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Vegetation distribution along mountain environmental gradient predicts shifts in plant community response to climate change in alpine meadow on the Tibetan Plateau

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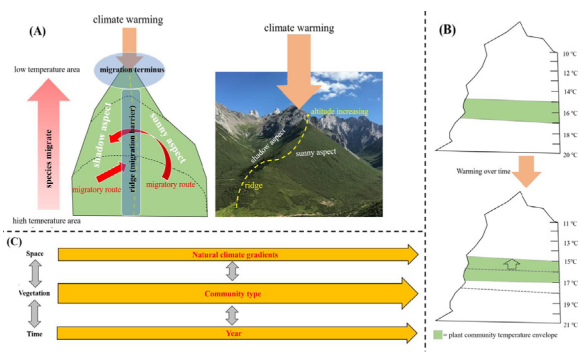
HIGHLIGHTS

- Using "space-for-time substitution" to study plant responses to climate warming
- Plant diversity significantly decreases with climate warming.
- Community biomass remains unchanged with climate warming.
- The change of community species composition is more dependent on the migratory ability of broadleaf forbs.

GRAPHICAL ABSTRACT



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ABSTRACT

Plants are particularly sensitive to climate change in alpine ecosystem of the Tibetan Plateau. The various mountain micro-climates provide a natural gradient for space-for-time substitution research that plant responses to climate change. In this study, we surveyed the plant community in term of species composition, diversity and biomass across 189 sites on a hill of the Tibetan Plateau and analysed the individual and integrated effects of soil temperature and moisture on the plant community. The results showed that, at the quadrat scale, there were decrease in richness of 1.08 species for every 1 °C increase in soil temperature and 3.56 species for every 10% decrease in soil moisture. The integrated effects of increasing soil temperature and decreasing moisture are expected to lead to a rapid decrease in species richness. Biomass had no significant correlation with soil temperature but significantly decreased with soil moisture decreasing ($p < 0.01$). Biomass would decrease when soil moisture was below 20%, no matter how the change of soil temperature. We also found that gramineae and perennial forbs were sensitive to climate change. With soil temperature increased, the proportion of gramineae increased, whereas the proportion of perennial forbs decreased. The integrated effects of soil temperature increasing and moisture decreasing caused a shift from sedge-controlled to gramineae-controlled communities in alpine meadow. This study not only enhances our understanding of mountain plant community dynamics under climate change, but also predicts the shift of vegetation response to climate change on high-elevation alpine meadow.

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1. Introduction

Global climate change is one of the most serious challenges facing humanity (IPCC, 2007; Seddon et al., 2016). The average global temperature has increased by 0.065 °C per decade since 1880, accompanied by significant changes in precipitation patterns (Ma et al., 2017). These rapid climate changes, unprecedented in human history, are likely to profoundly affect the functioning of terrestrial ecosystems (Garcia et al., 2014; Seddon et al., 2016). Climate change has been demonstrated to influence community structure and species interactions, which could potentially translate into changes in community biomass production, species diversity and species composition (Yang et al., 2011; Baldwin et al., 2014; Rudgers et al., 2014). Predicting and understanding the quantitative effects of global change on plant communities remains a key challenge, especially for the regions where long-term ecological data is scarce (Lester et al., 2014).

The Tibetan Plateau, the largest and highest plateau in the world, is known as the "third pole" of the Earth, and it is highly sensitive to climate change (Liu et al., 2018). Because, the current species composition in alpine region is the result of on-going speciation processes by adapting climate. High altitude restricted species are also the most threatened due to the limited areas into which they can migrate under conditions of increasing temperatures (Madriñán et al., 2013). Over the past six decades, the rate of climate warming on the Tibetan Plateau has been more than twice the global average (Chen et al., 2013; Ma et al., 2017), along with changes in precipitation patterns (Shen et al., 2015). The alpine meadow is the main ecosystem type on the Tibetan Plateau. Climate change is an important topic in ecological research in the sensitive alpine meadow ecosystem of the Tibetan Plateau. Both natural climate gradient studies and experimental climate manipulations have been performed to quantify effects of climate change on alpine ecosystems (Chen et al., 2013). Dunne et al. (2004) also integrated experimental/gradient research to study climate-ecosystem interaction. There are a few historical data in the long-term manipulation studies, accompanied by equally long-term field vegetation censusing to study the response of vegetation under climate change on the Tibetan Plateau (Chen et al., 2013; Ma et al., 2017; Liu et al., 2018). Short-term climate manipulation experiments in filed have frequently been used to simulate the effects of climate change on plant composition, species diversity, biomass, biochemical cycle and litter decomposition of plant communities in the alpine meadow in this region (Chen et al., 2013; Shi et al., 2014; Shen et al., 2015; Liu et al., 2018). Some studies have indicated that plant community biomass and species diversity show variable responses, involving decreases, increases, or no change, to climate change in arctic and alpine regions (Klein et al., 2007; Post and Pedersen, 2008; Wang et al., 2012). Notably, the effects of climate warming and altered precipitation on plant community properties, including plant composition, species diversity, biomass, and succession direction, may not be independent of each other. However, initial community responses to experimental climate change may greatly differ from the responses observed when the manipulation is sustained over longer periods (Dunne et al., 2004; Harte et al., 2015). There is not enough time for plants to adjust and adapt in the short experimental period, as a result, making it difficult to truly reflect the long-term responses of plants to climate change (Travis and Hester, 2005; Lester et al., 2014).

