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Interactive effects of large herbivores and plant diversity on insect abundance in a meadow steppe in China

Hui Zhu[a,b,c], Deli Wang[a,*], Qinfeng Guo[d], Jun Liu[a], Ling Wang[a]

[a] Institute of Grassland Science, Northeast Normal University, Key Laboratory of Vegetation Ecology, Ministry of Education, Changchun, Jilin 130024, China
[b] School of Life Sciences, Northeast Normal University, Changchun, Jilin 130024, China
[c] Jilin Provincial Key Laboratory of Animal Resource Conservation and Utilization, Northeast Normal University, Changchun, Jilin 130024, China
[d] USDA FS, Eastern Forest Environmental Threat Assessment Center, Asheville, NC 28804, USA

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ABSTRACT

The structure and dynamics of insect community in grasslands can be influenced by grazing management via altered characteristics of plant community. However, attempts to better understand the complex relationships among plants, insects, and large herbivores is still hampered largely by the interactive effects of plants, insects, and large grazers on each other. In this study, we test the hypothesis that the effect of large herbivores on insect abundance is grazer species-specific and pre-grazing plant diversity-dependent using an experiment with manipulating four grazing treatments (i.e., control, cattle, goats, and sheep) at low, intermediate, and high plant diversity levels in a meadow steppe at northeast in China. We show that grazing significantly increased the abundance of the entire insect community. The abundance of each insect order responded differently to grazing treatments, with higher abundance of Orthoptera and Homoptera under sheep grazing, enhanced abundance of Coleoptera and Diptera under cattle grazing, and reduced Hemiptera abundance, but greater abundance of Lepidoptera under goats grazing. Thus different treatments profoundly changed insect taxonomic composition. The six most dominant species (*Euchorthippus unicolor*, *Aelia nasuta*, *Trigonotylus ruficornis*, Curculionidae sp., *Coccinula quatuordecimpustulata*, and Cicadellidae sp.) responded differently to grazing by large herbivores, with either increased or decreased its abundance. The effects of grazing on insect abundance were driven by their differential responsive mechanisms for vegetation. More importantly, the effects of grazing on insect abundance at both order- and species-levels potentially depended on plant diversity levels of pre-grazing. Our results suggest that different herbivore species should be used in the background of different plant communities for better conservation of insect community in managed grassland.

1. Introduction

Insects are a major but often under-appreciated component of terrestrial ecosystems (Belovsky and Slade, 2000; Bronstein et al., 2006; Matt and Charlton, 2006). However, growing evidence shows that insects are also experiencing local/regional species loss or even global extinction (Collinge, 2000), and that the diversity of insects apparently declines even more rapidly than that of vertebrates and plants (Thomas et al., 2004). Therefore, understanding critical factors that determine their diversity and species composition becomes an urgent task facing ecologists and conservation biologists. Although many studies have identified a range of management factors that could contribute to changes in insect communities in grassland ecosystems (Kruess and Tscharntke, 2002a; Batáry et al., 2010), there is a need to integrate these knowledge into predictive and adaptive ongoing management options.

Livestock grazing is a key management tool in grasslands, and its widespread prevalence has generated great interest in understanding its ecological effects, especially for insects. Previous studies show that grazing managements in grasslands can lead to either lower (Gonzalez-Megias et al., 2004; Joern, 2005; Littlewood, 2008), or higher insect abundance and richness (Cagnolo et al., 2002; Ryder et al., 2005; Debano, 2006; Rosa-García et al., 2009). Such conflicting results might partly derive from the difference in grazing intensity (Kruess and Tscharntke, 2002b; Cease et al., 2012), grazing season (Fonderflick et al., 2014), and grazer species (Dolek and Geyer, 2002). Surprisingly, while most

* Corresponding author. Tel.: +86 431 85099737.
E-mail address: wangd@nenu.edu.cn (D. Wang).

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efforts have been devoted to the effects of grazing intensity on insect community, little attention has been given the effects of grazer species (Jáuregui et al., 2008). Different large herbivore species may alter vegetation features due to diet selection and body size, potentially influencing insect community, because grazing affect insect community through modifying plant communities (Kruess and Tscharntke, 2002b; Jonas and Joern, 2007; Zhu et al., 2012; van Klink et al., 2015). Therefore, the resulting 'species-specific' of grazing management difficultly renders the development and application of general management principles for biological conservation.

Food resources for herbivores are heterogeneously distributed in most grasslands (Li and Reynolds, 1995; Wang et al., 2014), the responses of plant community to large herbivores strongly depend on the distribution of plant resources before grazing (Palmer et al., 2003; Bakker et al., 2006). The difference in plant species diversity is a typically important characteristic of heterogeneity, and diverse plant communities can markedly affect foraging strategies of large herbivores and their concomitant impacts on the dynamics of vegetation itself (Bergvall et al., 2006; Miller et al., 2007; Wang et al., 2011). Our previous work found that complex spatial neighborhood of several plant species makes the palatable species for herbivores to less selected, contributing to the maintenance of plant diversity (Wang et al., 2010). This 'plant species diversity disaffinity' may be an important factor influencing subsequent herbivores' impacts on plant community, which, in turn, consequently impacts insect community. Therefore, understanding the effects of grazing by large herbivores on insect community will require explicit knowledge of pre-grazing plant diversity levels.

