Ecological Indicators 93 (2018) 555–561

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Effects of plant functional diversity induced by grazing and soil properties on above- and belowground biomass in a semiarid grassland

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A R T I C L E I N F O

Keywords:
Ecosystem function
Functional trait
Grassland degradation
Structural equation modelling
Horqin grassland

A B S T R A C T

The trait-based plant functional diversity is associated with ecosystem functioning. However, few studies show the effects of plant functional diversity induced by grazing disturbance and environmental changes on aboveground plant biomass (AGB) and belowground root biomass (BGB) in semiarid grasslands. We examined the effects of long-term grazing on plant functional diversity across four grassland types (meadow, steppe, scattered tree grassland and sandy grassland) in Horqin grassland, Northern China. The structural equation model (SEM) was used to evaluate the direct or indirect effects of long-term grazing, soil properties and functional diversity reflected by the single-trait (community-weighted mean) and multi-trait (functional dispersion, FDis) on AGB and BGB across four grassland types. We found that long-term grazing significantly decreased plant height and FDis, while the responses of leaf traits to grazing differed among four grassland types. The correlation analyses showed that AGB and BGB were negatively associated with grazing and positively associated with plant height, FDis, soil carbon (C) and nitrogen (N). The SEM results indicated that AGB was directly affected by grazing, soil N, plant height and perennial richness, and BGB was directly affected by grazing, soil N, soil water content and elevation. Grazing and soil N also indirectly affected AGB through their effects on plant height and FDis. Effect of plant height on aboveground plant biomass was direct rather than indirect, while FDis acted indirectly through its effect on perennial richness, thereby lending more support to the mass ratio hypothesis. Our results clearly highlight the critical role of plant functional diversity induced by grazing and soil properties in affecting AGB in a semiarid grassland ecosystem. So, we recommend considering the linkages of plant functional diversity with ecosystem function in assessing the effects of grazing and soil changes on grassland ecosystems.

1. Introduction

Grazing is one of the main drivers of plant community structure and ecosystem function in arid and semiarid grassland ecosystems (Zheng et al., 2010; Wu et al., 2015; Eldridge et al., 2016; Zhang et al., 2017a). Long-term grazing or overgrazing is thought to be an important cause for the grassland degradation (Bai et al., 2012; Li et al., 2011). Long-term grazing can affect plant community compositions by altering the plant functional traits (Niu et al., 2015). Long-term grazing can also result in the greater changes in soil properties (Medina-Roldan et al., 2012; Deng et al., 2017), and changes in soils are likely to induce the coordinate responses of different plant functional traits (Jager et al., 2015). A number of studies have revealed that the trait-based plant functional diversity has a strong effect on plant community assembly and ecosystem function (Lavorel, 2013; Milcu et al., 2016). So, it is essential to explore the effects of plant functional diversity controlled by long-term grazing and related soil properties on ecosystem functioning, thus giving guidelines for the improvement of grassland management practices.

Numerous studies have reported that long-term grazing decreases the species richness and community biomass in semiarid grasslands (Bai et al., 2012; Zhang et al., 2004). Grazing-induced habitat changes affect plant community compositions by reducing plant diversity or altering dominant species (Kohyani et al., 2011), and changes in community compositions have the direct impacts on aboveground biomass (Eldridge et al., 2016; Milcu et al., 2016). Aboveground plant biomass (AGB) and belowground root biomass (BGB) responses to long-term grazing are very important for understanding the effects of grazing regime on ecosystem function (Zeng et al., 2015). In many grassland ecosystems, there is more biomass in belowground than aboveground

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https://doi.org/10.1016/j.ecolind.2018.05.032
Received 12 January 2018; Received in revised form 17 April 2018; Accepted 15 May 2018
1470-160X/

