Modeling System Dynamics in Rangelands of the Mongolian Plateau

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ABSTRACT

The rangelands of the Mongolian Plateau are dynamic social-ecological systems that are influenced by a complex network of drivers, including climate, social institutions, market forces and broad scale policies affecting land tenure. These factors are linked via feedbacks and often exhibit non-linear relationships. The sustainability and resilience of rangelands in this region are dependent on the ability of residents and policy makers to respond to changes and uncertainties regarding climate, socio-economic conditions, and land use. However, the complex nature of these systems makes it difficult to predict how changes in one aspect of the system will affect the functioning of other areas.

We developed a system dynamics model to understand how the human, natural, and land-use systems in one part of the Mongolian rangeland ecosystem interact to produce dynamic outcomes in both grassland productivity and livestock population dynamics. An important contribution of this integrative model is to serve as a structure for synthesizing disparate data and models generated in several previous studies. It also provides a baseline for exploring future uncertainties and system dynamics in ways that can then be communicated back to stakeholders in the region. We present results from the model simulations of how ecosystem function and socioeconomic outcomes might change under alternative plausible climate, socioeconomic, and land use futures.

Keywords: grassland; climate, livestock, grazing, desertification, net primary production

INTRODUCTION

Semi-arid rangelands cover nearly twenty five percent of the global land surface and are home to nearly thirty percent of the world's population. These lands are experiencing increasing rates of degradation, due to climate change, overgrazing, and urban and agricultural development. The Mongolian Plateau contains a vast area of grassland straddling the border between northern China and Mongolia. Historically inhabited by pastoralists who migrated seasonally with livestock herds, these areas have undergone drastic changes over the past thirty years due to shifts in land tenure and livestock ownership, globalization, and urbanization (Kawada and Nakamura, 2011; Xie and Sha, 2012; Wang et al., 2013). Rapid ecological and socioeconomic changes have been linked to significant grassland degradation (Williams, 1996), although the universality of these links are contested (Taylor, 2006; Kolas, 2014). These changes have been particularly dramatic in the Inner Mongolia Autonomous Republic of PR China, which covers 1.18 million square kilometers on the southern end of the plateau.

Policies geared toward protecting grasslands and limiting cropland expansion were initiated by the government in the early 2000s in an attempt to slow grass degradation in Inner Mongolia (Li and Huntsinger, 2011). But it is unclear how effective such policies will be over the long term, under predicted increasing urbanization and changing climate patterns. Few models incorporate the socio-economic, land use, and climate data necessary to evaluate these interacting influences on the grasslands of the Mongolian Plateau. In order to understand and respond to future threats, we need a better understanding of the inter-connectivity between human, natural, and livestock sectors of the Plateau system. We adopted a system dynamics approach to explicitly link the social, environmental and land-use sectors to reveal underlying dynamics in this arid rangeland system. This aspatial approach to studying complex systems allows us to incorporate diverse data types and time series to model connections and feedbacks and predict behavior under future scenarios. We focused on Xilingol League of Inner Mongolia Autonomous Region, and present outcomes of a baseline simulation and four illustrative "what-if" scenarios. In particular we are interested the following questions: how will the rapid urbanization of northern China affect grassland resilience; and how sensitive is the grassland to changes in population, livestock and climate?

METHODS

Study Area

Xilingol League in located central Inner Mongolia, approximately 400km north of Beijing, and borders Mongolia to the north. A distinct aridity gradient extends east to west and divides the league into three grassland ecoregions from east to west, known respectively as the "meadow steppe," "typical steppe," and "desert steppe." The climate of the region is temperate and arid, with a mean annual temperature of approximately 1ºC, with an annual precipitation of 400mm in the east, decreasing to less than 200 mm in the more arid southwest.

The steppe grasslands in Xilingol are still primarily used for grazing but changes in land tenure and increasing privatization of livestock have resulted in declines in nomadic herding and subsequent intensification of grazing in certain areas (Li et al., 2007). The drier western portion of the league has experienced more desertification. Conversion of grassland to agriculture is occurring primarily in the relatively more mesic southeastern portion of the league. Xilingol is still a primarily sparsely populated region total population of approximately one million people. Xilingol has two primary urban centers, Xilinhot in the east and Erenhot in the west. The combined population of all 'urban' areas in the league is approximately 60% (stat. yearbook data) of the total population and is increasing steadily as people migrate from rural areas and from outside of Xilingol to access employment in cities.

