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Mongolian rangelands at a tipping point? Biomass and cover are stable but composition shifts and richness declines after 20 years of grazing and increasing temperatures

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ABSTRACT

Mongolian rangelands have experienced warming temperatures and increasing livestock densities over the past 20 years. Remote sensing studies report widespread degradation, but there are no long-term field studies of vegetation responses to shifts in climate and stocking densities.

In 2013, we resampled plots originally sampled in 1994–1995 in the desert-steppe, steppe and mountain-steppe, and analyzed changes in vegetation in relation to changes in climate, stocking densities and forage use. Summer temperatures significantly increased and stocking densities fluctuated in response to droughts followed by harsh winters. Total herbaceous biomass in 2013 was similar to (desert-steppe and steppe) or greater than (mountain-steppe) in 1995, and total foliar and herbaceous cover were unchanged since 1995 in all zones. In the mountain-steppe, functional type and species cover shifts were consistent with warming temperatures and increasing grazing pressure. All species richness and diversity indicators declined significantly in the mountain-steppe since 1995, as did richness in the steppe. Some Mongolian rangelands may be losing resilience due to interacting climate and grazing pressures, but our data suggest degradation observed at our study sites is reversible. Mountain-steppe systems appear more vulnerable to grazing- and climate-induced vegetation change than steppe and desert-steppe.

1. Introduction

Among the largest intact temperate grasslands on Earth, Mongolia's steppes are a globally significant resource. Recent changes in rangeland governance and management, combined with a changing climate, call into question the future of Mongolia's rangelands and the pastoralists and biodiversity they support. Although recent research reports widespread grazing-induced degradation (Liu et al., 2013; Hilker et al., 2014), opinions and evidence about the extent and causes of rangeland change differ widely (Addison et al., 2012). By resampling field plots originally measured in 1994–1995, this research contributes to understanding how interacting grazing and climate changes influenced rangeland vegetation conditions across an ecological gradient in central Mongolia over 20 years.

Until the early 1990s, Mongolia's rangelands were sustainably grazed by domestic livestock for centuries, under several different governance regimes (Fernandez-Gimenez, 1999), and livestock populations remained relatively constant for most of the 20th century. Following the transition to a democracy and market economy, and privatization of formerly state-owned livestock in 1992, the livestock population increased steeply until 1999. The national herd declined 30% between 1999 and 2002 due to drought combined with extremely cold winters, but recovered to its previous peak by 2009, when another harsh winter killed 8.5 million livestock, about 20% of the national herd (ReliefWeb, 2010). Following this second crash, the national herd again quickly

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recovered. From 1992 to 2013 herd composition also shifted, with an increasing proportion of goats to meet the rising global demand for cashmere. Also during this time, long-term trends of increased warming were documented over much of Mongolia (Angerer et al., 2008; Dagvadorj et al., 2009; Nandintsetseg and Shinoda, 2013), and herders (Bruegger et al., 2014), ground measurements (Addison et al., 2012; Nandintsetseg and Shinoda, 2013) and remote sensing (Sankey et al., 2009; Liu et al., 2013) detected declines in rangeland biomass or production. These concurrent apparent trends in climate, livestock and rangeland production have led to concerns about rangeland degradation and potential loss of resilience.

Non-equilibrium (NE) theory of rangeland dynamics predicts that in areas with low annual precipitation and high inter-annual variability in rainfall, vegetation dynamics are driven by rainfall rather than grazing, whereas in regions with higher precipitation and more constant conditions for plant growth, grazing plays a greater role in determining plant community structure and composition (Ellis and Swift, 1988). In 1994–1995, Fernandez-Gimenez and Allen-Diaz (1999) tested this theory across a gradient of precipitation amount and variability in Mongolia. They found that the more arid and variable desert-steppe displayed vegetation responses to grazing predicted by NE theory, while responses in the steppe and mountain-steppe were consistent with equilibrium (E) dynamics or a combination of NE and E dynamics (Fernandez-Gimenez and Allen-Diaz, 1999). Most subsequent studies in other Mongolian desert-steppe regions have confirmed these findings (Stumpp et al., 2005; Wesche and Retzer, 2005; Zemmrich, 2007; Zemmrich et al., 2007; Wesche et al., 2010; Zemmrich et al., 2010). Other desert-steppe studies, however, do not support NE theory or provide ambiguous results. Sasaki et al. (2008, 2011) showed that areas of high grazing intensity, close to water points and nomadic settlements, differed in species composition from areas of moderate to low grazing intensity. Subsequent removal of grazing did not result in recovery after 5 years, suggesting that a biotic threshold was crossed (Sasaki et al., 2013). In a 7-year exclosure experiment in the desert-steppe, Wesche et al. (2010) found that community composition and richness varied interannually with precipitation, but directional change (succession) did not occur, indicating an abiotically-driven NE system. However, slight but significant differences between grazed and ungrazed treatments suggested that grazing can affect production and composition of desert-steppe plant communities (Wesche et al., 2010).