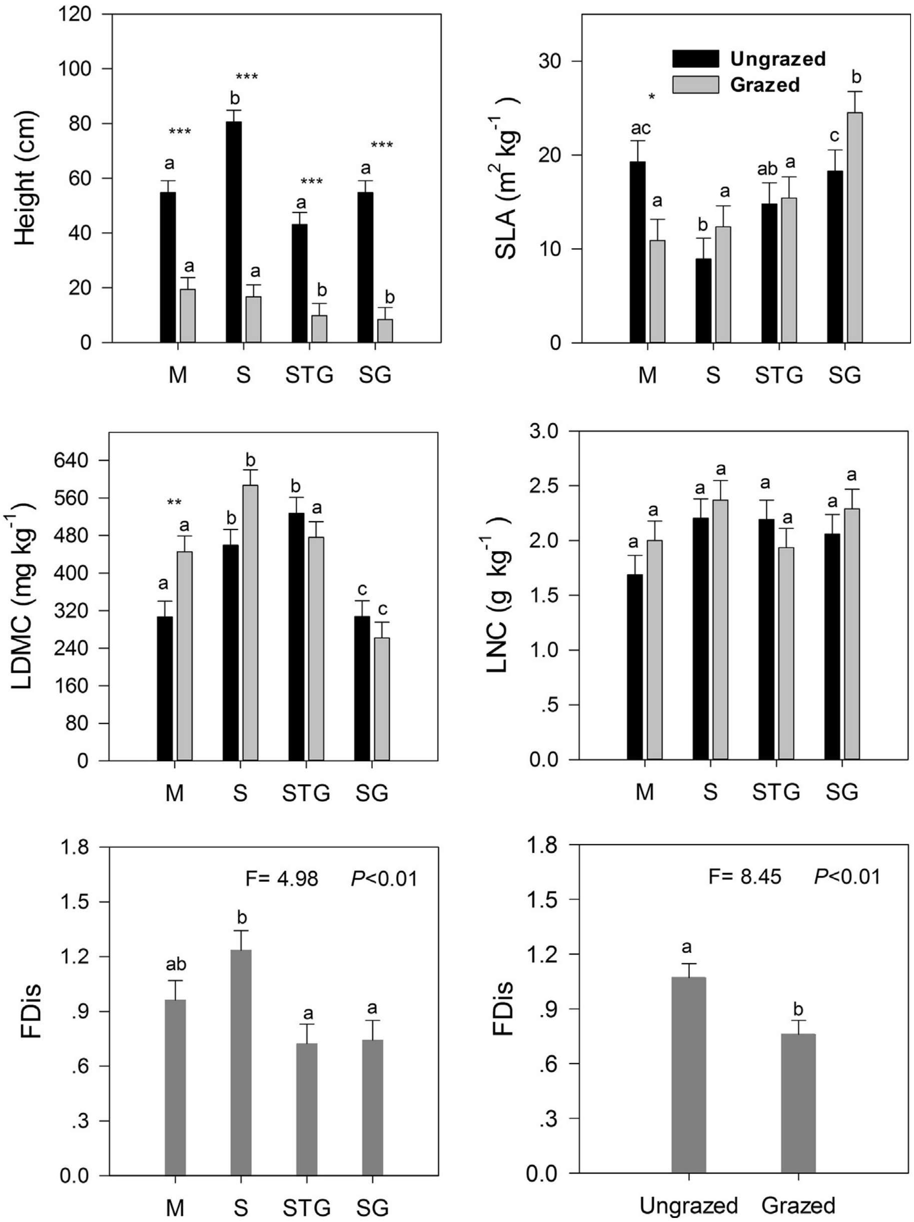

Fig. 1. Effects of grazing on plant functional diversity in different grasslands. M, meadow; S, steppe; STG, Sparse tree grassland; SG, Sandy grassland. The statistical differences among different grasslands are indicated by different letters at the level of $P < 0.05$. The statistical significance between ungrazed and grazed grasslands is labelled as $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$.

(Gill et al., 2002). However, few studies have examined the effects of long-term grazing on the linkages of community compositions with root biomass in grassland ecosystems.

Functional traits that illustrate the growth and photosynthetic rates of plants are subjected to long-term grazing disturbance in natural grasslands (Niu et al., 2015; Zheng et al., 2010). Plants that avoid grazing tend to have the adaptive traits with the low height and specific leaf area (SLA) and the high leaf dry matter content (LDMC) (Diaz et al., 2001; Wardle et al., 1998). The trait-based plant functional diversity can better reveal how biodiversity affects ecosystem function (Demenois et al., 2018; Schaller et al., 2016; Zheng et al., 2010). Two important hypotheses have demonstrated how plant functional diversity affects ecosystem function. The mass ratio hypothesis reflects how the functional trait (community-weighted mean, CWM) of the most abundant species impacts ecosystem function (Grime, 1998). The niche complementarity hypothesis reflects the impacts of the multi-trait index (functional dispersion, FDis) on ecosystem function through the complementary use of resources (Gamfeldt et al., 2008; Tilman, 1997). Therefore, to examine the relative importance of the CWM and FDis controlled by grazing in determining AGB and BGB is beneficial to understand the mechanism of how grazing exerts impact on ecosystem function through its impact on community structure and compositions.

Soil properties can be directly or indirectly altered by the long-term grazing in grassland ecosystems (Li et al., 2011; Medina-Roldan et al., 2012). Soil organic carbon (C) or nitrogen (N) often presents the positive (Derner et al., 2006) or negative (Eldridge et al., 2017) responses to long-term grazing. Long-term grazing strongly affects soil C and N loss or accumulation by altering community compositions (Olofsson et al., 2001), changing the tissue nitrogen content (Baron et al., 2002) and depositing decomposable feces (Rossignol et al., 2006). Long-term grazing greatly decreases soil C and N (Su et al., 2005) and soil moisture (Gan et al., 2012; Wang et al., 2015) in semiarid grasslands. Soil N and water contents are considered as the major factors in determining community compositions, species diversity, AGB and BGB (He et al.,