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Natural and anthropogenic influences on the spatiotemporal change of degraded meadows in southern Qinghai Province, West China: 1976–2015

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ABSTRACT

It is important to study the spatial variation of degraded meadows as it can shed light on the influence of natural settings on grassland degradation. Although attention has been paid to the spatiality of grassland degradation in the literature, nobody has assessed the impact of natural environment on meadow degradation quantitatively in relation to human impact. This study aims to overcome this deficiency by assessing the spatial variation of natural and anthropogenic variables influencing degradation of meadows in southern Qinghai Province of West China. After degraded meadows at six sites were mapped from satellite images, their changes over 1976–2015 were detected in ArcGIS. The obtained results indicate degraded meadows increased from 747.73 km^2 in 1976 to 900.01 km^2 (20.36%) by 2015. Spatially, there is a high variability among the six sites, with one site (Dari) contributing more than half of the total change alone. Annual temperature averaged over the preceding three years is the most crucial to change in degraded meadows (R^2 > 70%). However, the exact proportion of explanation varies widely from zero to 92% across the six sites, with most R^2 values falling between 33 and 51%. Such a large variability stems from the differential climate settings. Overall, climate influences on meadow degradation are much stronger than those of anthropogenic activity, namely, overgrazing defined as the discrepancy between the stocking rate and the meadows' theoretical carrying capacity. The latter played a noticeable role in meadow degradation only during certain temporal periods.

1. Introduction

Spatial settings affect not only the distribution of mountainous grasslands, but also their physiognomic and physiologic changes (Gartzia, Pérez-Cabello, Bueno, & Alados, 2016). Spatiality also influences how grassland vegetation adapts to climate change (Li et al., 2013), and abandonment of managed grasslands (Pazúr, Lieskovský, Feranec, & Otˇahelˇ, 2014). Moreover, it even affects the distribution of small mammals that can trigger and exasperate grassland degradation (Marston et al., 2014). So far, Fassnacht, Li, and Fritz (2015) have studied where the most severely degraded grassland was located on the Eastern Tibetan Plateau. However, the influence of natural settings on meadow degradation has not been assessed comparatively in relation to anthropogenic influence over a vast geographic region. This study aims to overcome this deficiency by focusing on the meadows distributed over tens of thousands of square kilometers on the Qinghai Plateau.

Swampy meadows atop the Qinghai-Tibetan Plateau in western China were formed around 2000 years ago (Han, Li, An, Li, & Qiao, 2016). These grassland ecosystems are extremely vulnerable and have shown signs of degradation. Meadow degradation refers to deterioration in meadow ecosystem functionality that is accompanied by declined grass coverage, reduced forage yield, and appearance and overgrowth of unpalatable and toxic species of grass (Li, 2007). The destruction of the hardy sod layer exposes the underlying soil to wind and water erosion (Li, Perry, & Brierley, 2016). In the worst case, this can lead to the formation of "black soil land" of infertile materials (Gao & Li, 2016), after the initial small barren patches coalescence to form larger patches (Ma, Lang, & Wang, 1999; Shang & Long, 2007). Degradation of swampy meadows, a precious grazing resource, in this environmentally fragile region threatens the livelihood of local pastoralists. Therefore, it is important to study the spatiality of degraded swampy meadows and how they have changed in different geographic areas over various periods. Such knowledge can help bring the issue under control most effectively in that more preventative efforts can be directed at those areas suffering from more severe degradation.

A common and effective means of studying meadow degradation is

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to use satellite images (An, Xu, Li, & Liang, 2013; Li, Wang, & Zhao, 2008; Liu & Wei, 2007). Medium resolution images such as Landsat Thematic Mapper (TM) are useful for mapping degraded meadows at the regional scale (Li & Yin, 2011). Landsat TM imagery is able to fulfill the mapping with sufficient details (Zhu, Chao, Yang, & Zhang, 2014). After degraded meadows have been mapped from multi-temporal images, their spatiotemporal patterns can be analyzed (Guo, Du, Xue, & Cai, 2012; Zhu et al., 2014). Ying, Wang, Yang, and Dong (2001) found that well-covered grassland in Maduo County, Qinghai Province suffered the largest decrease during 1990–2000. After analyzing the variation of Zoige wetland in Sichuan Province, Deng et al. (2010) found that degraded meadows expanded. However, degraded meadows in one township in the Three River Source Region decreased from 2007 to 2011 (Zhu et al., 2014). Frigid marshy meadows in the headwater zones of the Yangtze and the Yellow Rivers decreased by 2744.77 km^2 from 1986 to 2000 (Pan, Wang, & Wang, 2007). After changes in meadows and wetlands have been detected, they can be further analyzed in relation to environmental drivers (Monteiro, Fava, Hiltbrunner, Della Marianna, & Bocchi, 2011), agricultural land use (Zhang, Ma, & Fu, 2010), and climatic variables (Li et al., 2013).

In addition to climate variables, changes in degraded meadows on the Qinghai-Tibetan can be caused by anthropogenic variables. Anthropogenic forces take the form of overgrazing that reduces surface biomass and grass cover directly. Climate change and human activities such as overgrazing are the two important factors affecting the alpine grassland ecosystem (Chen et al., 2014; Du, Kawashima, Yonemura, Zhang, & Chen, 2004). Variability of temperature and solar radiation exasperated alpine grassland degradation (Gao et al., 2010). Overgrazing of grassland increases potential evapotranspiration and thereby promotes climate warming. Xu, Wang, and Zhang (2017) further quantified the influence of climate and human activities on aboveground net primary productivity in the source zone of the Yellow River, but not degradation of swampy meadows. Therefore, the relative influences of climate change and human activities on degraded meadows remain unknown.