Adding to confusion is the lack of a clear definition of degradation in most Mongolian rangeland studies. Following Milton et al. (1994) and Whisenant (1999), we view degradation as a continuum of conditions from reversible and potentially temporary changes in biotic communities, to irreversible and permanent changes in both biotic and abiotic indicators and processes. Reversible degradation in rangelands is signaled by a shift in plant species or functional group composition towards more grazing-tolerant, less palatable taxa, or disturbance-associated weedy species. Such species shifts may sometimes be long-term, but functional group composition and associated ecological processes are not irreversibly changed. More severe degradation that requires greater time and inputs for recovery is indicated by declining plant production, diversity and cover, where cover is an indicator of site and soil stability. Species losses associated with these changes may be permanent, but primary ecological functions such as nutrient and water retention remain or are recoverable. Irreversible degradation in rangelands denotes permanent loss of productive potential associated with soil loss or changes in soil chemistry or hydrology (Whisenant, 1999). It is important to recognize that in semi-arid NE rangelands, inter-annual variability in precipitation may drive fluctuations in plant cover, production and species composition that can be mistaken for degradation if care is not taken to compare the same sites over time in similar rainfall years.

Interacting effects of changes in climate and grazing regimes in Mongolia may weaken the resilience of steppe ecosystems to future stressors. Ecological resilience is the ability of a system to recover its structure and function following a perturbation (Gunderson, 2000). Resilience can be measured directly if data are collected before and after a disturbance event (e.g. fire or episode of overgrazing), or a period of stress (e.g. extended drought). Resilience is indicated if the system maintains or recovers to pre-stress or pre-disturbance levels of key system functional and structural variables such as plant production, cover, and diversity. Thus, temporary shifts in species composition might indicate reversible degradation but not necessarily loss of resilience, whereas reductions in total cover, production, or diversity could signal weakened resilience and a potential transition towards longer-term degradation.

In this study, we resampled plots originally studied in 1994–1995 across a precipitation gradient from the mesic mountain-steppe to the arid and variable desert-steppe to assess whether long-term changes have occurred in standing crop biomass; total foliar, functional type and species cover; and species richness and diversity; and to determine whether observed changes are associated with changes in livestock densities, herd composition or climate trends. At both study sites, growing season precipitation in 1994 was much higher than the 30-year average, whereas both 1995 and 2013 had lower than average or average precipitation that was similar between years within each study site. The similarity in 1995 and 2013 rainfall enables us to compare degradation indicators at the two sampling times without the confounding effects of rainfall differences between sampling years.

Based on herder observations of environmental changes in Mongolia (Marin, 2010; Bruegger et al., 2014), we anticipated finding multiple indicators of degradation and resilience loss. Reversible degradation would be indicated by changes in plant species or functional type composition without significant changes in total standing crop, cover or diversity. Loss of resilience and potential transition toward irreversible degradation would be signaled by significant declines in total plant production, cover or diversity in addition to species and functional type changes.

Past research on the grazing ecology of the Mongolian steppe, and NE theory, led us to expect that indicators of grazing-associated degradation (e.g. shifts toward more grazing-tolerant, disturbance-associated, and less palatable plants) would be most apparent in the mountain-steppe, moderately so in the steppe, and less so in the desert-steppe. Similarly, we expected that increases in temperature would have the greatest effects in the mountain-steppe and steppe zones, where changes in climate are expected to have the largest impacts on vegetation (Angerer et al., 2008).

This research provides new insights into the types and potential causes of rangeland changes occurring in Mongolia in response to changing herd sizes and composition coupled with increasing temperatures, and their implications for rangeland monitoring and management, governance and climate change adaptation. As the first long-term (20-year) multi-site observational study of Mongolian rangeland changes, it provides critical insights to inform rangeland monitoring, management and governance in Mongolia and beyond.

2. Methods and materials

2.1. Study sites

We sampled in Bayan-Ovoo and Jinst districts (*soum* in Mongolian) in Bayankhongor province (*aimag*) (Fig. 1), located in central