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Assessment of biotic and abiotic factors controlling herbaceous biodiversity in Mongolian steppes

Amartuvshin Narantsetseg [a,b], Sinkyu Kang [b], Bolor-Erdene Lkhamsuren [b], Keunchang Jang [b], Dongwook W. Ko [c,*]

[a] Institute of Botany, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia
[b] Department of Environmental Science, Kangwon National University, Chuncheon, Republic of Korea
[c] Department of Forest Environmental Systems, Kookmin University, Seoul, Republic of Korea

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ABSTRACT

Spatial patterns of herbaceous biodiversity in Mongolia steppe were examined and explained with biotic and abiotic factors including climate, livestock grazing, and fire disturbance. Vegetation data were collected from 63 sites across different steppe types (i.e., semi-desert, typical, and forb steppes) in 2012 and 2013. Three categorical (three steppe types, burned or not, grazed or not) and three continuous variables (precipitation, vegetation productivity, site-camp distance) were developed from national climate and GIS database of Mongolia and two satellite sensor products: Tropical Rainfall Measuring Mission (TRMM) precipitation and June-to-August accumulated Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index ($NDVI_{JJA}$). The prescribed factors were utilized to examine single- and multiple-factor effects on biodiversity and community structure, by using correlation, stepwise multiple regression analysis, and ordination. Our results indicate the positive effect of precipitation and fire but negative effect of grazing on biodiversity in our study region. Localized herding effect was recognized to areas less than 1.5 km away from the herder's camp sites. Fire, precipitation and productivity ($NDVI_{JJA}$) were identified as important factors affecting biodiversity of remote regions. Based on the results, we infer that pastureland biodiversity of Mongolia is controlled by region-scale variations of climate and vegetation productivity, but locally modified by intensive livestock grazing pressure with different grazing sensitivity for different steppe types.

1. Introduction

In arid and semi-arid regions, plant biodiversity is highly relevant with inter-annual variation of precipitation (Fernandez-Gimenez and Allen-Diaz, 1999; Loeser et al., 2006), livestock grazing (Fujita et al., 2009; Marion et al., 2010; Zhao et al., 2004), fire (Capitanio and Carcailet, 2008), and inter-specific interactions (Huston, 2004). There are many evidences on how biotic and abiotic factors control grassland biodiversity. For example, spatial distribution of plant biodiversity is positively correlated with annual precipitation in temperate steppe and desert-steppe regions (de Bello et al., 2006). Temporally, grassland plant biodiversity is higher during rainy periods than sustained drought periods (de Bello et al., 2006; Loeser et al., 2006; Zhao et al., 2011). It is also recognized that plant biodiversity is greater with grazing pressure in humid and nutrient-rich environments, but vice versa in dry and nutrient-poor environments (de Bello et al., 2006; Fujita et al., 2009; Proulx and Mazmunder, 1998). Low-to-moderate grazing pressure seems to enhance plant biodiversity (Marion et al., 2010), because grazing decreases inter-specific interaction (Collins, 1987; Collins et al., 1998; Milchunas et al., 1992; Zhao et al., 2004). Heavy grazing, however, tends to reduce biodiversity (Biondini et al., 1998; Busso et al., 2004; de Bello et al., 2006; Fuhlendorf and Smeins, 1997; Haidari et al., 2012). Fire effect on plant biodiversity was characterized by fire intervals (Morrison et al., 1995), plant resistance or sensitivity to fire (Belsky, 1992; Keeley et al., 1981), or fire-induced nutrient effects (Chou, 1973; Guo, 2001). Plant biodiversity is generally higher with short fire-free period and lower with long fire-free period, but fire-induced inter-specific interaction is also known to be important (Capitanio and Carcailet, 2008; Guo, 2001).

Although there are numerous studies on grassland biodiversity, our understanding on biotic and abiotic controls on grassland vegetation biodiversity across different climate and disturbance regimes remains uncertain because those prescribed factors frequently interact with each other (Fernandez-Gimenez and Allen-Diaz, 1999). Mongolian steppe provides a unique opportunity to explore the interactions of the environment, plants, and humans in creating various spatial patterns of grassland ecosystem with its highly diverse floral communities, considerable gradient

* Corresponding author at: Department of Forest Environmental Systems, Kookmin University, Seoul 136-702, Republic of Korea. Fax: +82 2 910 5826.
E-mail address: dwko@kookmin.ac.kr (D.W. Ko).

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of environmental factors and human impact across an extensive region (Hilbig, 1995; Karamysheva and Khramtsov, 1995).

Plant biodiversity were investigated in various steppe types in Mongolia (Fernandez-Gimenez and Allen-Diaz, 1999; Fujita et al., 2009; Liu et al., 2013). Previous studies found a positive relationship of plant diversity with precipitation in Mongolian steppe, suggesting considerable drought controls on species composition (Fujita et al., 2009). Also, the role of livestock grazing and precipitation in determining biodiversity in semi-arid mountain and arid desert steppes, respectively, was recognized (Fernandez-Gimenez and Allen-Diaz, 1999). It seems that grazing effect on grassland plant biodiversity is represented by greater dominance of grazing-tolerant pasture plants in the semi-arid mountain steppe (Fernandez-Gimenez and Allen-Diaz, 1999; Fujita et al., 2009). Drought tolerance might be, however, more important for plant survival in the arid desert steppe (Fujita and Amartuvshin, 2012). Meanwhile, Liu et al. (2013) suggested that grazing and drought are equally important in determining biodiversity in the typical steppe zone, which occurs between mountain and desert steppes.