This paper attempts to overcome the above deficiencies by studying the spatiotemporal change of degraded meadows at six sites in southern Qinghai Province during 1976–2015, and to assess the relative importance of climate and anthropogenic variables on the change. The specific aims are: (1) to assess the spatial variability of degraded meadows over different periods; (2) to quantitatively evaluate the importance of climate variables on the observed changes; and (3) to examine the impact of changed grazing practices on meadow degradation.

2. Material and method

2.1. Study area

Southern Qinghai Province located in the hinterland of the Qinghai-Tibet Plateau forms part of the Sanjiangyuan (the headwater region of the Yangtze, Yellow, and Lancang Rivers) region. Extending from 89°24′-102°27′E and 31°39′-37°10′N (Fig. 1), it is 395,000 km^2 in size with a population of 1,273,000 (Li et al., 2016). This mountainous region has a highly dissected terrain whose elevation ranges from 3335 to 6564 m a.s.l. This area has a perennially frigid weather with an annual temperature of −5.6 to −3.8 °C. In spite of its abundant water resource, this area still faces a negative hydrologic budget caused by strong evaporation registered at 730–1700 mm per annum. This region has a fragile meadow ecosystem that is highly sensitive to climate change. Some of the meadow resources have shown signs of degradation (Zhao, Wu, Li, & Li, 2013).

Degraded meadows at six severely affected sites were selected for study based on the consideration of accessibility. These sites lie in close proximity to human settlements. They are widely distributed across southern Qinghai, with more sites in the east than in the west (Fig. 1). Each site covers the most severely degraded area in each sub-region (e.g., county), and corresponds to one 1:50,000 map sheet (10′ by 15′) or 427 km^2 in size (Table 1). In total, the six sites encompass 2563.45 km^2. Grassland management in this region has gone through several regimes over the last half a century caused by changes in land use rights. In response to the emergence and worsening of degradation, considerable efforts have gone into the protection and rehabilitation of the degraded meadows. These changes and protection measures offer an excellent opportunity to study how natural and anthropogenic forces have affected the grassland conditions.

2.2. Data used

Three kinds of data were collected and used in this study, satellite images, climate data, and livestock population. Cloud-free Landsat MSS and TM images recorded in 1976/77, 1987, 1995, 2000, 2010, and 2015 were used due to frequent cloud contamination of images in other times. All the images were captured over the summer growing season when healthy meadows differed from degraded meadows maximally in their spectral reflectance. All the 2000, 2005, 2010 and 2015 images across all the six sites were acquired within the same year. However, it was impossible to select cloud-free images of the same year for all six sites in 1976/77, 1987 and 1995, so images recorded in the preceding or following year had to be used. The number of images collected for a given year varies widely. In general, it is easier to collect more images for recent years than for the earlier years. For instance, in 2005 a total of 12 images were collected, two for each site. The number of collected images dropped to 11 in 2000, with one site having only one image. The number of images decreased further to 8 for the 1990s. Only six images (one for each site) were collected for the 1980s and the 1970s periods. The collection of more images is desirable as they can help circumvent the cloud cover issue. The images are Landsat multispectral scanner (MSS) for the 1970s, TM and enhanced TM plus (ETM+), and SPOT images for the remaining periods. Apart from these medium resolution images (79–30 m), some very high resolution (< 4 m) images such as QuickBird, GF-1 and ZY-3 images were also collected. The MSS, TM and ETM+ data served as the primary data source for interpreting degraded meadows. The other types of images were used as reference or to facilitate interpretation and check interpretation accuracy.

The climate data used include daily precipitation and temperature recorded at six weather stations, each being closest to one study site (Table 1). These data span a period of 1961–2015. The record was complete for all the stations except 56045 (Gande) whose records between 1 May 1962 and 1 July 1975 were missing. This discontinuation of observation, however, is not problematic as the earliest satellite images available were recorded in 1976/7, still one year later. Livestock population data over the period of 1952–2015 were collected from the Statistical Yearbooks of the Guole Tibetan Autonomous Prefecture.

2.3. Photointerpretation

All the Landsat images were visually interpreted onscreen in ArcGIS using the standard color composite of bands 4 (red), 3 (green) and 2 (blue). Prior to formal indoor interpretation, reconnaissance visits were made to each of the six sites in December 2015. Ground pictures were taken to illustrate the general degradation situation and to prepare for subsequent indoor interpretation. Besides, the finer-resolution GF-1 and ZY-3 images were consulted extensively. Interpretation criteria include tone, texture, and location. In reality, degraded meadow is characterized by a reduced vegetative cover (< 40% of original vegetation juxtaposed with barren ground). On the satellite images, it manifested as patchy grassland with denuded patches intermixed with residual vegetation. Thus, it has a whitish red color of a medium texture. This color could be grayish if more denuded patches are present and if the soil contains a high moisture level. Geographically, all degraded meadows are located in the lower slopes or on the piedmonts adjoining a channel