Global and Planetary Change 108 (2013) 29–41

Contents lists available at SciVerse ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Assessing the impact of restoration-induced land conversion and management alternatives on net primary productivity in Inner Mongolian grassland, China

Shaojie Mu [a], Shuangxi Zhou [b], Yizhao Chen [a], Jianlong Li [a,*], Weimin Ju [c], I.O.A. Odeh [d]

[a] School of Life Science, Nanjing University, Nanjing 210093, PR China
[b] Department of Biological Sciences, Macquarie University, Sydney NSW 2109, Australia
[c] International Institute of Earth System Science, Nanjing University, Nanjing 210093, PR China
[d] Faculty of Agriculture, Food & Natural Resources, The University of Sydney, Sydney NSW 2006, Australia

ARTICLE INFO

Article history:
Received 31 December 2012
Accepted 13 June 2013
Available online 20 June 2013

Keywords:
Inner Mongolia grassland
vegetation restoration programs
land use and cover change
net primary productivity
human activities

ABSTRACT

To address severe grassland degradation problems, China has been implementing a number of national restoration programs, whose significant environmental effect has attracted the attention of many researchers. In this paper, land use and cover change (LUCC) in the Inner Mongolia grassland and the consequent change in net primary productivity (NPP) were studied by combining the land use data of the study area for 2001 and 2009 derived from the MODIS global land cover product and the CASA (Carnegie–Ames–Stanford Approach) model driven with MODIS-NDVI data. The results indicate that the area of Inner Mongolia grassland had a net increase of 77,993 km^2 during the study period, which was mainly attributed to the conversion from desert and cropland. The total NPP of Inner Mongolia grassland increased by 29,432.71 Gg C yr^{-1} during 2001–2009, of which the human activities and climate change were responsible for 80.23% and 19.77%, respectively. Land conversion and improved management increased grassland NPP directly, and the ecological restoration conducted by large-scale conservation programs could be the intrinsic driving force for this change.

1. Introduction

Land use activities have transformed one third to one half of our planet's land surface in the form of land use and cover change (LUCC), which made profound impacts on ecosystem structure, function and diversity (Foley et al., 2005; Pielke, 2005; Yan et al., 2009). As grassland vegetation type is one of the world's most widespread land cover types, it has been deeply influenced by human activities for food and forage production (Conant et al., 2001). China has 3.93 million km^2 of grassland, accounting for 40% of China's total land area and 13% of the world's total grassland (Ni, 2002). Concurrent with population growth and socio-economic development, substantial LUCC has occurred in China's grassland over the last half century. However, unsound human activities have led to large-scale land degradation across the vast Inner Mongolia grassland, which constitutes the main grassland region of China and a significant part of the Europe-Asia Steppe. Specifically, overgrazing and land conversion are suggested to be the primary impetus for grassland degradation in this region (Jiang et al., 2006). Historically, the generation of land degradation was as a result of intensive migration of Han people into Inner Mongolia since the early 19th century. Since then the human population of the grassland area has increased rapidly, causing drastic conversion of grassland to cropland and thus increasing grazing pressure. This overexploitation of the grassland led to soil structural decline and depletion of mineral content, therefore, triggering growing erosion and land degradation. The consequence of this is a significant decrease in land suitable for grazing, for example, between 1949 and 2000, the number of grazing animals has increased 18-fold, while the total usable grassland decreased from 88 Mha to 63 Mha during the same period (Chuluun and Ojima, 2002).

Land degradation in this region has led to the deterioration of biodiversity and ecosystem function and services as well as serious environmental problems such as desertification and carbon sink loss (Liu et al., 2006). Taking Hunshandak sandy land for example, the available grasslands declined by some 40% between the 1950s and 1990s, while the proportion of shifting sand dunes rose from 2.3% to 50% during the same period. This decline in grassland and proportionate increase in desert land is generally believed to be a major reason for the increased frequency of severe sandstorms in northern China in recent decades (Liu et al., 2006). Similarly the Horqin sandy land in eastern Inner Mongolia, the total loss of soil organic carbon resulting from grassland degradation was 107.53 Mt on land area of 26,393 ha

* Corresponding author at: School of Life Science, Nanjing University, Hankou Road 22, Nanjing 210093, PR China. Tel.: +86 25 86214644; fax: +86 25 83302728.
E-mail address: jianlongli@gmail.com (J. Li).

0921-8181/$ – see front matter
http://dx.doi.org/10.1016/j.gloplacha.2013.06.007

during the last century (Su et al., 2010). To mitigate the impacts of land degradation, China has launched a number of national conservation policies on payments during the late 1990s and early 2000s. Two of them, the Grain to Green Program (GTGP) and the Grazing Withdrawal Program (GWP) have been introduced in different ways in Inner Mongolia with particular emphasis on grassland (Dai, 2010; Yin et al., 2010; Qiu et al., 2011). The GTGP, which is usually explained as "replacing cropping and livestock grazing in fragile areas with trees and grass", is the most renowned activity because of its ambitious goals, massive scales, huge payment and potentially enormous impacts (Wang et al., 2007). A GTGP pilot study started in three provinces in 1999 which was expanded to 25 provinces in 2002 (Liu et al., 2008). To complement the effort of GTGP, the national government initiated the GWP, another large vegetation restoration program, in 2003. Compared with the GTGP, the GWP focuses on alleviating grazing pressure in the degraded natural grassland in western China. The program was aimed to conserve grassland through banning of grazing, rotational grazing or converting grazing land to cultivated pasture (Tong et al., 2004). These two vegetation restoration programs implemented in Inner Mongolia have induced changes in area coverage and management practices of grassland, and consequently, the grassland productivity.