Data Sources

We relied on a combination of data sources to develop inputs and mathematical relationships for our model, including: our own datasets and that of our collaborators, (e.g., Wang et al., 2013; Chen et al., 2015); primary literature from the region; data from census and statistical yearbooks. From these sources we were able to gather data on population trends, livestock, and land use. We derived the function to predict the proportion of the population that is urban using a combination of historical data and published relationships. We also used previously published data on net primary productivity, derived from remote sensing (Wang et al., 2013), and combined this with time series precipitation data collected from 15 weather stations located throughout Xilingol. Land-cover trends were predicted based on published data (Baotana, 2011) and time series data on cultivated areas from statistical yearbooks.

System dynamics model

We modeled the Xilingol system as an interacting set of three subsystems: human system (population and livestock sectors); natural system (grassland biomass, climate); and land-use system (grassland, cropland, urban land, and degraded land). The interactions/causal-effective relationships between the sectors are visualized in simplified form in Figure 1. Many more variables and relationships are included in the model, but in the interest of space we provide only broad descriptions.

Scenarios

After establishing a baseline model that represents continuation of current conditions and dynamics, we then subjected the model to a series of scenarios, based on plausible changes in demography, environmental policy, and climate that could create challenges to the sustainability of livelihoods in the region. Here we report on the results of four of those scenarios, which we projected to 2050.

In *Scenario 1* we assume an increasing trend in Jan-July precipitation from 2000-2050, as predicted for the region under IPCC climate scenarios (Li et al., 2014). In *Scenario 2* we removed all of the current policies that protect grassland in an attempt to promote restoration. In *Scenario 3* we removed any policy restrictions on cropland expansion, and also forced the rural population (and thus the rural labor force) to increase by holding constant the proportion of the population that is urban, rather than allowing it to increase according to present day trends. *Scenario* 4 is our "Worst Case" scenario; we assume a decline in precipitation trends, no restriction on cropland expansion, no policies to protect grassland and an increase in the rural population.

RESULTS AND DISCUSSION

Baseline simulation

To validate our model we compared the simulated changes in livestock, cropland, population and urbanization percentage to our historic records. All four corresponded well to the observed trends (correlation coefficients = 0.89 to 0.91; see Figure 2 for grassland and livestock data).

The base run simulation of the dynamics of the human, environmental, and land-use sectors of Xilingol revealed several long-term trends that will affect the future resilience of the Plateau. Consistent with the historical data, the total area of grassland decreased in the 1990s, during the period of grazing intensification, stabilized through the early 2000s, then steadily increased over time after grassland protection policies were implemented around 2005. Future predictions suggest the total grassland area continues to increase over time (Figure 2e), but never completely rebounds to the level at the start of the simulation, due to the slow rates of vegetative succession and restoration.

Cropland area remains fairly steady over time under the base run, due to the assumed continuation of current policies that restrict agricultural expansion (Figure 2c). Policies restricting livestock density and introducing subsidies were initiated in the early 2000s in an attempt to combat desertification due to overgrazing. Livestock population dropped significantly after that point (Figure 2d). The population is predicted to continue to decrease into the future as well, and this is largely due to increasing urbanization resulting in a lower rural workforce available for herding. Concomitant with the decline in livestock numbers, the amount of biomass remaining at the end of the year (a proxy for overgrazing) is predicted to increase over time (Figure 2f).

Scenarios

Several key findings or trends were robust throughout our predictions. First, a continued increase in urbanization removes a significant amount of pressure from the grassland system. In fact, the projected steady decrease in livestock population over time alleviates degradation pressure on the grasslands even under fairly extreme decreasing trends in precipitation. However, that trend assumes the continuation of the current policies promoting protection and restoration of grasslands (via grazing prohibitions and active restorations). In the absence of such policies, grassland area declines steadily (Figure 2e, Scenario 4).

We modelled several different future climate scenarios by varying precipitation trend, mean and variability. We present the results of a predicted increase of over 40% by 2050 in Scenario 2. However, the amount of biomass remaining at the end of the year, per unit grassland, is predicted by the model to rise over time under all climate scenarios, even those with declining precipitation trends (not pictured). This is due to the previously stated effect of decreasing rural population on livestock numbers and grazing pressure, which is greater than any potential decline in biomass due to drying climate. The one scenario under which remaining biomass declined over time is under the assumption of no change in the proportion of rural population (Scenarios 3, 4). Under that scenario rural population increases over time, rather than declines, resulting in an increasing in grazing pressure due to livestock population density (Figures 2b, d).

