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Comparison of ecosystem characteristics between degraded and intact alpine meadow in the Qinghai-Tibetan Plateau, China

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ABSTRACT

Climate warming and overgrazing are inducing degradation of the alpine meadow ecosystem on the Qinghai-Tibetan Plateau. The Plateau is an important pastoral region in China and controversy surrounds the estimated carbon release occurring in this region of the world. Nevertheless, little comprehensive research analyzing land degradation has been conducted involving multiple factors in this region. Using two years of observational data, we compared differences in air temperature and relative humidity, soil temperature and moisture, soil texture, soil bulk density, soil organic carbon, soil respiration, vegetation height, coverage and biodiversity, above- and below ground biomass between moderately degraded and intact alpine meadow, and analyzed their relationships. The results show that the main process occurring during degradation was that *Spenceria* species and weeds with deep roots and a relatively high ability to resist drought replaced *Kobresia* species that previously exhibited high vegetation coverage and low vegetation height in alpine meadows of the Qinghai-Tibetan Plateau; these changes fundamentally affected corresponding changes in soil physical, chemical and thermal characteristics of the meadows. The change of vegetation species is believed to be the result of drought in the shallow soil of this habitat and is controlled by temperature and precipitation. The results suggest that a good collocation between temperature and precipitation is beneficial to the development of the alpine meadows; conversely, a poor pairing of temperature and precipitation not only causes the degradation of alpine meadows, it can even continually intensify the process by creating a vicious circle involving changes in soil physical, chemical, thermal and hydraulic conditions.

1. Introduction

Land degradation caused by climate change and human activities has attracted extensive attention worldwide, especially in arid regions, because the reduced land productivity combined with the increasing human population result in poverty and famine; these conditions severely impede efforts to achieve sustainable development targets in the future (UNCCD, 1994, 2008; UNCSD, 2012). Land degradation occurs not only in arid and semi-arid regions, it occurs on the Qinghai-Tibetan Plateau at high elevations and in alpine climates in past 20 years (Yang et al., 2004; Xue et al., 2009; Harris, 2010; Wang et al., 2012; Zeng et al., 2013). Many types of evidence have proven that climate warming causes degradation of permafrost, the active layer, glaciers, lakes, and marshes (Cheng et al., 1993; Zhao et al., 2004; Pu et al., 2007; Wu and Zhang, 2008; Wu and Zhang, 2010; Yang et al., 2010; Cheng and Wu, 2007); these changes accordingly result in the degradation of alpine ecosystems by causing drought near the soil surface, the loss of soil organic matter, the release of soil carbon and nitrogen, a decrease of biomass, reduced biodiversity, and an increase in wind erosion, etc. (Wang et al., 2007a, 2011, 2012; Xue et al., 2009; Wen et al., 2010; Zeng et al., 2013). Some researchers have also pointed out that overgrazing can cause or intensify the degradation of alpine ecosystems by destroying vegetation coverage (Du, 2004; Shang and Long, 2005; Song et al., 2009), but climate warming is thought to be the main cause of land degradation in the Qinghai-Tibetan Plateau (Klein et al., 2007; Xue et al., 2009; Harris, 2010; Zeng et al., 2013).

The Qinghai-Tibetan Plateau is called “the third pole” because the mean elevation stands 4000 m above sea level and it covers

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an area of 2.0×10^6 km^2 (Harris, 2010; Cheng and Wu, 2007). The processes involved in the degradation of the alpine ecosystem in the Qinghai-Tibetan Plateau are very different from those in arid regions due to its uniquely cold environment and humid characteristics. The interaction of heat and water fluxes and their impact on the ecosystem may play important roles in the process of degradation (Wang et al., 2008; Hu et al., 2009). Few studies have been conducted in the Qinghai-Tibetan Plateau that were designed to understand the influence of the degraded alpine ecosystem on soil temperature, soil moisture, vegetation, soil nutrients or soil respiration (Cao et al., 2004; Klein et al., 2004; Yang et al., 2004; Wang et al., 2007b, 2012; Hu et al., 2009; Zeng et al., 2013). A comprehensive exploration involving a variety of environmental factors has not been conducted in the Qinghai-Tibetan Plateau. Those factors might include soil temperature, moisture, and texture, as well as soil organic matter and respiration. In addition, such a study might include the coverage, height, biomass and diversity of plants as well as the microclimate near the surface. It is also important to understand the cause and processes of land degradation in alpine ecosystems, and to forecast the changes occurring in alpine ecosystems with a warming climate and increasing human population.

Alpine meadows cover an area of 4800×10^4 ha in regions with elevations over 4200 m above sea level in the southern and eastern parts of the Qinghai-Tibetan Plateau and include 38% of all grassland area in the Plateau (DAHVGS and GSAHV, 1996). The annual average temperature in the alpine meadows is lower than 0 °C, but solar radiation can reach 670–837 kJ/cm^2 because these high elevation sites receive intense sunshine (DAHVGS and GSAHV, 1996). High temperatures during the day benefit photosynthesis of these forage plants while low temperature at night weakens their respiration rate and is still beneficial to the accumulation of aboveground biomass; therefore, alpine meadows serve as the main pasture grassland in the Plateau.

