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# Grazing effect on growing season ecosystem respiration and its temperature sensitivity in alpine grasslands along a large altitudinal gradient on the central Tibetan Plateau

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ABSTRACT

Little is known about how livestock grazing could modify altitudinal trends in seasonal ecosystem respiration (Re) and its temperature sensitivity ($Q_{10}$). We aim to test the hypotheses that the altitudinal grazing effect on growing-season Re is well correlated with the grazing-induced change of plant biomass, and grazing exclusion tends to reduce the $Q_{10}$ of Re along altitudes. We conducted a 7-year altitudinal grazing exclusion experiment across lower and upper limits of alpine meadows (4400–5100 m) on the central Tibetan Plateau. Plant biomass, Re and related environmental factors were observed across fenced and grazed treatments at each of 6 altitudes during the growing seasons of 2012–2013. The stimulations of above- and belowground biomass due to grazing exclusion decreased with increasing altitude, which were positively correlated with the change of Re. The $Q_{10}$ of seasonal Re generally increased with increasing altitude, but tended to decrease under grazing exclusion. Soil organic carbon did not have a direct effect on the altitudinal variation of Re. Our data supported the hypotheses, suggesting that plant biomass change could be served as an integrated indicator for spatiotemporal variations of Re. Grazing exclusion might be a promising measure to reduce the temperature sensitivity of Re.



## 1. Introduction

Ecosystem respiration (Re), consisting of plant autotrophic and soil heterotrophic respirations, is a major carbon flux from terrestrial ecosystems to the atmosphere (Cox et al., 2000; Davidson et al., 2006; Chen et al., 2014), which is mainly controlled by temperature and soil moisture (Lloyd and Taylor, 1994; Saito et al., 2009) as well as plant growth and substrate availability (Wan and Luo, 2003; Schmitt et al., 2013). It is expected that Re would be highly sensitive to climate change. In grasslands, however, it is still difficult to clarify the warming impact on Re because the controls on Re can be confounded by the presence of livestock (Wan and Luo, 2003; Asner et al., 2004; Wang and Fang, 2009; Tanentzap and Coomes, 2012). Grassland ecosystems contain high belowground biomass and soil organic carbon stocks, and are currently experiencing rapid climate and land use changes (Saito et al., 2009; Chen et al., 2013; Ernakovich et al., 2014). In conjunction with a rapid warming, overgrazing may result in an imbalance of photosynthesis and respiration, which can strongly affect the global carbon cycles (Cox et al., 2000; Davidson et al., 2006). As the grazing effects on Re are very difficult to distinguish from the influences of other biotic and abiotic factors, it is still debatable whether livestock grazing could have a significant impact on net carbon budget and carbon cycles in grassland ecosystems (Wang and Fang, 2009; Sjögersten et al., 2012). Thus, quantifying the grazing effects on Re is the key to assessing the vulnerability of grassland ecosystems to global warming (IPCC, 2014). Such knowledge is also important to provide a scientific basis for effective ecosystem management in adapting to future climate change.

The Tibetan Plateau (TP) has experienced a more rapid warming than other regions in the world (Liu and Chen, 2000; Yang et al., 2014; Pepin et al., 2015). How the world's highest and largest alpine grasslands respond to the warming has caused the extensive concern in recent years (Babel et al., 2014). Since livestock husbandry is the main land use on the TP, the disturbance of grazing activity may also play an important role in the regional biogeochemical cycles (Chen et al., 2013). With increasing human and livestock populations during recent decades, the long history of

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heavy grazing has caused severe grassland degradation or even desertification (Song et al., 2009; Chen et al., 2014). To protect grassland degradation on the TP, local governments have carried out the project of restoring pasturage to natural grassland since 2008, in which grazing exclusion through mesh fencing to create a large-scale enclosure has been widely applied as a simple and effective method. Previous studies have indicated that the practice of grazing exclusion has significantly improved vegetation and soil properties in alpine grasslands (Wu et al., 2010; Shi et al., 2013). However, little is known about how grazing exclusion could modify altitudinal trends in Re and its temperature sensitivity. Such knowledge is important to evaluate benefits of the ecological project with general concerns on adaptation to climate change.

Generally, livestock grazing may reduce Re by reducing aboveground biomass and litterfall (Wan and Luo, 2003; Cao et al., 2004; Kang et al., 2013) and/or enhance Re through increased soil temperature (Wei et al., 2012; Li et al., 2013b) and fertilization effects of grazer urine and dung on plant growth and microbial activity (Augustine et al., 2003; Bardgett and Wardle, 2003). The temperature sensitivity ($Q_{10}$) of Re may be also regulated by changes in carbon substrate availability (Yuste et al., 2004; Davidson et al., 2006; Gershenson et al., 2009), which would be subjected to increased livestock grazing pressures in grassland ecosystems. The net effect of grazing on Re should be attributed to the balance of negative and positive effects. Many experiments have examined the Re response to grazing, but contradictory conclusions were reached (Wang and Fang, 2009; Lin et al., 2011; Sjögersten et al., 2012). It is still debated how livestock grazing could modify the $Q_{10}$ of Re, with contradictory results that $Q_{10}$ may decrease (Cao et al., 2004; Lin et al., 2011; Chen et al., 2015) or increase (Paz-Ferreiro et al., 2012; Wei et al., 2012) under the disturbance of grazing activity. Such discrepancies between results may depend on altitudinal variations of grazing intensity and history (Cao et al., 2004; Wang and Fang, 2009; Peichl et al., 2012). However, previous studies are mainly conducted within a site, with a distinct lack of data on Re and its response to grazing along a large altitudinal gradient.

