Organized by:

BUILDING RESILIENCE OF MONGOLIAN RANGELANDS

A TRANS-DISCIPLINARY RESEARCH CONFERENCE

June 9-10, 2015

Sponsored by:

Tsogt Print 2015. Printed in Ulaanbaatar, Mongolia

ISBN-978-99962-971-7-5

ISBN 978-99962-971-7-5

Proceedings of Building Resilience of Mongolian Rangelands: A Trans-disciplinary Research Conference, Ulaanbaatar, Mongolia, June 9-10, 2015

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Contents

Acknowledgement of Conference and Proceedings Funders

The Organizing Committee of the Building Resilience of Mongolian Rangelands: A Trans-disciplinary Research Conference would like to acknowledge all supporters and organizers of this conference.

Major funding for this conference was provided by the US National Science Foundation (CNH Program Grant No. BCS-1011), the Embassy of the United States of America, and The Reed Funk Foundation Account at Utah State University. Additional support was provided by the Climate-Resilient Rural Livelihoods Project (JFPR 9164-MON) funded by Japan Fund for Poverty Reduction administered by Asian Development Bank, The Nature Conservancy's Mongolian Program, The Sustainable Fibre Alliance and Land Test LLC.

We thank our colleagues and partners from Colorado State University's Warner College of Natural Resources, Nutag Action Research Institute, American Center for Mongolian Studies, Research Institute of Animal Husbandry, Institute of Meteorology, Hydrology and Environment, Mongolian University of Life Sciences, Institute of Geography and Geo-Ecology, Mongolian Foundation of Science and Technology, Mongolian Society for Rangeland Management, and the Center for Nomadic Pastoralism Studies for their collaboration and support in preparing for this conference. All these contributions have been instrumental in maintaining this highly successful program.

CLIMATE-RESILIENT RURAL LIVELIHOODS PROJECT (JFPR 9164-MON) INTRODUCTION

The Climate-Resilient Rural Livelihoods (JFPR 9164-MON) Project is a program that is being implemented in Buutsagaan, Zag and Khureemaral *soums* of Bayankhongor *aimag* from June 2012 to June 2016, funded by Japan Fund for Poverty Reduction administered by Asian Development Bank. The total project budget is 2.8 million US dollars, out of which 2.5 million dollars are granted by Japan Fund for Poverty Reduction, 298.4 thousand dollars are allocated from the Mongolian Government and 61.6 thousand dollars are being collected by herders' involvement.

The objective of the project is to improve the adaptation of the livestock industry to climate change while promoting sustainable livelihoods for herders in the three target *soums*. To achieve this objective the following components are being implemented: (a) improving local capacity for sustainable herding, (b) establishing and managing water points, (c) diversifying and enhancing income generation, and (d) providing effective project management. The herders of the above-mentioned *soums* are the target group who receives the benefits of the project, and the project is focused on facilitating them to jointly implement rangeland management, enhance their incomes and acquire knowledge and experience in the above-mentioned directions.

The project's first component is to support herders in forming organized groups to sustainably implement pasture management plans in the long-term and improve them as need arises, and supporting the work to improve the adaptation of livestock industry such as hay and fodder preparation, enhancement of winter livestock shelters, improving of livestock health conditions and etc.

The second component is to promote participation of herder groups in rehabilitating and constructing new engineered deep wells and rehabilitation of damaged wells, as well as promoting herders to increase pasture water supply by protecting wells and headsprings sources, and to appropriately use water points in a long-term.

The third component includes supporting herders to integrate into cooperatives with purpose of enhancing their livestock and non-livestock income opportunities, and creating opportunities to get trained in business strategies and management. This will contribute to reduction of risks of herders' dependence on climate change.

The fourth component includes the establishment of successful project management and implementation that include step-wise implementation of the project activities, developing local leadership, preparing the project manuals, conducting baseline surveys, engaging *aimag*, *soum* and *bag* governments and specialists in the project implementation, and preparing and submitting timely project progress reports and financial statements.

The Climate-Resilient Rural Livelihoods Project is providing support in organizing the “Building Resilience of Mongolian Rangelands” scientific conference and provides financial assistance in printing the conference proceedings.