Numerous studies have been published on the ecological effects of vegetation restoration programs in China's grassland. Huang and Liu (2002) reported an increase in the grassland area ratio and a decrease in the farmland ratio in a catchment following the implementation of GTGP. This could also effectively reduce surface runoff. A recent study carried out in Hunshandak sandy land shows that without grazing, the previously degraded grassland was restored to the 1960s level after only three years of fencing and plant height (Jiang et al., 2006). As a result, plant cover and above-ground biomass all increased once grazing was stopped under the GWP. In this paper, we focus on regional ecosystem net primary productivity (NPP), defined as the net amount of solar energy converted to chemical energy through photosynthesis.

NPP represents the net carbon input from the atmosphere to the terrestrial vegetation (Imhoff et al., 2004). As an important parameter of ecosystem function and the carbon cycle, NPP can be used to quantify the impact of LUCC across a broad spectrum of issues in earth system science and global change research (Xu et al., 2007). This paper aims to assess the impact of LUCC on NPP change as a consequence following the implementation of government policies on the restoration of degraded grassland. Reciprocally, through distinguishing NPP change due to human activities (land conversion and management alternatives) and climate change, we also determined the two driving factors to LUCC using NPP as an index for measurement. This is essential to maintain optimal ecosystem functioning and to predict future global carbon cycle trends.

We used satellite remote sensing to monitor LUCC at large scales and quantifying vegetation productivity, as it is able to detect land cover type and actual vegetation dynamics top-down over large areas directly. By integrating land use data derived from the MODIS global land cover product (MCD12Q1) and NPP data, the impacts of human activities on ecosystem productivity from those of climate change for the period of 2001–2009 were disaggregated. Furthermore, the spatial–temporal distribution of grassland productivity caused by various types of grassland transformation was differentiated in detail, and its implications for regional carbon cycle and sand storms control were examined.

2. Data and methods

2.1. Study site

Inner Mongolia is located between 37°24′–53°23′N and 97°12′–126°04′E, and is the 3rd largest in China (Fig. 1). Most of Inner Mongolia is 1000–2000 m above sea level with widely varied topography, comprising mainly of plateaus which are not generally precipitous, extending 2400 km from northeast to southwest. The province is characterized by an arid to semi-arid continental climate with strong climatic gradients and varied land use practices. The majority of cropland is located in the transitional zone where the grassland biome meets the forest biome in northern Inner Mongolia, while a fraction of cropland scatter in the transitional agro-pasture area in the central region of grassland biome. There is a large area of desert in Inner Mongolia, including the Horqin sandy land in Chifeng city, the Hunshandak sandy land in contiguous area of Xilin Gol and Ulanqab league, the Tengger and Badain Jarian desert in Alax league and the Hobq desert and Mu Us sandy land centering on the Ordos Plateau.

In China, more than 20% of grassland distributed in Inner Mongolia, which is the representative for large areas of the Europe–Asia Steppe belt that stretches from east China to Hungary. Grassland is the dominant vegetation type in Inner Mongolia. A strong east-to-west precipitation gradient results in a decrease in annual precipitation from more than 500 mm in eastern Inner Mongolia to less than 100 mm in western part. With this large precipitation range, three major zonal grassland types, meadow steppe, typical steppe and desert steppe are distributed along the northeast to southwest in Inner Mongolia. Typical steppe, developed under semi-arid conditions with annual precipitation from 200 to 400 mm and annual mean temperature from 0 to 8 °C in central Inner Mongolia, is the most widely spread type (Piao et al., 2006). Meadow steppe, which is more productive than typical steppe, is developed in areas with moist fertile soils rich in organic matter in northeastern Inner Mongolia, with annual average precipitation ranging from 300 to 600 mm and annual mean temperature from 2 to 5 °C. The desert steppe found in areas with annual precipitation between 150 and 200 mm and annual mean temperature between 5 and 10 °C, has the least biomass (John et al., 2008).

2.2. Data source

2.2.1. NDVI data

We chose the MODIS data and geo-spatial meteorological data as input parameters to CASA model for calculating NPP in Inner Mongolia. We downloaded the MODIS-derived 16-day composite atmospherically corrected vegetation indices (MOD13A1) at 500-m resolution from EOS data gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/) for 2001 and 2009. MODIS-NDVI data was extracted from MOD13A1 using the MODIS re-projection tool (MRT). A 32-day composite product of the maximal values was produced for a time series based on these NDVI data. Given that each period covers 32 days, one year thus includes about 11 time series of composite product of maximal NDVI. These data were re-projected to the Albers equal area projection and WGS84 datum using MRT and nearest neighbor method resampling. We then calculated NPP by using the MODIS-NDVI data as input to the CASA model to evaluate the effect of restoration oriented LUCC.

2.2.2. Land cover data

The MODIS Collection 5 Land Cover Type product (MCD12Q1) based on IGBP global vegetation classification scheme was used to track land cover changes and to guide the calculation of NPP in Inner Mongolia. The IGBP classification has 17 LCLU classes, including 11 natural vegetation classes, 3 developed and mosaiced land classes, and three non-vegetated land classes. In this paper, the land cover maps were reclassified into the following 7 dominant categories based on the IGBP classification scheme: (1) water bodies, (2) forest, (3) grassland, (4) cropland, (5) cropland/natural vegetation, (6) urban and built-up, and (7) desert. Evergreen needleleaf, deciduous needleleaf, deciduous broadleaf, mixed forests and closed shrublands were recoded to forest, whereas open shrublands, woody savannas, savannas, grasslands and permanent wetlands were recoded to grassland.

The MODIS global land cover product was derived from MODIS 500-m resolution data using a state of the art supervised classification