CONCLUSION

The model we present provides somewhat hopeful predictions for the future resilience of the rangelands in Inner Mongolia. This resilience is reliant on two factors, namely the continuation of grassland protection policies and continued rural-urban migration. It is unclear how sustainable this urban migration might be, and how such a demographic shift might affect food security or increase demand for cultivated lands. However, we recognize that in adopting this aspatial approach to modelling the system we must necessarily generalize some trends across what is an admittedly varied region. In particular, we acknowledge that the aridity gradient that exists across the region shapes the relative impacts of climate factors versus grazing on grassland productivity and resilience (Fernandez-Gimenez and Allen-Diaz, 1999). Interpretations of our model predictions must take these distinctions into consideration. Further, it is likely that the predictions we draw from a model built for Xilingol might not translate directly to other parts of the plateau, which face differing socio-economic and environmental dynamics and challenges.

Our goal is to apply system dynamics models at multiple scales in the region, and to parameterize and apply them separately for Inner Mongolia and Mongolia. Our next step is to adapt this model to areas directly across the border in Mongolia. As IMAR and Mongolia have distinct socio-economic and political histories, as well as structures of land use, tenure, and market access (Wang et al., 2013), Mongolia and Inner Mongolia rangelands are likely to respond to alternative future scenarios in very different ways. By comparing these different situations we will gain a clearer understanding of the critical dynamics and drivers for grassland sustainability.

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REFERENCES

Baotana. (2011). *Research on dynamic change of land use in Xilingol*. Inner Mongolia Normal University. (Dissertation in Chinese)

Chen J, John R, Zhang Y, Brown D, Batkhishig O, Amarjargalj A, Ouyang A, Dong G, Qi J. (2015). Divergences of two coupled natural and human systems on the Mongolian Plateau. *BioScience* (in press).
Fernandez-Gimenez ME, Allen-Diaz B. (1999). Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology,* 36, 871-885.
Kawada KW, Nakamura T. (2011). Land degradation of abandoned croplands in the Xilingol steppe region, Inner Mongolia, China. *Grassland Science*, 57, 58-64.
Kolas A. (2014). Degradation discourse and green governmentality in the Xilinguole grasslands of Inner Mongolia. *Development and Change*, 45, 308-328.
Li W, Huntsinger L. (2011). China's grassland contract policy and its impacts on herder ability to benefit in Inner Mongolia: tragic feedbacks. *Ecology and Society*, 16, 1.
Li Q, Tuo D, Zhang L, Wei X, Wei Y, Yang N, Xu Y, et al. (2014). Impacts of climate change on net primary productivity of grasslands in Inner Mongolia - ProQuest. *The Rangeland Journal*, 36, 493–503.
Taylor JL. (2006). Negotiating the grassland: the policy of pasture enclosures and contested resource use in Inner Mongolia. *Human Organization*, 65, 374-386.
Wang J, Brown DG, Chen J. (2013). Drivers of the dynamics in net primary productivity across agro-ecological zone on the Mongolian Plateau. *Landscape Ecology*, 28, 725-739.
Wang J, Brown DG, Agrawal A. (2013). Climate adaptation, local institutions, and rural livelihoods: A comparative study of herder communities in Mongolia and Inner Mongolia, China. *Global Environmental Change*, 23, 1673-1683.
Williams DM. 1996. Grassland enclosures: catalyst of land degradation in Inner Mongolia. Human Organization, 55: 307-313.
Xie Y, Sha Z. (2012). Quantitative analysis of driving factors of grassland degradation: a case study in Xilin River Basin, Inner Mongolia. *The Scientific World Journal*, [doi: 10.1100/2012/169724].

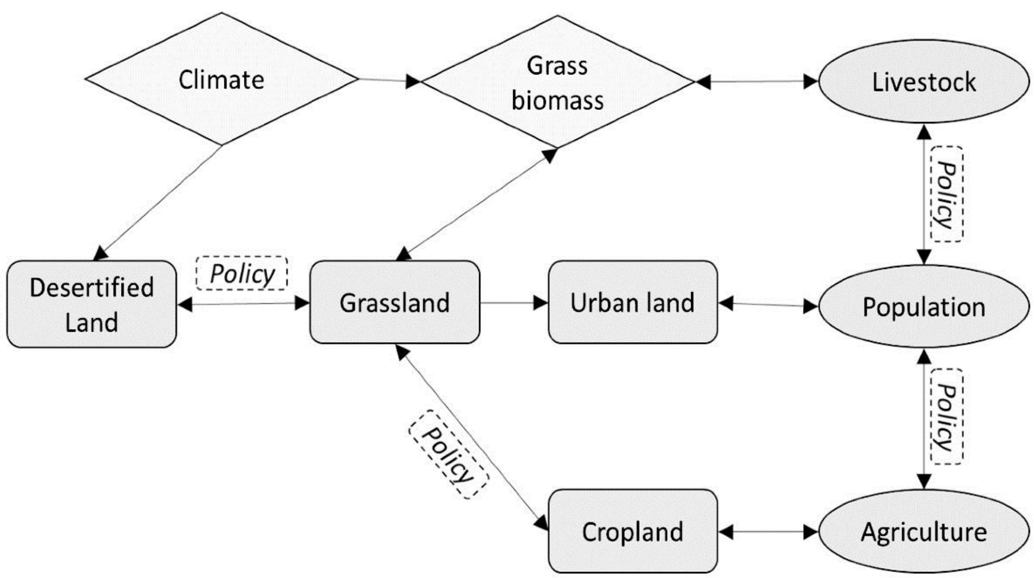

Figure 1. Conceptual diagram of the structure of the system dynamic model for Xilingol League.

