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Multiple afforestation programs accelerate the greenness in the 'Three North' region of China from 1982 to 2013

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ABSTRACT

China has launched multiple afforestation programs since 1978, including the 'Three North' Shelterbelt Development Program (TNSDP), the Beijing–Tianjin Sand Source Control Program (BSSCP), the Nature Forest Conservation Program (NFCP), and the Grain to Green Program (GTGP). These programs focus on local environment restoration by planting trees in semi-arid and arid regions and by protecting natural forests. However, the effectiveness of these programs has been questioned by several previous studies. Here, we report an increasing trend of greenness in this region using the satellite-retrieved normalized difference vegetation index (NDVI) from GIMMS, GIMMS-3g and MODIS datasets in the past 32 years. The NDVI increase for the 'Three North' region was 0.28%–0.38% yr^{-1} in 1982–2000 and 0.86%–1.12% yr^{-1} in 2000–2013, which is much higher than the country's means of 0.060%–0.063% yr^{-1} and 0.27%–0.30% yr^{-1}, respectively. Most of the increase occurred in low and sparsely vegetated areas; and enlarged the moderate vegetated area (growing season mean NDVI above 0.5) from 16.5% to 25.7% for the two time periods, respectively. We also analyzed changes in the length of the growing season and the climate conditions including temperature, precipitation and two drought indices. However, these environmental factors cannot completely explain the changes in vegetation activity. Our study suggests these multiple afforestation programs contributed to the accelerated greening trend in the 'Three North' region and highlight the importance of human intervention in regional vegetation growth under climate change condition.

1. Introduction

An increasing vegetation activity has been reported in the northern hemisphere as a result of the global climate change (Nemani et al., 2003; Piao et al., 2006a; Xu et al., 2013). Many studies have investigated the climate change impact on the vegetation growth in China for the past decades (Peng et al., 2011; Piao et al., 2009). However, as vegetation growth is influenced by both environmental drivers (e.g., climate change) and human activities, the role of human played in the changing environment still remains less studied (Piao et al., 2015). During the past decades, the interaction between natural ecosystems and humans has intensified with increasing human productivity (Vitousek et al., 1997), understanding human impacts on vegetation change is one of the key challenges facing our research community as it seeks to solve current and future environmental problems (Falkowski et al., 2000).

Along with rapid economic growth, China is facing various environmental problems, including desertification, sandstorms, soil water erosion, and land degradation in dry northern regions (Liu and Diamond, 2005). Since 1978, China has launched a series of ecological restoration programs to mitigate these increasingly devastating environment problems, particularly in the 'Three North'

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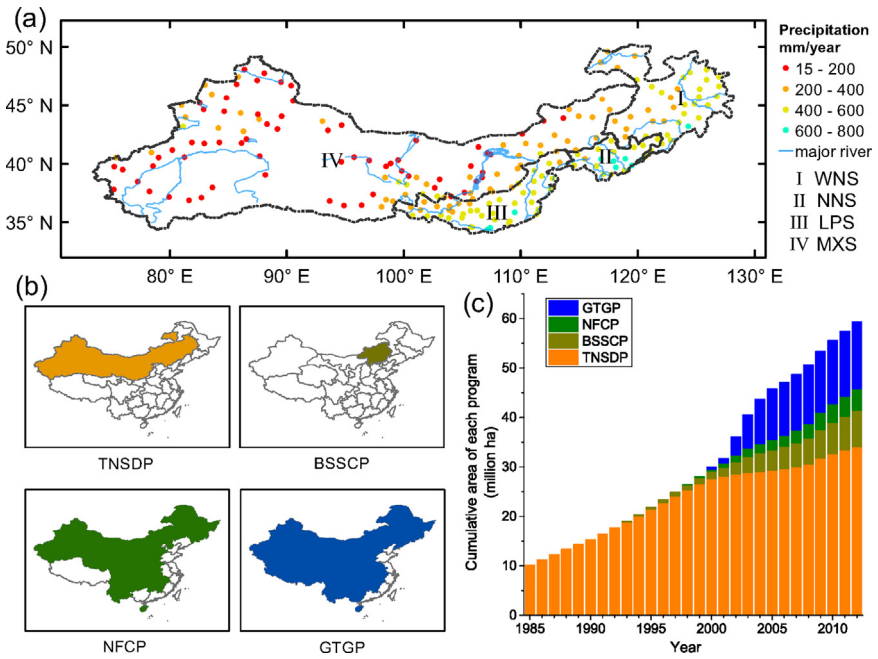

