitive manifestation of land degradation. Meanwhile, NPP is sensitive to both climatic change and human activities (Schimel, 1995). In this study, NPP and coverage were selected as vegetation dynamic indicators to reflect grassland degradation situation. In order to calculate the driving contribution, potential NPP and LNPP (NPP loss caused by human activities), which is the difference between potential NPP and actual NPP, are used to assess the relative roles of climate change and human activities in grassland degradation.

There are 18 grassland types according to grassland classification system of China in 1980s. The probability distribution function of each grassland type can reveal the probabilistic structure of grassland type and the universality findings across macro-geographical areas. Therefore, it is fundamentally important to predict the distribution of grassland species with low system energy. And the $M_{AX}E_{NT}$ is one of the popular presence only species distribution model (SDMs) and widely used in species prediction and biodiversity conservation.

This study aims to make clear the spatial-temporal characteristic of grassland degradation in China and then determine the dominant factor of grassland degradation. Meanwhile, the results of this study will provide a deeper and more comprehensive knowledge of grassland degradation as well as useful suggestions provide recommendations for grassland resource management and sustainable development.

2. Materials and methods

2.1. Study areas

The Global Land Cover 2000 dataset (GLC, 2003) indicated that China's grassland area are 3.35 million km^2, cover approximately 35% of the country's total land area, mainly distributed in the northwest China and Tibet plateau. The nine provinces regions in China, namely, IM, Xinjiang, Qinghai, Tibet, Gansu, Shaanxi, Ningxia, Yunnan, and Sichuan, account for 94% of the total grassland in China (Fig. 1).

Northwest China is characterized by arid and semi-arid climate and large temperature differences between day and night. The high mountains with high precipitation, such as Altai, Tianshan, Kunlun, and Qilian, block atmosphere circulation and create vast desert basins in the rain shadow, such as Tarim, Junggar, and Qaidam (Shi et al., 2007). Grassland degradation is serious because of the land use change, overgrazing, and global warming.

Tibet Plateau is the highest contiguous area of the world with approximately 1.4 million km^2 in land area perched 4500 m above sea level (Huddleston et al., 2003). It is characterized by a subtropical to temperate mountain climate unique to the Qinghai–Tibet Plateau (Chen et al., 2006). Its surface temperature is relatively low because of its high altitude. However, Tibet Plateau has been experiencing a warming trend since the mid-1950s. Precipitation in Tibet Plateau is relatively low and extremely variable in time and space (Ueno et al., 2001). Natural vegetation in Tibet Plateau varies greatly and comprises forests, grasslands, and shrubs, which are very sensitive to environmental changes and human activities. To date, Tibet Plateau approximately has 425,100 km^2 of degraded grassland, and severely degraded grassland accounts for approximately 16% of the degraded grassland (Wang et al., 2006a).

2.2. Data sources and processing

2.2.1. Normalized difference vegetation index (NDVI) data and post-processing

We used NDVI data and geo-spatial meteorological data as input data for the Carnegie–Ames–Stanford Approach (CASA) model to calculate the actual NPP (Potter et al., 1993). The study period was from 1982 to 2010. Two types of NDVI dataset were used in this study: moderate-resolution imaging spectroradiometer (MODIS)-NDVI (MOD13A2) data with 1 km × 1 km spatial resolution, covering the periods from 2001 to 2010 and downloaded from the earth observing system data gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/); and advanced very high-resolution radiometer global inventory modeling and mapping studies (GIMMS)-NDVI data with 8 km × 8 km resolution, covering the periods from 1982 to 2006.

A regression model for the entire pixel was established based on the two types of NDVI dataset (through the overlap time period of the two types NDVI datasets and total of 72 months from 2001 to 2006) to produce a long period of NDVI datasets from 1982 to 2010. Firstly, Savitzky–Golay filters were used to smooth the NDVI data and reduce image noises. Secondly, the nearest neighbor method was used to resolve the different spatial resolutions of the two types of NDVI dataset. Finally, Maximum-value compositing was used to merge the MODIS_NDVI value from 16 and GIMMS_NDVI 15 days to produce the monthly NDVI datasets. The two NDVI products were re-projected to Albers equal area projection based on the WGS-84 datum using ArcGIS V10.1 software (ESRI, California, USA).

2.2.2. Meteorological data

Meteorological data from 1982 to 2010, including average monthly temperature and precipitation for 680 stations as well as total solar radiation data for 102 stations, were obtained from China Meteorological Data Sharing Service System. Ordinary Kriging interpolation was used to interpolate the meteorological data into grid at 1 km × 1 km spatial resolution. The driving meteorological data for the Miami memorial model to estimate the potential NPP (Lieth, 1975) were annual temperature and precipitation. This can be calculated through incorporating the 12 month temperature and precipitation.

2.2.3. Field survey of NPP

We sampled 51 sites across northwest China from April to August of 2009. At each site (20 m × 20 m), we set four quadrates (5 m × 5 m) and marked as S1, S2, S3, S4. In order to calculate the NPP of all plants, we investigated twice in the quadrates, early April in quadrate S1 and S3, and later August in quadrates S2 and S4. The biomass increment for grassland was obtained by the difference between the maximum