Our previous experimental efforts at the same grassland mainly focus on the treatment effects on diversity. Zhu et al. (2012) showed that large herbivores strongly affected insect species richness by modifying plant structural heterogeneity, which reversed the positive relationship between plant and insect diversity. Zhong et al. (2014) found that the positive interactions between large herbivores and grasshoppers were driven by differential herbivore foraging preferences for plant resources that break down the associational plant defense between grasses and forbs. In contrast, the main goal of this study is to test the effects of different large herbivore species on insect abundance at different plant diversity levels. Although most extensive research on the effects of livestock grazing on grassland insect abundance has taken place, and has provided valuable insights (Littlewood, 2008; Cease et al., 2012), several important gaps in our knowledge remain. Because not all species are sensitive to grazing, and the use of taxonomic hierarchies such as order and species levels could be advantageous in biodiversity assessments (Williams and Gaston, 1994). Thus, there is a pressing need for studies that examine how insect community responds to livestock grazing at taxonomic composition. In this study, as part of a previous, targeted experiment to identify multiple species interactions (plants, insects, and large herbivores) under large herbivore grazing at different plant diversity levels, we examined that the responses of insect abundance at both order- and species-levels to the interactive effects of large herbivore grazing and plant diversity of pre-grazing. Specifically, we test the hypothesis that the effect of large herbivores on insect abundance is grazer species-specific and pre-grazing plant diversity-dependent using a field experiment in a meadow steppe at northeast in China.

2. Methods and materials

2.1. Study site

This study was conducted at the Grassland Ecological Research Station of Northeast Normal University, Jilin Province, P.R. China (44°45′N, 123°45′E). The site is in a meadow steppe region where mean annual temperature and precipitation are from 4.6 °C to 6.4 °C, and 280–400 mm, respectively. Monthly mean temperature ranges from −16 °C in January to 25 °C in July, and ninety percent of the total precipitation is distributed from May to October. Annual potential evaporation is approximately three times as much as the mean annual precipitation. Soils are mixed saline and alkaline (pH 8.5–10.0). The dominant plant species in meadow steppe that lies in the eastern region of the Eurasian Steppe Zone is perennial grasses, *Leymus chinensis* (Wang and Ba, 2008; Gao et al., 2008). Other species include perennial and annual grasses such as *Phragmites australis*, *Calamagrostis epigejos* and *Chloris virgata*, legumes such as *Lespedeza davurica*, and forbs such as *Potentilla flagellaris*, and *Artemisia scoparia*.

2.2. Experimental design and grazing treatments

To test the interactive effects of large herbivore species and plant diversity of pre-grazing on insect community, three plant diversity levels and three single grazer species were selected. In this study, 9 blocks (each for 0.3 ha in size) with flat topography and similar soil type were established. The nine blocks investigated were classified into three plant diversity levels: low (4–5 species), intermediate (8–9 species), and high (15–17 species) based on vegetation investigation of pre-grazing, with three blocks (three replicates) for each plant diversity level. Each block for each plant diversity level was one plant community, and the plant community composition (species, and individual number of each plant species) that was similar with other blocks in same plant diversity level, and was different from the blocks in other plant diversity levels. Detailed descriptions of experimental plant diversity treatments of pre-grazing can be found in Zhu et al. (2012). Grazing treatments were nested within the block of each plant diversity treatment, and no grazing and three single grazing treatments with one grazer in each grazed plot were used. That is, each block was composed of four plots (each for 0.05 ha in size) enclosed with barbwire. Neighboring plots within each block were separated by 18–20 m. The four grazing treatments were assigned randomly to the four plots in each of the nine blocks as follows: (1) no livestock grazing (control); (2) grazing by cattle (a hybrid of native and yellow breed), and two cattle (221 ± 5.5 kg) per plot (= 7.14 sheep ha^{-1}); (3) grazing by goats (Liaoning Cashmere breed), and eight goats (34 ± 1.6 kg) per plot (= 7.08 sheep ha^{-1}); (4) grazing by sheep (small-tail Han breed), and eight sheep (33 ± 1.6 kg) per plot (= 7.21 sheep ha^{-1}).

Intermediate grazing intensity (50–65% of the available forage was removed) was used in all grazed plots. The similar grazing pressure (sheep unit per hectare) among cattle, goats, and sheep was gained by calculating the intake and body weight of each individual of the three grazers. The plots were grazed by livestock from the second week of July in 2007 and 2008 when new growth ensured sufficient forage for grazing. Grazing was conducted twice per day: from 06:00 to 08:00 AM and from 16:00 to 18:00 PM during their normal grazing time and was terminated when about 60% of the available forage was removed (about 10–15 d within each month). Large herbivores were not allowed to graze the plots that were visibly wet or following measurable rain (10 mm). Vegetation and insects were assessed after 1.5 years of grazing treatments.

2.3. Vegetation measurements

All plots were sampled in July, August, September, and October in 2008. Plant species richness, the individual number, height, and cover of each species were assessed within ten quadrats (0.25×0.25 m) arranged evenly along each of two 20 m cater-