Ecological Engineering 82 (2015) 276–289

Contents lists available at ScienceDirect

Ecological Engineering

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

Response of vegetation activity dynamic to climatic change and ecological restoration programs in Inner Mongolia from 2000 to 2012

Haijing Tian [a,b], Chunxiang Cao [a,*], Wei Chen [a], Shanning Bao [a,b], Bin Yang [a,b], Ranga B. Myneni [c]

[a] State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Center for Applications of Spatial Information Technologies in Public Health, P.O. Box 9718-13, Datun Road, Chaoyang District, Beijing, PR China
[b] University of Chinese Academy of Sciences, Beijing, PR China
[c] Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA

ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form 1 April 2015
Accepted 28 April 2015
Available online 19 May 2015

Keywords:
Ecological restoration programs
NDVI
Climate change
Inner Mongolia
Vegetation activity
MODIS

ABSTRACT

To address devastating land desertification and soil erosion and to improve human well-being, central government in China has implemented a number of ecological restoration programs. It is essential to rigorously monitor the dynamic of vegetation activity and evaluate the effectiveness of these programs, not only to provide scientific support for ecosystem monitoring in arid and semi-arid region, but also to assess the efficiency of ecological restoration policy. Taking Inner Mongolia as study area, we used 13 years (2000–2012) of both climatic data and MODIS NDVI data to (1) assess the spatiotemporal vegetation dynamic and map areas of significant vegetation restoration and degradation, (2) analyze the impacts of climatic changes on vegetation activity and map areas where vegetation activity dynamic was significantly affected by climatic change, (3) map main driving forces of significant vegetation restoration or degradation, (4) validate the zones where vegetation significant restoration were mainly impacted by ecological restoration programs with vegetation fractional cover data in 2000 and 2012. Results showed an overall greening (15.38% significant NDVI increasing) and partial degradation (1.64% significant NDVI decreasing) in Inner Mongolia. It was estimated that annual precipitation most strongly and significantly limited vegetation growth over 45.1% of Inner Mongolia, whereas sunlit hours significantly limited growth over 3.37% and air temperature significantly over 0.73% of Inner Mongolia. Among the 15.38% significant greening region, 5.86% was caused by climatic changes, 5.67% was caused by ecological restoration programs, and the other 3.8% was caused by multi-factors. Among the 1.64% significant degradation region, 0.17% was caused by climatic changes and other 1.47% can be explained by human activities, such as population growth and city expansion.

1. Introduction

Arid and semi-arid regions make up about 40% of the earth's land surface and are home to about 20% of the human population (Fernández, 2002). In China, the main arid and semi-arid lands are currently located in north-western parts of the country, including Inner Mongolia, Ningxia autonomous regions, Shanxi, Qinghai, Xinjiang provinces, and other nearby areas (Liu and Diamond, 2005): an estimated 2.62 million km^2 have been affected by desertification at the end of 2009, accounting for 27.3% of China's total land area (State Forestry Administration, 2011). Except Xinjiang province, Inner Mongolia is most seriously affected by desertification, with the desertified land area of 0.62 million km^2 until 2009, accounting for 52.2% of Inner Mongolia's total land area (State Forestry Administration, 2011). The term of desertification in this paper refers to land degradation in the arid, semi-arid and dry sub-humid areas as result of various factors including climatic variation and human activities. The term of sandification in the paper refers to the land degradation characterized by appearance of sand or gravel on ground surface as result of various reasons in all climatic zones (State Forestry Administration, 2011).

The central government has proposed a science-based approach to development designed to realize balanced sustainable development (Ma, 2006). Especially since 2000, there have been rapid and extensive changes in forestry policy in China. Investments in the forestry sector since 2000 have exceeded the total investments during the period 1949–1999 (Wang et al., 2007). In its scale, the number of participants, and the magnitude of the

* Corresponding author. Tel.: +86 010 6483 6205; fax: +86 010 6483 6205
E-mail address: caocx@radi.ac.cn (C. Cao).

http://dx.doi.org/10.1016/j.ecoleng.2015.04.098
0925-8574/

investment, China's afforestation projects are largest in the world (Liu and Diamond, 2005; Uchida et al., 2005; Zhang et al., 2000). The six large-scale ecological restoration programs are most pronounced, including "Beijing–Tianjin Sand Source Control Program", fourth phase of "Three-north Shelterbelt Forest Construction Project", "Natural Forest Conservation Program", "Grain for Green Project", "Wildlife Protection and Nature Reserve Development Program" and "Fast-Growing and High-Yielding Timber Base Construction Program" (Zhang et al., 2000). Inner Mongolia is the key implementation provinces in the six large-scale ecological restoration programs.

For the first time since the establishment of People's Republic of China, desertification has been reversed, from an annual increase of 3436 km^2 at the end of the 20th century, to the average annual reduction of 7585 km^2 from 1999 to 2004 and annual reduction of 2491 km^2 from 2004 to 2009 (State Forestry Administration, 2005, 2011). As to Inner Mongolia, the average annual reduction of desertified land areas is 3211 km^2 from 1999 to 2004 and 934 km^2 from 2004 to 2009 (State Forestry Administration, 2005, 2011).