In alpine grasslands, pasture for sheep and yaks is a common land use type (Fu et al., 2012). Vegetation production and grazing intensity as well as climatic and soil factors usually co-vary with altitudes (Ohtsuka et al., 2008; Li et al., 2013a; Wang et al., 2013). It has been observed that seasonal and spatial variations of respiration are well explained by plant biomass (Hirota et al., 2009; Geng et al., 2012; Jiang et al., 2013), and plants at lower altitudes often experience higher grazing intensity (Li et al., 2013a; Wang et al., 2013). The altitudinal pattern of vegetation biomass may change as livestock directly consumes the aboveground parts of plants, which may be also feedback to Re. However, it is still difficult to identify the grazing intensity and its effect on Re along an altitudinal gradient because previous observations are mainly confined to within-site experiments (Cao et al., 2004; Lin et al., 2011; Wei et al., 2012; Chen et al., 2015). The long-term grazing exclusion experiment along a large altitudinal gradient would be helpful to understand the relative effects of grazing and climatic factors on altitudinal trends in Re and its temperature sensitivity. To the best of our knowledge, however, such experimental data are lack in the literature. In this study, we hypothesize that the altitudinal grazing effect on ecosystem respiration (Re) is well correlated with the grazing-induced change of plant biomass, and grazing exclusion tends to reduce temperature sensitivity ($Q_{10}$) of Re along altitudes.

To test the hypotheses, we conducted an altitudinal grazing exclusion experiment across lower and upper limits of alpine meadows (4400–5100 m, started since 2006) along the south-facing slope of Nyaiqentanglha Mountains on the central TP. Seasonal ecosystem respiration rate (Re), vegetation biomass and relevant environmental factors were observed across fenced and grazed treatments at each of 6 altitudes during the growing seasons of 2012–2013. Our objectives were to: (1) study the seasonal and altitudinal patterns of Re and their driving factors, (2) quantify the grazing effect on the variation of Re across altitudes and (3) investigate altitudinal trends in temperature sensitivity ($Q_{10}$) of Re under fencing and grazing treatments.

## 2. Methods

### 2.1. Study sites

On the central TP, Nyaiqentanglha Mountains lie in the zonal ecotone between alpine *Stipa* steppe and alpine *Kobresia* meadow. The semi-arid climate is characterized by Indian monsoon in summer and the westerlies in winter. According to meteorological observations from 1963 to 2010 at Damxung station (4288 m, ca. 4 km from our study site), annual precipitation was 479 mm and annual mean air temperatures was 1.8 °C. During 1963–2010, annual mean air temperature has increased by 1.6 °C, but annual precipitation varies with timescales, with a decreasing trend from 1963 to 1990 and an increasing trend from 1991 to 2010 (Wang et al., 2013). Along the south-facing slope (30°30′–30°32′ N, 91°03′ E), vegetation types changed from the steppe-meadow dominated by *Stipa capillacea* at 4400–4650 m, to the typical meadow dominated by *Kobresia pygmaea* at 4700–5100 m. Other coexisting species mainly included *Androsace tapete*, *Arenaria lancangensis*, *Potentilla nivea*, *Carex atrofusca* etc. At community level, the canopy height was generally less than 10 cm with a slightly decreasing trend with increasing altitude. Pasture for domestic yaks and sheep is the main land-use type in this region. The stock rate would be higher at lower altitudes because the most severely degraded grasslands were found at 4300–4500 m. In August 2005, 6 HOBO weather stations (Onset Inc., Bourne, MA, USA) were set up at 4400 m, 4500 m, 4650 m, 4800 m, 4950 m, and 5100 m along the slope. Air temperature (1.5 m aboveground), precipitation, and soil temperature and moisture (−5 cm in soil) were recorded by the HOBO data logger at 30-min intervals. In May 2006, six 20 m × 20 m fenced plots were set nearby the HOBO weather stations at each of the 6 altitudes, in which livestock grazing has been excluded for the whole year since 2006. Detailed information is found in Wang et al. (2013).

### 2.2. Measurements of plant biomass and soil organic carbon

Within each of the 6 fenced plots, we set up five quadrats (0.5 m × 0.5 m) at 3-m intervals along the contour line. We additionally set up five unfenced (grazed) quadrats along the contour line at a distance of 5 m from the upper edge of the fenced plot. In total, 60 fenced and grazed quadrats were sampled at six altitudes from 4400 to 5100 m. We harvested maximum aboveground biomass (AGB) in each quadrat in mid-August of 2012 and 2013, which was dried in an oven at 65 °C for 48 h. We measured belowground biomass (BGB) by collecting five soil cores in each quadrat (diameter: 5.0 cm; depth: 30 cm). BGB samples were washed off the soil by a 2-mm sieve and dried at 65 °C for 48 h. We collected top soil samples (0–10 cm in depth) with a soil auger (diameter: 3.0 cm) from each quadrat in mid-August of 2012 and 2013. After removal of any visible roots, soil samples were air-dried at room temperature and sieved for measuring soil organic carbon (SOC) according to the Walkley and Black dichromate oxidation method (Nelson and Sommers, 1982).

### 2.3. Measurements of seasonal ecosystem respiration rate (Re)

Within each of the 6 fenced plots, five polyvinyl chloride collars (diameter: 20 cm; height: 5 cm) were set at 3-m intervals along the contour line (nearby the five biomass harvesting quadrats