The Climate-Resilient Rural Livelihoods
Project Implementation Team

Building Resilience of Mongolian Rangelands: A Trans-disciplinary Research Conference – Preface

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ABSTRACT

Mongolia is a semi-arid and arid country in Asia where the climate has been changing more drastically than many other locations across the globe. The proceedings of the "*Trans-disciplinary Research Conference: Building Resilience of Mongolian Rangelands*" is divided into five sections: 1) Rangeland Ecology and Management, 2) Climate Change and Hydrology, 3) Institutional Innovations in Mongolian Rangelands, 4) Social and Economic Development in Rural Mongolia, and 5) Methods of Knowledge and Data Integration. The papers presented provide cause for concern regarding observed changes in climate, rangeland conditions and livestock populations, as well as reasons for hope and motivations for action to address the current challenges. We hope that this volume and the conference it accompanies, will inspire renewed commitment to support science and science-based policy-making and management to sustain Mongolia's unique natural and cultural heritage as they adapt to a changing planet.

INTRODUCTION

Mongolian rangelands and the pastoral systems that depend on them are at a potential tipping point. Some research reports widespread grazing- and climate-induced degradation (Liu et al., 2013; Hilker et al.m 2014), while other assessments find that Mongolian rangelands are resilient but at risk (Khishigbayar et al., 2015). Herders observe changes in both climate and rangeland conditions (Bruegger et al., 2014; Fernandez-Gimenez et al., 2015a), and rural poverty remains a persistent challenge. New institutional innovations in rangeland assessment, monitoring and management offer reason for hope (Baival and Fernandez-Gimenez, 2012; Fernandez-Gimenez et al., 2012; Leisher et al., 2012; Upton, 2012; Fernandez-Gimenez et al., 2015b), but scientific evaluations of their process and outcomes are scarce. This trans-disciplinary scientific conference provides a venue for researchers from physical, biological and social sciences to share recent scientific advances in understanding the causes and consequences of rangeland social-ecological transformation in Mongolia, and emerging solutions to climate and socio-economic changes.

BACKGROUND OF THE CONFERENCE

Mongolia's grasslands cover 75% of its land area and support globally important wildlife populations as well as a vibrant nomadic culture whose herds depend on the steppe for their sustenance. The average annual temperature in Mongolia has risen by 2.1 over the past 60 years (Dagvadorj et al., 2014), one of the steepest increases on Earth. Since the transition to a democracy and market economy in 1992, poverty in rural areas has grown from zero to over 35% of the population. As a result, herding families are increasingly vulnerable to severe weather events, such as the winter disasters (*dzud*) of 1999-2002 and 2009-2010, as well as volatility in world markets. At the same time, the number of livestock grazing Mongolia's steppes has increased, leading to concern for the future sustainability of the steppes and the people and animals that depend on them. To address these concerns, over 2000 formally organized herder groups formed since 1999 to help empower and educate herders to manage their lands and herds sustainable (Mau and Chantsalkham, 2006). This movement, called community-based rangeland management (CBRM), is unprecedented in the world and offers an unparalleled opportunity to learn from the outcomes of grassroots collective action, and put this knowledge to work designing better policies and practices.

The Mongolian Rangelands and Resilience (MOR2) project is a collaborative, interdisciplinary research, education and outreach project that seeks to understand the impacts of climate and socio-economic change on Mongolian rangelands and pastoral people, and to identify the management practices and institutions that build rural community resilience and improve rangeland sustainability. This project grew out of a collaborative research planning meeting held in Ulaanbaatar in June 2008, in which herders, Mongolian and US scientists, donors and policy-makers met to identify critical questions facing Mongolia's rangeland systems and pastoral communities. At this meeting, participants collaboratively designed a country-wide research program to understand how livestock grazing and climate change are affecting the condition of Mongolia's rangelands across multiple ecoregions, and whether and how institutional innovations such as formally organized community-based rangeland management (CBRM) are affecting rangeland health and pastoral livelihoods and social conditions.