Nevertheless, there is an ongoing debate on the effectiveness of the national ecological restoration programs in China as well as in Inner Mongolia. On one hand, numerous researchers and government officials claimed that ecological restoration programs have successfully combated desertification and the vegetation coverage and biomass has been improved (Tian et al., 2014; Wang et al., 2007; Wu et al., 2013; Yin and Yin, 2010; Zhang et al., 2000). Liu et al. (2008) found that the "Natural Forest Conservation Program" and the "Grain to Green Program" have not only increased vegetative cover, enhanced carbon sequestration, and reduced dust to other countries by controlling soil erosion, but also provided important experiences and lessons for other ecosystem service programs in China and many other parts of the world. Wu et al. (2013) evaluated the effectiveness of "Beijing–Tianjin Sand Source Control Program", and suggested that the vegetation activity in Beijing–Tianjin Sand Source Region has been improved due to the implementation of ecological restoration program. Tian et al. (2014) found that the vegetation coverage in Jungar Banner, Inner Mongolia has been significantly improved as a result of numerous ecological restoration programs. On the contrary, many social scientists and scholars argued that ecological restoration programs in arid and semi-arid regions may not work well (Cao, 2008; Jiang, 2005; Wang et al., 2010). Jiang (2005) believed that the large-scale afforestation in the Three Norths has produced largely unfavorable results. Cao (2008) further asserted that these costly programs have yielded little success thus far and afforestation could lead to increased ecosystem deterioration and wind erosion because it has ignored climatic, pedological, hydrological and landscape factors. Wang et al. (2010) suggested that the importance of "Three-North Shelterbelt Forest Construction Project" seems to have been overstated and there is little unassailable evidence to support those claims that the huge investment in the program has beneficial effects on combating desertification and controlling dust storms.

To some extent, these divergences derived from different judging criteria. In fact, taking vegetation restoration into consideration, the goals of ecological restoration programs are to increase vegetation activity (such as vegetation coverage, biomass, leaf area index and net primary productivity) and enrich the value of ecosystem services provided by vegetation (Cai, 2008). Thus, increasing or decreasing vegetation activity can be utilized to assess the success or failure of ecological restoration programs. Due to the robust relationship between normalized difference vegetation index (NDVI) and vegetation production, NDVI has commonly been used as a proxy of vegetation activity (Boschetti et al., 2013; Jobbágy et al., 2002). The MODIS NDVI products with multiple spatial resolutions (250 m, 500 m and 1 km) and multiple temporal resolutions (8 days, 16 days and 1 month) have always been used for vegetation dynamic research (Fensholt and Proud, 2012; Wu et al., 2013, 2014). In this research, vegetation activity refers to green vegetation cover as determined by MODIS NDVI.

In addition, variations in vegetation and the relationship and interaction of vegetation with climate have become important issues in global change research (Hall-Beyer, 2003; Kawabata et al., 2001; Park and Sohn, 2010; Piao et al., 2006, 2011a,b,c; Wang et al., 2011). Previous studies suggest that climatic factors, such as rainfall, air temperature and solar radiance, is the main factors influencing the vegetation activity and vegetation production in arid and semi-arid regions (Nemani et al., 2003; Yang et al., 2012; Yu et al., 2012; Zhang et al., 2014). Nemani et al. (2003) assesses a climate-driven increase in global terrestrial net primary

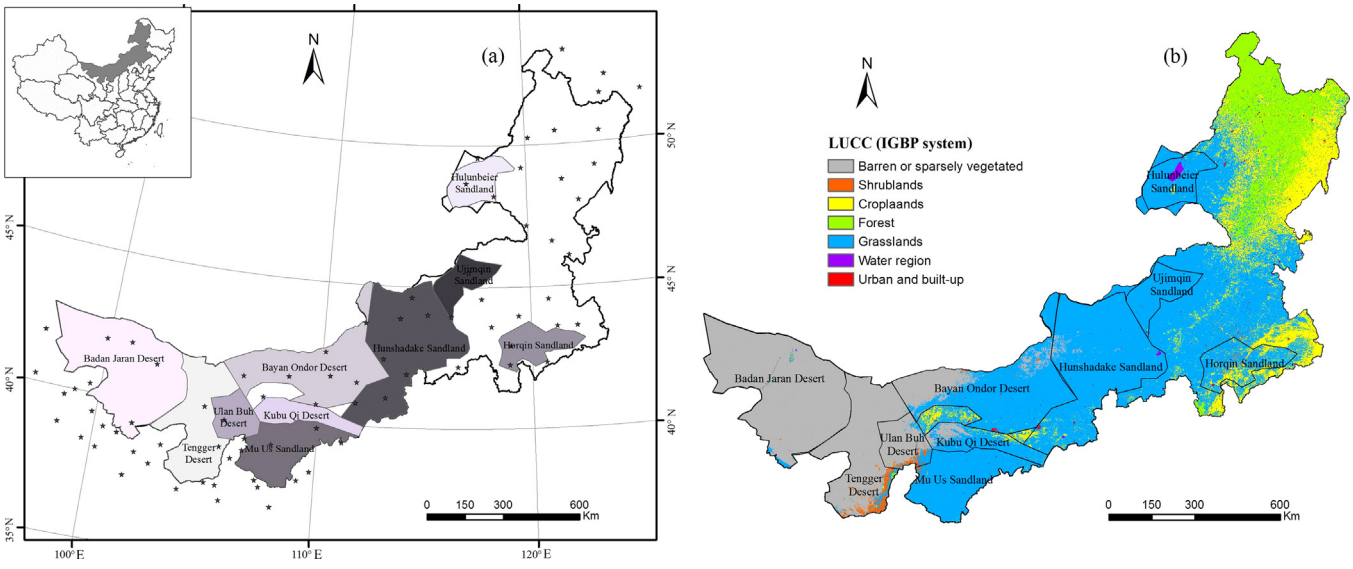

Fig. 1. (a) Location of study area and spatial distributions of these five deserts, five sandlands and 85 ground meteorological stations, and (b) land cover map in Inner Mongolia derived by MODIS MCD12Q1 product in 2012.