The high elevation and low temperatures make the alpine meadow ecosystem sensitive to climate warming, and hence easily degraded. However, recovering their ecological structure and biodiversity similar to that of the original conditions will require 45–60 years after alpine meadows become degraded (Jin et al., 2008). Degradation of alpine meadows can directly affect the carrying capacity of pastures and the livelihood of local people; this type of degradation is also presumed to indirectly affect regional climate, because alpine meadows store more soil organic carbon than alpine steppes (Yang et al., 2009a). A positive feedback may be present and increasing regional air temperatures as a result of the increasing release of carbon from degraded meadows (Wang et al., 2002; Xu et al., 2004; Schaefer et al., 2011).

Therefore, we selected moderately degraded alpine meadow (MDAM) and intact alpine meadow (IAM) as the research objects in an attempt to reveal the degradation mechanism of alpine meadow habitat and to understand how degraded alpine meadow develops and how MDAM affects the biogeochemical cycle, by comparing the differences in soil, plant and microclimate characteristics of MDAM and IAM.

2. Materials and methods

2.1. Site description

The processes of weathering and the development of soil in alpine meadows of the Qinghai-Tibetan Plateau occur very slowly because of the high elevation and cold climate. Therefore, the soil layer with abundant organic matter averages only 30 cm thick, although it can reach 50 cm in some regions. Under the soil layer, coarse particles make up the largest percentage of substrate, which results in rapid water conductivity and weak water holding capacity. In the surface layer of soil, dense, compact and flexible roots compose the 0–10 cm turf layer, which can protect fine soil particles from wind and water erosion. However, the yearly and daily process of freeze/thaw in soil can lead a loss of the turf layer, especially in some regions with steep slopes. Without the protecting turf, fine particles in the surface layer are easily eroded by the strong winds predominant in the Qinghai-Tibetan Plateau; then the underlying coarse particles become exposed and alpine meadow is replaced by the bare land covered by sand and gravel. Climate warming and overgrazing can exacerbate the soil freeze/thaw process, and this accelerates land degradation.

In this study, we did not select bare land or the end stage of degraded alpine meadow, but studied alpine meadow with a moderate level of degradation for three reasons. First, alpine meadow with a medium level of degradation occupies a large area of the total grassland in the Qinghai-Tibetan Plateau. Second, bare land cannot be restored quickly or even in hundreds of years because of the extremely cold climate; alpine meadow with a moderate level of degradation can be restored in a short period of time under rational and eco-friendly management. Third, understanding the intermediate processes of alpine meadow degradation will be helpful for revealing the mechanisms causing degradation and provide land managers with the support they need to prevent the further degradation. The intact alpine meadow (IAM) selected for this study forms part of the typical Alpine Meadow typically found in the Qinghai-Tibetan Plateau with >95% vegetation coverage that averages 5 cm tall. The moderately degraded alpine meadow (MDAM) selected here is an area of typical moderately degraded land commonly found in the Qinghai-Tibetan Plateau with about 50–70% vegetation coverage in an area covered where gravel and sand covered 30–50% of the surface.

The experimental site is near the source of the Yangtze River in an inland area of the Qinghai-Tibetan Plateau at 92°55′E, 34°49′N an elevation of 4635 m a.s.l. (Fig. 1). Based on ten recent years (2002–2011) of metrological data from the Beiluhe Weather Station, the mean annual, mean annual maximum, and mean annual minimum air temperatures are −3.8 °C, 19.2 °C, and −27.9 °C, respectively. The mean annual precipitation is 290.9 mm with over 95% falling during the warm growing season from April to October; the mean annual evaporation is 1316.9 mm, mean annual relative humidity is 57%, and mean annual wind velocity is 4.1 m s^{-1}. The site is grazed during the summer and dominated by alpine meadow vegetation such as *Kobresia capillifolia*, *Kobresia pygmaea*, *Carex moorcroftii* with a mean height of 5 cm in the undisturbed ecosystem.

Two 2 m × 2 m plots of MDAM and three 2 m × 2 m plots of IAM, all spaces more than 4 m apart were selected at the experimental site with a distance of about 50 m between the MDAM and IAM blocks. Continuous observation and measurement on soil, plant and microclimate characteristics were conducted in these five plots in 2011 and 2012.

2.2. Temperature and moisture content of air and soil measurements

In each plot, air temperature (T_{air}) and relative humidity (RH_{air}) at 20 cm above the surface were measured by Model HMP45C Vaisala Temperature and Relative Humidity Probes (Campbell Scientific, Logan, UT, USA). Ground surface temperatures (T_{soil_surf}) were measured by SI-111 Apogee 20 Infrared Radiometers (Campbell Scientific, Logan, UT, USA). Soil temperature (T_{soil}) was measured at depths of 20, 40, 60 and 100 cm by Model 109SS-L Temperature Probes (Campbell Scientific, Logan, UT, USA) with an endurance range of −40–100 °C. Soil moisture content (M_{soil})