The overarching objectives of the MOR2 project are to: 1) assess the vulnerability of Mongolian pastoral systems to climate change; 2) evaluate the effects of community-based rangeland management on the resilience of Mongolian pastoral systems; 3) strengthen linkages between natural resource science and policy-making in Mongolia; and 4) build the capacity of Mongolian and US scientists and students to analyze the dynamics of complex natural-human systems.

The *Building Resilience of Mongolian Rangelands Conference* brings together researchers from Mongolia and around the world to share what we have learned about the dynamics and vulnerability of Mongolia's rangelands and the potential for new innovative solutions to the challenges Mongolia's pastoral communities and ecosystems face. In addition, this conference provides a scientific foundation for policy recommendations grounded in the empirical findings included in this volume. Finally, it provides an opportunity for all participants to participate in an international scientific conference and publish in this peer-reviewed conference proceedings, advancing our capacity-building objective.

In this preface to the proceedings, we briefly summarize key findings within and across the major conference themes: rangeland dynamics and changes, climate and hydrological changes and impacts, institutional innovations for rangeland management, rural social and economic development, and methods to advance knowledge and data integration in transdisciplinary research.

RANGELAND ECOLOGY AND MANAGEMENT

To manage rangelands sustainably, it is essential to understand the differences in ecological capacity of different soil and vegetation types across the landscape, and the distinct ways that different plant communities respond to management and disturbance. Heiner et al. and Bulgamaa et al. both propose improved approaches to classifying ecosystems (Heiner) and soil-plant complexes (Bulgamaa), also referred to as ecological sites—a type of land with the potential to produce a certain kind and amount of vegetation (Bestelmeyer and Brown 2010), as determined by climate, landform and soil type. The ecosystem-scale classification proposed by Heiner is based on a combination of satellite (remotely sensed) data and field validation plots, and is useful for conservation planning at the ecoregional scale. The ecological site classification advanced by Densambuu is based on extensive field sampling and forms the basis for soum-level rangeland assessment, planning and monitoring. Together these classifications should help inform conservation and rangeland planning in the future and both local and regional scales.

Amartuvshin et al. and Baasandorj et al. inform current knowledge of rangeland dynamics using observational studies of vegetation response along grazing intensity gradients. Amartuvshin et al. confirm that different desert steppe plant community types respond differently to grazing, but the three communities studied all show a gradient in the cover of perennial grasses with increasing distance from a water point, where grazing pressure is presumed to be heaviest. Baasandorj et al. sampled soils along gradients from winter camps in three ecological zones and found that bulk density was highest close to the camps, where trampling is greatest, and that humus, soil carbon, nitrate, phosophorous and potassium generally increased with increasing distance from camps.

Tserendulam observed the phenology of two important feathergrass (*Stipa*) species in Hustai National Park over 10 years found that climate variables correlated with each phonological stage varied with species and topographic location. Only one species (*Stipa krylovii*) in one plot significantly shifted phenology over the observational period.

The question of whether Mongolia's rangelands are overgrazed has been the subject of public and scientific debate. While one recent broad-scale remote sensing study claims that observed declines in greenness (a proxy for vegetation production) are correlated with increases in livestock density (Hilker et al. 2014), a recent field study in three ecozones within Bayankhongor Aimag found that rangelands are resilient but potentially at risk (Khishigbayar et al. 2015) and another study of winter-grazed pastures across 4 ecological zones in 10 aimags found that these pastures showed little evidence of degradation (Chantsallkham 2015). Gao et al. conducted a novel country-wide analysis comparing stocking densities and forage availability to calculate percent forage use over time in all Mongolian *soums* from 2000-2014. Contrary to reports of widespread overgrazing, they found that heavy stocking was pervasive on about a third of Mongolia's rangelands with 11% experiencing consistent overgrazing (more than 70% use for 10 or more years out of the 15 year period assessed). A remote sensing study of Gobi Altai *Aimag* by Vova et al. advances methods for using remote sensing to detect land degradation, but found no net change in degradation over a 13 year period of observation. In another country-wise study, Kang et al. used remote sensing, climate and livestock data to assess the predictors of livestock mortality in *dzud*, finding that the causes are spatially variable across the county, but that temperature, precipitation and production play important roles.