Such results indicate that factors controlling biodiversity in different steppe types may reflect different plant adaptation traits to local environmental conditions (Wise and Abrahamson, 2007). Hence, for better understanding, it is necessary to integrate multiple cause-and-effect relationships across different climatic and disturbance regimes. Unfortunately, previous studies were constrained by limited field data in tackling the issues of how biodiversity and vegetation communities interact with climate and disturbances in shaping the current spatial biodiversity patterns.

In this study, we investigated spatial distribution of biodiversity and grassland communities and their relationships with various environmental and human factors across diverse Mongolian steppe types. We developed an extensive field dataset of vegetation description over wide geographic regions covering semi-arid, typical, and forb-steppe types in Mongolia, across different disturbance regimes of livestock-grazing and fire, climate, and vegetation productivity. Our objectives were to utilize such datasets to examine their individual and integrative effects on grassland biodiversity and community structure in Mongolian steppe.

2. Materials and method

2.1. Study area

Our study area includes central and eastern parts of Mongolian steppe (Fig. 1). Mongolian steppe can be divided into forb-, typical, and desertified, and desert steppe, based on botanico-geographical maps of the Central Asia sub-region (Lavrenko et al., 1991) and the Mongolian steppe zone (Karamysheva and Khramtsov, 1995). The desertified steppe, designated by Karamysheva and Khramtsov (1995), is a transition zone from typical steppe to desert steppe. Hereafter, we refer it as semi-desert steppe. Based on the above-mentioned steppe zone classification, we divided our study area into forb-steppe, typical steppe and semi-desert steppe with different climate and vegetation type (Fig. 1).

Mongolian steppe zone occupies 26 percent of Mongolian territories and is characterized by lightly rolling hills and broad flat depressions with an elevation range between 500 and 1800 m (Narangarav and Lin, 2011; Olson et al., 2010). Along the latitudinal gradients from south to north, precipitation increases and air temperature decreases, and steppe type changes from semi-desert to forb-steppe types. Such distinct climatic gradients were identified across the weather stations in our study area (Table 1). Generally, distinct biome-specific climate gradient in our study region can be distinguished as: hot (mean annual temperature 2.6 °C) and dry (mean annual precipitation 132 mm y^{-1}) semi-desert steppe, cool (0.40 °C) and wet (284 mm y^{-1}) forb-steppe, and intermediate temperature (1.39 °C) and precipitation (201 mm y^{-1}) of typical steppe (Table 1).

Fire data during the 2000s displayed distinct spatial patterns of fire frequency, with more frequent fire disturbances in the eastern steppes, and rare fire occurrences in the central part of study area (Fig. 1b). Livestock population was higher in the central part of Mongolian steppe (Fig. 1c). Fire and livestock information were utilized to divide our sampling sites into sub-groups depending on grazing and fire disturbance regimes: natural, grazed, burned-natural and burned-grazed sites.

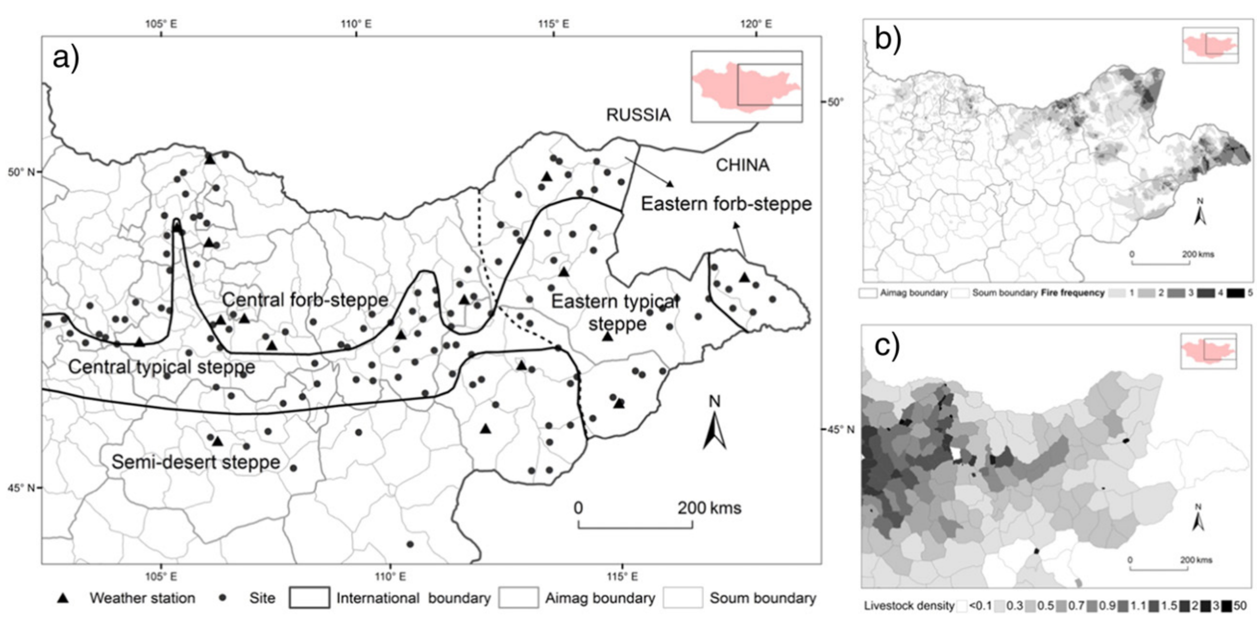

Fig. 1. Maps of study area: (a) field survey sites (circle) and weather stations (triangle) in the study area, overlaid by biome boundary lines, (b) fire frequency during 2000–2011 (darker color indicates higher fire frequency), and (c) soum-level livestock density per ha in 2008 (darker color indicates higher livestock density). Gray boundaries represent soum administration districts, which is the second smallest administration unit in Mongolia.