Fig. 1. (a) The location of the Three North region. The dots represent the annual mean precipitation from weather stations beginning in 1951. (b) Spatial extent of the four major ecological restoration programs in China since 1978. (c) Cumulative afforested area for each ecological restoration program from 1985 to 2012. The TNSDP began in 1978, but the annual planted area could not be obtained until 1986; therefore, the total planted area from 1978 to 1985 is shown for 1985. The GTGP and NFCP are countrywide restoration programs, and only provinces in our study area, i.e., Heilongjiang, Jilin, Liaoning, Inner Mongolia, Beijing, Tianjin, Hebei, Shanxi, Shaanxi, Ningxia, Gansu, Xinjiang and Qinghai are included in our statistics.

region (Northern part of China, see Fig. 1) (Yin and Yin, 2010). The 'Three North' Shelterbelt Development Program (TNSDP), which was initiated in 1978, is the largest afforestation program in the world (Li et al., 2012). Aimed at planting protective forests in arid and semi-arid areas, this program has been in place for more than three decades and will continue until 2050. The subsequent Beijing–Tianjin Sand Source Control Programs (BSSCP), which aims to protect against sandstorms through afforestation (Wu et al., 2013), the Natural Forest Conservation Program (NFCP), which aims at protecting natural forests through logging bans, and the Grain to Green Program (GTGP), which targets to convert farmland into forests and grasslands (Jia et al., 2014; Liu et al., 2014), have all been implemented in the 'Three North' region since 2000. Although enhanced vegetation had successfully combated the desertification and dust storms (Zhang et al., 2012; Fan et al., 2014; Piao et al., 2005; Tan and Li, 2015), sequenced carbon in both above ground biomass and soil (Deng et al., 2014; Song et al., 2014; Zhou et al., 2014), cooled down the surface temperature (Peng et al., 2014), and showed a positively feedback to the regional environment (Jiang et al., 2015; Zhang et al., 2014), the effectiveness of planting trees has been questioned by other researchers because of low precipitation in these dry regions (Cao, 2008; Cao et al., 2010; Ma et al., 2013; Sun et al., 2006). Cao (2008) even asserted that afforestation would lead to wind erosion but was rebutted by other scholars (Yang and Ci, 2008). Alongside with the global climate change, increasing drought frequency also offset the effectiveness of these programs (Wu et al., 2014). However, these studies often focused on a small region or used single dataset to evaluate the vegetation activity in a short period, the representative of these studies are limited due to the very large temporal and spatial span of the afforestation programs. A recent study by He et al. (2015) investigated the vegetation change using the satellite images in the 'Three North' region but focused more on the environmental effects. The overall contribution of multiple afforestation programs are still less investigated. How to discriminate the effects of climate change from human afforestation remains unclear.

In this study, we investigated the effectiveness of ecological restoration programs on vegetation activities in the 'Three North' region over the past three decades, using the satellite-derived normalized difference vegetation index (NDVI) from Global Inventory Modeling and Mapping Studies (GIMMS, 1982–2006), GIMMS third generation (GIMMS 3g, 1982–2012) and Moderate Resolution Imaging and Spectroradiometer (MODIS, 2000–2013) datasets. Specifically, we compared the NDVI trends based on multiple methods in two periods: 1982–2000 and 2000–2013. The breakpoint in 2000 was selected because the three later ecological restoration programs (GTGP, NFCP, and BSSCP) were implemented around 2000 following the TNSDP. Additionally, the MODIS NDVI dataset begins in 2000 and a breakpoint in 2000 was also found in analysis. To better understand the human intervention in our study area, the statistical data of afforestation area was obtained from the China Forestry Administration. The trend of the length of growing season (LGS) and two drought indices were also calculated to indicate the effect from climate change. The final conclusion was drawn through the comparison between two study periods and comparison with other parts of China.

2. Materials and methods

2.1. Study area

The 'Three North' region includes the northwestern, central north and northeastern part of China. The geographical extent ranges from 73°27′ E to 128°13′ E, 34°2′ N to 50°11′ N. It is constituted of 13 provinces and accounts for 42.4% of the total land area in China (Fig. 1a). The program region is further divided into four subregions including western Northeast China (WNS), northern North China (NNS), the Loess Plateau (LPS) and Mongolia–Xinjiang subregions (MXS). This partitioning was adopted from the project plans and were categorized by multiple characteristics, including soil properties, vegetation, climate, and program objectives