Together, these studies provide important tools and results to inform the assessment and management of Mongolia's rangelands and the livestock populations that graze them. Moving forward, it will be ever more critical for Mongolia to adopt a uniform system for classifying, assessing and monitoring rangeland conditions and to make use of both field-based monitoring to assess changes in species composition as well as remote sensing, meteorological and livestock census data to forecast forage availability in relation to livestock forage demand, and the probability of forage shortages or extreme weather events.

CLIMATE CHANGE AND HYDROLOGY

How climate change will unfold and its current and future impacts on Mongolia's rangelands and pastoral economy are themes of critical concern to scientists, policy-makers and herders. Venable et al. used gridded data to track changes in temperature and precipitation over the past 50 years across Mongolia, finding significant increases in minimum and maximum temperatures for all and most of the country, respectively, with significant declines in precipitation over 25-30% of the country. These results largely confirm past analyses based on station data with a few important differences. Hessl et al. used tree-ring methodology to track changes in drought over centuries, demonstrating that the early 21st century droughts are the most severe in 1100 years (Hessl et al.). Wolf and Venable examined tree-ring correlations with seasonal precipitation regimes. Kenner et al. determined minimum flows of the Orkhon River required to maintain ecological function. As Mongolia considers water storage projects (reservoirs) to address increasing climate variability, understanding flow regimes is essential to implementing adaptive management. Fassnacht et al. described the hydraulic conditions of the internally draining Tuin River, laying the groundwork for future hydrologic modelling of climate change scenarios.

INSTITUTIONAL INNOVATIONS

The dramatic socio-economic and political changes of the late 20th century in Mongolia, coupled with sequential severe winter disasters in 1999-2002 and 2009-2010 gave rise to a number of institutional experiments and innovations across Mongolia. Primary among these was the initiation of over 2000 formally-organized, donor facilitated community-based rangeland management groups. Several papers in this proceedings report on the social and ecological outcomes of these formally organized groups, which demonstrate significant social outcomes, dependent on key facilitating factors and donor approaches (Ulambayar et al), but only slight ecological benefits to date (Reid et al, Angerer et al). Livelihood outcomes have also been modest but Solongo and Batkhishig and Ulambayar et al. show that households belonging to formal CBRM groups have more diverse income streams and more non-livestock income sources than other households, which may reduce their vulnerability to climate and socio-economic shocks.

Thrift and Byambabaatar identify shortcomings in CBRM approaches to risk management, and advise that greater attention is needed to the role of herder-non-herder social networks that transcend local social groupings and link rural and urban households. Murphy shows how herder views about institutional change, especially property rights, may be conditioned by recent climatic and pasture conditions, alerting us to the potential for institutional transformation to be triggered by such events. Upton and colleagues assess the potential for novel payment for ecosystem services schemes that link ecological and cultural services.

Several papers on the history of land tenure in Inner Mongolia and the attitudes and preferences of Inner Mongolian pastoralists provide a useful comparative contrast to Mongolia's institutional context. Zhang and Amarjargal review the theoretical basis for managing the commons, and then compare and contrast the evolution of pastoral property rights in Inner Mongolia and Mongolia. Reporting on a survey of Inner Mongolian herders, Xu et al. report that the majority currently graze within fenced pastures with a small minority continuing traditional nomadic movements. Most herders report satisfaction with their current management, and perceive that fencing combined with grazing prohibition, controlled stocking or rotational grazing are the most effective means of restoring pastures.

In sum, recent decades have brought promising institutional innovations to Mongolia, and the research reported here shows that formal community-based management organizations demonstrate significant social outcomes compared to informal herder neighborhoods. Other studies in this volume suggest that institutional innovations may not provide all the benefits expected and that approaches to major policy changes, such as pasture possession leases, should be cautious.

RURAL SOCIAL AND ECONOMIC DEVELOPMENT

In the wake of the transition to a market economy and the recent mining boom, the future of rural social and economic development and the pastoral economy remain in question. Papers in this volume explore multiple dimensions of rural development from the through reducing vulnerability and improving the economic and ecological sustainability of livestock production, and understanding the economic impacts of mining.