Within some studies, soil temperature and moisture gradients have been mainly used to describe climate change, whether focusing on natural climate gradients or climate manipulations (Shi et al., 2014; Harte et al., 2015; Little et al., 2016; Ma et al., 2017; Panetta et al., 2018). Space-for-time substitutions, also known as ergodic gradient studies, are often used to develop quantitative predictions of ecological responses to climate change (Travis and Hester, 2005; Lester et al., 2014). Natural gradient studies have been applied to a wide range of ecological variables in the past, often with great success (Dunne et al., 2004; Travis and Hester, 2005; Lester et al., 2014). The Tibetan Plateau is a large mountain system consisting of contiguous mountains and hills and the long-term ecological data is scarce. The vegetation in plateau mountains is compressed into a smaller spatial scale. The mountain slope and altitude create a distinct gradient of the soil temperature and moisture, which provide the gradient studies of plant responses global climate change using space-for-time substitution (Cortés and Wheeler, 2018). The distribution of vegetation along a temperature and moisture gradient under natural conditions is the result of plant adjustment and adaption to the micro-climate over a very long period of time, therefore, it can truly reflect the long-term adaptation of plants to the climate. Thus, space-for-time substitutions use multiple sites across a mountain environmental gradient to predict a temporal trajectory in ecological change that is assumed to be causally related to changes across the gradient (Dunne et al., 2004).

In our study, we selected a representative alpine meadow on a hill located in the north-eastern Tibetan Plateau and studied the changes in plant community along temperature and moisture gradients at the hill scale over several hundred hectares. The value of predictions from gradient analyses at hill scale depends on the fact that the plant community will track the changing climate over time in the same way that the plant community now varies with microclimate variability over space (Dunne et al., 2004; Travis and Hester, 2005). Although we adopt the space-for-time assumption in this work, we are aware that the time scales for establishment of vegetation patterns along spatial gradients may be much longer than the time scale governing vegetation responses to anthropogenic global warming. Blois et al. (2013) also concluded that predictions relying on space-for-time substitution were ~72% as accurate as "time-for-time" predictions. The largest soil temperature difference in the surface layer (0–30 cm) on the hill was around 10 °C. The Tibetan Plateau has experienced more rapid climate warming with 0.2 °C per decade over the past 50 years (Chen et al., 2013; Ma et al., 2017). Likewise, in the past 65 years (1951–2016), there has also been an average temperature increase of 0.23 °C per decade in this study area. Therefore, it takes approximately 500 years to increase the average temperature by 10 °C. The trend of changes in the species composition, diversity and biomass of the alpine meadow community were quantitatively predicted under the individual and integrated effects of soil temperature and moisture in this study. Besides, the possible succession directions of the community under climate change were predicted. Our purpose was to understand how climate change would affect the changes in alpine meadow plant community and the potential adaptive mechanisms of the plant community to climate change on the Tibetan Plateau.

2. Materials and methods

2.1. Study area

The study area is located on the north-eastern Tibetan Plateau (37°09′–37°14′ N, 102°40′–102°47′ E). It is part of the Qilian Mountain in Tianzhu Tibetan Autonomous County in Gansu Province, China. Based on a systematic survey of mountain vegetation and topography in the study area, we selected the pasture of an alpine meadow on a hill with an altitude of 2850–3200 m (Fig. 1A). It is a winter grazing pasture and the pasture area is 150 hm^2. The length from the bottom to the summit of the mountain along the ridgeline is 3.2 km. In the past 65 years (1951–2016), there has been an average annual temperature increase of 0.23 °C per decade in this area, but no trend of significant changes was observed in the average annual precipitation during the past 65 years (Fig. 1B). This area is an ideal place to study the effects of climate change on vegetation. For the past 5 years, the average annual temperature was 0.83 °C, and the cumulative temperature of growing degree days (GDD; sum of daily mean temperatures above 5 °C) were 1097 °C. The average annual precipitation was 463 mm and was mainly concentrated in July–September, accounting for 76% of the total annual precipitation. The annual potential evaporation was 1592 mm. The mountain is also part of the seasonal snowfall region, and all the snow melts within a few days. The plant growth period lasted 120–140 d.