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Comparative assessment of grassland degradation dynamics in response to climate variation and human activities in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013

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ABSTRACT

Quantifying the driving force is significant to understand the impact of climate variation and human activities on grassland degradation. In this study, we selected net primary productivity (NPP) as an indicator to quantitatively assess the relative roles of climate variation and human activities in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013. The results showed that 1.9% of grassland areas experienced degradation in Uzbekistan. By contrast, 29.6%, 16%, and 32.5% of grassland areas underwent restoration in China, Mongolia and Pakistan, respectively. Furthermore, 83.9%, 85.1%, 6.7% of restored grassland areas were influenced by climate variation and 65%, 79.1%, 11.6% of degraded areas were affected by human activities in Mongolia, Pakistan and Uzbekistan, respectively. The NPP variation also could be calculated to evaluate the impacts of these factors and results were consistent with the findings based on area. Therefore, climate variation dominated grassland restoration, human activities dominated degradation in Mongolia and Pakistan, and Uzbekistan was just the opposite. In China, 38.5% of the grassland restoration areas was caused by climate variations compared with 38% induced by human activities. On the contrary, 37.4% of grassland degradation was caused by climate variation and 30% resulted from human activities. In addition, the results based on NPP variation revealed that 39.2% of restored grassland areas were influenced by human activities and 38.2% of degraded areas were affected by climate variation. Therefore, climate variation dominated grassland degradation and the driving force of restoration was determined by the effectiveness of environmental protection programs.

1. Introduction

The terrestrial ecosystems have undergone dramatic environmental changes, including alterations in climate, atmospheric composition, land use and management (Intergovernmental Panel on Climate Change, 2014). Global warming and increasing human activities have significantly affected the natural ecosystems in the world (Gao et al., 2013; Wang et al., 2012a). Grassland, one of the largest types of vegetation in the world, accounts for nearly 25% of the global land surface. As important natural ecosystems, grasslands play a significant role in maintaining material circulation, and balancing greenhouse gas, particularly in terms of global carbon storage and further carbon sequestration (French, 1979; O'Mara, 2012; Scurlock and Hall, 1998).

Grassland degradation is one of the global ecological environmental problems, and the area of grassland degradation has reached 1401×10^4 km^2 in 2010, accounting for nearly 49.3% of the world's grassland areas (Gang et al., 2014). These grassland areas have been degraded to a certain extent because of excessive land use (Harris, 2010), population growth (Nan, 2005), and global warming (Chengqun et al., 2012). Grassland resources in China, Mongolia, Pakistan and Uzbekistan are abundant and most of them

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have had pastoral use. As the four countries are located in the Silk Road Economic Belt, they form a connected whole. Comparative assessment of these four countries' grassland degradation dynamics is helpful to learn from each other and make progress together to protect grassland. The large grasslands can serve as a significant repository of natural resources and can provide vast lands for farming and grazing. However, many researches on grassland ecosystems in these four countries have focused on local and sub-catchment scales (Peng et al., 2013). In recent years, global climate and overgrazing have caused grassland degradation in Mongolia (Kawamura et al., 2005; Sekiyama et al., 2014) and Pakistan (Scarnecchia et al., 1998). The area of grassland have gradually reduced in Uzbekistan (Fan et al., 2012). China has become one of several countries severely affected by the degradation, approximately 90% of the grassland area in China has been degraded because of climate and human activities (Harris, 2010; Nan, 2005). Therefore, a deeper understanding of the driving factor of degradation is necessary and fundamental to restore degraded grasslands and promote sustainable development of grassland resources. (Han et al., 2008).

