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Urbanization and environmental policy effects on the future availability of grazing resources on the Mongolian Plateau: Modeling socio-environmental system dynamics

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ABSTRACT

The rangelands of the Mongolian Plateau are dynamic socio-environmental systems that are influenced by a complex network of drivers, including climate, social institutions, market forces, and national-scale policies affecting land access and management. The sustainability and resilience of rangelands in this region depend on the ability of residents and policy makers to quickly respond by adapting livelihoods and land uses to changes in environmental and socio-economic conditions, but the responses of the system to these changes are often non-linear and difficult to predict. We developed a system dynamics model to understand how the human, natural, and land-use processes in the Mongolian rangeland ecosystem interact to produce dynamic outcomes in both grassland productivity and livestock populations. We developed two separate models based on a common integrative framework for two case study areas: Suhkbaatar Aimag in Mongolia and Xilingol League in Inner Mongolia. We used future scenarios for each region generated with stakeholder input to forecast trends in grassland area, livestock numbers, and biomass under alternative climate, socioeconomic, and land-use futures. By incorporating stakeholder-developed scenarios, we were able to explore future scenarios tailored to the particular questions and concerns relevant to the individual study areas. We find that while there are many similarities in the factors driving system dynamics in the two countries, the trajectories of key grassland resources are quite different, both between the two study regions and across the individual scenarios. Environmental policies play a key role in Xilingol, while economic development is a key driver in Sukhbaatar. Urbanization dynamics will be a major influence on the availability of grassland resources in the future.

1. Introduction

Significant degradation is occurring across the world's arid and semi-arid rangelands (Maestre et al., 2016; Reynolds et al., 2007) and is projected to increase under climate change (Huang et al., 2015). The status of arid rangelands, which provide forage for 75% of the world's livestock, has implications for livelihoods, ecosystem services, and carbon storage, which can feedback to affect climate change. Thus, there is a real need to understand both the interacting factors affecting degradation as well as potential future restoration trajectories. We know that rangelands are socio-environmental systems (Liu et al., 2007; Chen et al., 2015a,b). To understand rangeland dynamics, particularly at landscape scales, we need to consider how societal and environmental changes affect rangeland biophysical conditions and, additionally, how those conditions feed back to affect decisions by individuals and government about livelihoods and policy. To evaluate the future sustainability of arid rangelands, data and models are needed to describe the natural and human components of these systems, their dynamics, and their interactions (Maestre et al., 2016).

The Mongolian Plateau is one of the world's largest areas of continuous arid rangeland, covering most of Mongolia and the Inner Mongolian Autonomous Region of northern China, and is a clear example of a coupled human-natural grassland system. The Mongolian Plateau was historically inhabited by pastoralists who migrated seasonally with livestock herds. Although the people of the region have a shared ecological and cultural history stretching back thousands of years, Mongolia and China have undergone

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significant socio-political changes over the past fifty years that have dramatically affected the environments and economies of the two countries (Chen et al., 2015a,b; Kawada and Nakamura, 2011; Wang et al., 2013a; Xie and Sha, 2012).

Rapid ecological and socioeconomic changes, including climate change, population growth, infrastructure investment, and sedentarization have been linked to significant grassland degradation in parts of the plateau (Hilker et al., 2014; Williams, 1996, 2000), although the universality of these links are contested (Kolås, 2014; Taylor, 2006). These changes have been particularly dramatic in the Inner Mongolia Autonomous Region of China, but recent socioeconomic and environmental changes in Mongolia have put increasing stress on the grasslands, particularly in the northern half of the country (NAMEM and MEGDT, 2015). Drivers such as rapid urbanization and spread of informal settlements in peri-urban areas, record high livestock numbers, and climate changes have also been identified as potential limits on future grassland resilience in Mongolia as well; there is debate about the relative impacts of each of those factors (Addison et al., 2012).

Across the Plateau, several dynamics could affect rangelands in the future. Rates of urbanization, i.e., migration of populations from rural to urban areas, are increasing (Fan et al., 2015); the climate is changing, becoming drier in some places, wetter in others, and more variable overall (NAMEM and MEGDT, 2015); and livestock herd sizes and composition are in flux (Huang et al., 2015). All of these dynamics have the potential to alter the ability of grasslands to sustain their function and continue to provide ecosystem services. The status of grasslands on the Plateau is unclear, with reports from Mongolia stating anywhere from 10% to 90% (Addison et al., 2012; Hilker et al., 2014; NAMEM and MEGDT, 2015) of the grazing lands are degraded to some extent.

In order to better prepare for the future, a better understanding is needed of how the human, natural, and livestock sectors interact to affect the rangelands on the Plateau. We adopted a system dynamics approach (Forrester, 1961; Scholl, 2001) to explicitly link the social, environmental, and land-use sectors and represent how their interactions affect dynamics in this arid rangeland system. System dynamics (SD) models facilitate learning about how a system changes over time in response to various shocks, and how dynamic feedbacks can lead to non-linear behavior in complex systems (Ford, 1999). While primarily developed for analyses of industrial systems (Forrester, 1994; Holmberg, 2000), SD models are also appropriate for trying to understand coupled human and natural systems (Rasmussen et al., 2012; Shen et al., 2009; Stave, 2010). Properly constructed, SD models can be run with different initial or boundary conditions to evaluate system behavior, or with alternative assumptions about future conditions (e.g., policy or climate). To date, few dynamic models have incorporated socio-economic, land use, and climate data together to evaluate these interacting influences on grassland systems (Herrmann et al., 2014).

We used SD models to evaluate the potential impacts of changes in policy, internal migration (urbanization), and climate on the trajectory of grassland biomass production and livestock populations on the Plateau. Given their contrasting histories, we focused our modeling work on comparing two representative case-study regions in Mongolia and Inner Mongolia, China. The basic framework for the models includes human, natural, and land use sub-models that are dynamically linked through key endogenous variables. Model details are based on a common conceptual structure but vary slightly between the two regions because of differences in the underlying socio-environmental conditions and in the data available to model them (Supp Fig. 1). Our model development, simulation, and analysis were aimed at improving our understanding of the potential for future resilience of rangelands on the Mongolian Plateau. We assessed resilience through three key variables that represent the socio-environmental status of the system: availability of grazing area (grassland cover), livelihoods (livestock population), and forage resources (biomass availability). We assess the potential for the region to continue to support livestock husbandry by addressing the following questions: How will grassland area respond to changes in policy, climate and the economy? How will urbanization affect the availability of grazing resources?

2. Methods

2.1. Study area

Our adjacent case study regions, one in China and one in Mongolia, are located centrally on the Mongolian Plateau; Xilingol League, China and Sukhbaatar Aimag (province) in Mongolia (Fig. 1). They share the international border and similar environmental conditions, but differ in their recent socio-political history.

Fig. 1. Location of the two case study regions, Xilingol League and Sukhbaatar aimag.