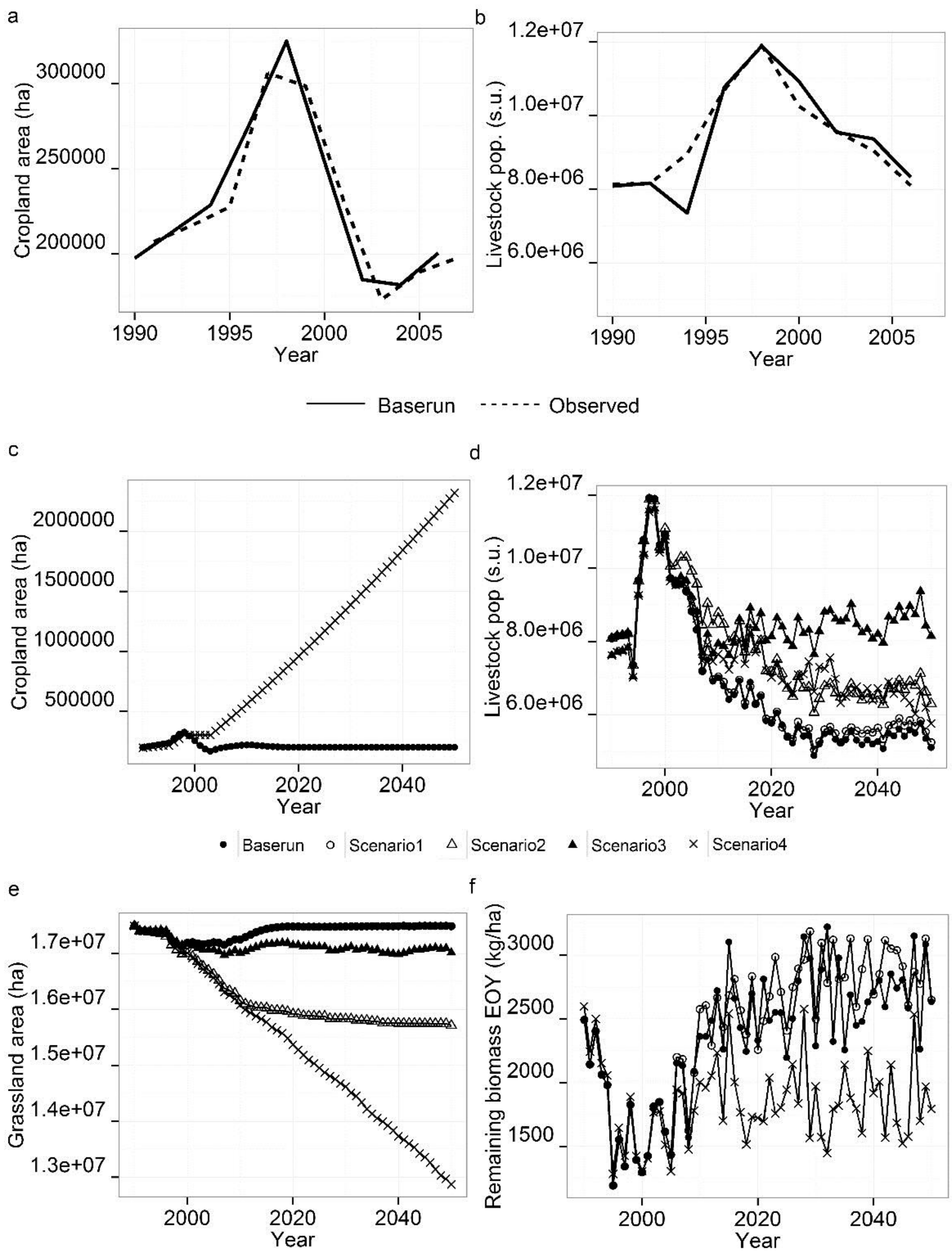

Figure 2. Model validation and comparison of scenarios. Validation: (a) Timeseries of observed cropland area plotted against the area predicted by the baseline model; (b) Observed livestock population