According to the previous researches, climate and human activities are the main driving forces of grassland degradation (Esser, 1987; Field, 2001; Haberl, 1997). Many researchers have realized that the grassland degradation is caused by over-grazing and extensive cutting, particularly in the developing countries (Liu and Diamond, 2005; Yang et al., 2005). Similarly, other studies have attributed the degradation to increased global temperature and different precipitation patterns such as drought and winter precipitation (Ravi et al., 2010; Zhou et al., 2005). Nevertheless, it is difficult to distinguish the effects of these two factors (Wessels et al., 2007). It is crucial to use an optimal quantitative assessment method to evaluate the effects of climate and human factors (Verón et al., 2006). Net primary productivity (NPP), the net amount of solar radiation converted to plant organic matter by plants through photosynthesis, is a reliable indicator of ecosystem function and plays a crucial role in regulating carbon balance and maintaining ecosystem health (Yeganeh et al., 2012). NPP can reflect the growth status of vegetation and is sensitive to both climate variation and human activities (Odum, 1971; Schimel, 1995). Therefore, many researchers have adopted NPP as an indicator of degradation and to distinguish the impact of climate from that of human activities (Prince et al., 1998, 2009; Wessels et al., 2008; Zheng et al., 2006). However, the monitoring and assessment of these two factors traditionally depend on field surveys or social statistical data, which is inefficient, particularly in regions where field survey is difficult to perform or statistical data are lacking (Li, 1997; Rojstaczer et al., 2001). To date, few studies have been conducted to quantify the relative roles of climate and human activities in degradation (Gang et al., 2014; Xu et al., 2010; Zhang et al., 2011; Zhou et al., 2014a, 2014b).

In this study, NPP coupled with scenario simulation method was applied to assess the grassland degradation status in the four countries from 2000 to 2013. Six kinds of scenarios were built on the basis of the slope of NPP to evaluate the impacts of climate variation and human activities on degradation or restoration. The primary objectives of this study were as follows: to explore and compare the degradation dynamics in China, Mongolia, Pakistan and Uzbekistan from 2000 to 2013; and to distinguish the relative roles of climate variation and human activities in degradation or restoration. The outcomes of this study not only provide an overall picture of grassland degradation, but also may serve as a firmer basis for policy and decision making in the course of pasture production and grazing management practices.

2. Materials and methods

2.1. Data source and processing

The global grassland map was obtained from the MODIS Terra + Aqua Combined Land Cover product MCD12Q1, which was downloaded from the MODIS Land website (http://modis-land.gsfc.nasa.gov/landcover.html/). The primary land cover scheme identifies 17 classes defined by the International Geosphere-Biosphere Program (IGBP), including 11 natural vegetation classes, three human-altered classes, and three non-vegetated classes. In this study, class number 6–10, with shrubland cover, savanna cover and grassland cover, were selected as a single grassland land cover type.

The global monthly precipitation and temperature data were derived from UDel_AirT_Precip (University of Delaware Air Temperature and Precipitation). The data were downloaded from the Web site at http://www.esrl.noaa.gov/psd/which were provided by NOAA/OAR/ESRL (PSD, Boulder, Colorado, USA). The mean annual temperature and mean annual precipitation were calculated from the downloaded monthly data by using ArcGIS V10.0 (ESRI, California, USA).

Livestock numbers of these four countries in this study were obtained from Food and Agriculture Organization of the United Nations, the annual data were downloaded from the Web site at http://faostat3.fao.org/download/E/EK/E.

All of the related databases were resized to 1-km spatial resolution and the coordinate and projection system used were the World Geodetic System 1984 and the Albers equal area conic projection respectively.

2.2. Estimation of actual NPP

The actual NPP was estimated from the global NPP product MOD17A3 (1 km spatial resolution), which was obtained from the NASA MODIS Land Science team website (http://landval.gsfc.nasa.gov/). The MOD17A3 NPP was calculated based on the BIOME-BGC model, which is expressed as follows:

$$\mathrm{NPP} = \sum_{t}^{365} \mathrm{PSNet} - \left(R_m + R_g\right) \tag{1}$$

$$\mathrm{PSNet} = \mathrm{GPP} - R_{lr} \tag{2}$$

where NPP is the annual NPP (gC/m^2/year) and PSNet is the net photosynthesis. R_m and R_g are annual maintenance respiration of live cells in woody tissue and annual growth respiration, respectively. R_{lr} refers to the daily leaf and fine root maintenance respiration.

2.3. Estimation of potential NPP

In this study, we estimate potential NPP using the Thornthwaite memorial model, which is based on the Miami model and modified by Thornthwaite's potential evaporation model (Lieth, 1975; Lieth and Box, 1972). This model mainly consists of annual average evapotranspiration, annual total precipitation and the annual average temperature, which is presented as follows:

$$\mathrm{NPP} = 3000\left[1 - \mathrm{e}^{-0.0009695(\mathrm{v}-20)}\right] \tag{3}$$

where NPP is the annual total NPP (gC/m^2/year) and v is the annual actual evapotranspiration (mm). The calculated equations are presented as follows: