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Alpine grasslands response to climatic factors and anthropogenic activities on the Tibetan Plateau from 2000 to 2012

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ABSTRACT

To address pasture degradation on the Tibetan Plateau, the Chinese government has launched the ecological restoration project Grazing Withdrawal Program (GWP) since 2004. However, few studies have evaluated the impact of the GWP on grassland recovery. Based on monthly remote-sensed vegetation index and meteorological data from 2000 to 2012, we assessed the dynamics of annual net primary productivity (NPP) in alpine grasslands and quantified the effects of climatic factors and anthropogenic activities on NPP change by using the climate-driven NPP and the Carnegie-Ames-Stanford Approach (CASA) models. We found that there existed two distinct periods with an accelerating trend in NPP increase before and after 2004. The area percentage of NPP change induced by climatic factors increased from 41.55% to 83.75%, but that percentage caused by human activities decreased from 58.45% to 16.25% in the two periods of 2000–2004 and 2004–2012. Between 2000 and 2004, overgrazing reduced the positive effect of climate change on NPP variability, resulting in wide-scale grassland degradation. Between 2004 and 2012, grassland ecosystems gradually recovered from heavy grazing pressure, and the human-induced degradation was reversed after the implementation of the GWP. Thus, temperature and solar radiation became dominant factors in driving NPP change. Our results indicated that the GWP produces a significant positive effect on the restoration of alpine grasslands by controlling livestock numbers and decreasing grazing intensity. This study provides an objective assessment of restoration actuation on grassland ecosystems, having important implications for demonstrating the effectiveness of the GWP on grassland restoration on the Tibetan Plateau.

1. Introduction

Over the past few decades, Earth has undergone dramatic environmental changes, such as alterations in atmospheric composition, climate and land-use management (Stocker et al., 2013). These ongoing changes have affected a wide range of terrestrial ecosystems (Walther et al., 2002). Grasslands, one of the most extensive terrestrial ecosystems, comprise approximately 30% of the global land surface (Houghton, 1994) and display greater interannual variability in net primary productivity (NPP) than deserts and forests (Knapp and Smith, 2001). NPP is the net amount of carbon captured by vegetation through photosynthesis in a given period (Potter et al., 1999), influencing biodiversity, hydrological cycle, carbon budget, energy flow and ecosystem service provision (Crabtree et al., 2009; Haberl et al., 2007). Indeed, understanding the spatial and temporal variations in grassland NPP and its interaction with climate change and anthropogenic activities are critical for ecological monitoring and ecosystem management (Dirnböck et al., 2003; Scurlock et al., 2002).

The Tibetan Plateau (TP), the largest geomorphological unit on the Eurasian continent with an average elevation of more than 4000 m, is dubbed the "Third Pole" and is of immense importance to climates, water resources and ecosystems at local, regional and global scales (Immerzeel et al., 2010; Rajagopalan and Molnar, 2013). Mutual influences between vegetation and the atmosphere contribute to diverse terrestrial ecosystems, from subtropical rain forests in the southeast to alpine deserts in the northwest (Luo et al., 2004). Alpine grasslands cover more than 50% of the entire plateau area and supply the feed to a variety of livestock on which millions of people depend for their survival (Du et al., 2004). Mounting

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evidence supports that TP has shown an overall warming and wetting trend from 1961 to 2010 (Chen et al., 2013; Kleinherenbrink et al., 2015). It is supposed that increasing temperature will increase alpine grassland NPP due to easing thermal constraints on vegetation growth (Herzschuh et al., 2006; Kato et al., 2004; Xu et al., 2011). However, human activities may reverse the climate-induced trend in alpine grassland NPP on the TP (Akiyama and Kawamura, 2007). For example, Arthur et al. (2008) and Harris (2010) suggest that overstocking may be the principal culprit for wide-scale pasture degradation before 2000 in spite of a favorable thermal condition.

Ecological engineering aiming for the restoration of grassland ecosystems has been practiced in many countries (Céspedes-Payret et al., 2012; Conrad and Tischew, 2011; McLachlan and Knispel, 2005). To alleviate the impact of intense human activities on alpine grasslands on the TP, the Chinese government has developed a national conservation policy on payments for launching the ecological restoration project Grazing Withdrawal Program (GWP) to reduce grazing pressure on natural grasslands since 2004 (Cai et al., 2015; Mu et al., 2013). Recent studies demonstrate that alpine grasslands have transformed from a net carbon source into a net carbon sink since 2000 (Kato et al., 2004; Piao et al., 2012). However, whether climate change or the GWP that leads to substantial changes in alpine grasslands remains largely unknown (Fassnacht et al., 2015; Ma et al., 2013). In addition, a detailed investigation into the extent to which the GWP affects alpine grassland growth has not been systematically undertaken (Cai et al., 2015; Huang et al., 2013). Otherwise, it is essential to determine which climatic variables, such as temperature, precipitation and solar radiation, are primarily responsible for the dynamics of alpine grasslands (Churkina and Running, 1998; Nemani et al., 2003; Wang et al., 2002). Since alpine grasslands are responsive to climate change and human disturbance (Dirnböck et al., 2003), the TP is regarded as an ideal place to study the response of grassland ecosystems to climate variability and anthropogenic activities (Piao et al., 2006).

This paper analysed the spatiotemporal variations in alpine grassland NPP and established its relationships with climatic factors and human activities for the period of 2000–2012. Our primary goal was to differentiate climatic and anthropogenic influences on alpine grasslands and test the effectiveness of the GWP on the restoration of alpine grassland ecosystems. We used the climate-driven and remote-sensed NPP models to calculate potential and actual NPP (Potter et al., 1999; Zhou and Zhang, 1996). The human-induced NPP was estimated concerning the difference of potential and actual NPP (Haberl et al., 2007). By comparing the trend of the potential and human-induced NPP over time, we determined whether climatic factors or human activities that led to the variation of alpine grassland NPP (Chen et al., 2014). This study provides relevant information for pastoral management to minimize the risk of grassland degradation and desertification processes on the Tibetan Plateau.

2. Materials and methods

2.1. Study area

The Tibetan Plateau (25°54′–39°50′ N, 73°26′–104°30′E) is bordered by the Himalayan Mountains in the south, the Kunlun Range in the north, the Karakoram Range and the Pamirs in the west, and the Qilian Mountains in the northeast (Fig. 1). To the east and southeast, it is characterized by forest canyons and steeper terrains of the mountainous headwaters of the Mekong, Salween, and Yangtze Rivers. The TP encompasses most of the Tibet Autonomous Region, Qinghai and Sichuan Provinces, as well as some parts of the Xinjiang Uyghur Autonomous Region, Gansu and Yunnan Provinces, covering a total area of approximately 2.56×10^6 km^2. This region has a typical mountain plateau climate, with strong solar radiation, low air temperature and broad diurnal temperature range (Luo et al., 2004). According to long-term climatic records over the period of 1961–2010, mean annual temperature varies between −2.2 and 0 °C, with the lowest temperature of −13.5 °C in January and the highest of 9.7 °C in July. Mean annual precipitation is between 415 and 512 mm, 73% of which occurs from June to September. Mean annual sunshine duration ranges from 2730 to 2915 h, and average annual potential evapotranspiration is approximately 940 mm (Chen et al., 2013). Generally, the climate of TP has a gradient from warm and humid in the southeast to cold and arid in the northwest (Wang et al., 2002). The major land cover types include forests, shrublands, grasslands and croplands, which account for 6.14%, 3.48%, 55.63% and 0.58% of the plateau area, respectively (Fig. 1). Alpine grasslands are composed of alpine meadows, alpine steppes and swamp meadows. The growing season of alpine grasslands lasts from May to September (Gao et al., 2013). Livestock overstocking is pervasive, for animal husbandry is the backbone of the plateau's economy (Du et al., 2004).

2.2. Datasets

The Normalized Difference Vegetation Index (NDVI) dataset derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors was processed to simulate actual alpine grassland NPP by using the Carnegie–Ames–Stanford Approach (CASA)

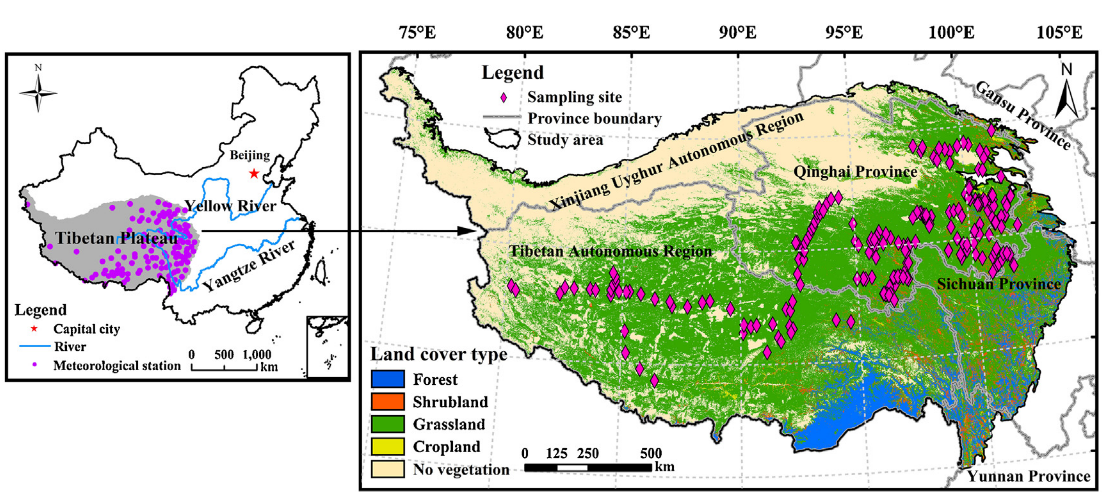

Fig. 1. The Location of the study area and spatial distributions of meteorological stations and land cover types on the Tibetan Plateau.