Altanbagna et al. present a case study applying an integrated vulnerability index that integrates different ecological sources of vulnerability for livestock production including the frequency and intensity of drought and *dzud*, vegetation production, hay and fodder storage, and surface water among others. Suvdantsetseg et al. report on a test of a new text message (SMS)-delivered early warning system for disasters (*dzud*), which would provide herders real-time information on weather and forage conditions and encourage them to prepare for severe weather events, enhancing their adaptive capacity.

Ge and Kinnucan assess the potential effects of Mongolia's mining boom on Mongolia's agricultural economy, diagnosing an incipient case of "Dutch Disease" whereby a commodity boom leads to currency appreciation, decline in the strength of other economic sectors, potentially increasing vulnerability to future economic shocks. Using employment survey data for the entire country, Amarjargal et al. examine whether mining is affecting migration patterns within Mongolia and conclude that is not. This suggests that mining is not producing sufficient local economic benefits to motivate herders to immigrate from other *soums* to mining *soums* in order to share in these economic opportunities. Yan et al. propose an agent-based model of meat distribution in Mongolia to help improve the quality of meat, its distribution and improve terms of trade and incentives for quality production over livestock quantity in rural Mongolia.

These papers address diverse challenges and opportunities facing rural Mongolia at the beginning of the 21st century. Though the challenges are great, and the impacts of the mining boom requires further study, these contributions suggest how technological innovations from SMS to refrigeration could improve herder livelihoods while helping to protect the resource base on which they depend.

METHODS OF KNOWLEDGE AND DATA INTEGRATION

The study of complex natural-human systems requires new tools to organize, integrate and analyze disparate types of data and the relationships that link biophysical and social systems. Further, research that aims to solve applied problems and empower non-scientists to participate meaningfully in the scientific process calls for novel approaches to knowledge integration and cross-sectoral participation in research. In this section of the volume, authors share a diverse set of approaches to organizing, integrating and analyzing diverse data and knowledge sources.

Laituri et al. report on the process of assembling and organizing a multi-scale holistic database of physical, ecological and social data from the Mongolian Rangelands and Resilience (MOR2) Project, identifying key challenges and lessons learned that can inform future efforts. Allington et al. demonstrate how dynamic modelling can be used as an integrative analytical approach to understand coupled system dynamics. Using data from Xilingol, Inner Mongolia they created a dynamic model that integrates human population, land use, grazing policies and climate and validated the baseline scenario against historic trends in the Xilingol area. Comparing the baseline with four potential future scenarios which varied with regard to human population, policies and rainfall, the model predicted increases in rangeland biomass under all scenarios, including a scenario of declining precipitation, except when the proportion of rural inhabitants remained constant instead of declining or current policies restricting grazing were removed.

Several contributions address ways to incorporate herder knowledge into research. Allegretti et al. advance participatory mapping and analysis of resulting maps and map narratives as a method to document both intangible and visible boundaries into our understanding of landscape and institutional dynamics, with potential implications for future pastoral land use policy. Fernandez-Gimenez et al. and Odgarav et al. both combine herder observations of climate and rangeland change with instrument-based meteorological and vegetation observations, illustrating the complementarity between these approaches and highlighting the potential need for more fine-resolution weather and rangeland monitoring.

CONCLUSIONS

While this volume does not encompass all of the excellent research underway to understand the dynamics of biophysical, social and economic change in rural Mongolia, it provides summaries of some of the most important recent advances in knowledge, with an emphasis on innovations in governance, marketing, communication and trans-disciplinary research. As such, the papers presented provide cause for concern regarding observed changes in climate and rangeland conditions and livestock populations, as well as reasons for hope and motivations for action to address the current challenges. We hope that this volume and the conference it accompanies, will inspire renewed commitment to support science and science-based policy-making and management to sustain Mongolia's unique natural and cultural heritage as they adapt to a changing planet.

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1 Rangeland Ecology and Management

Defining the Ecological Site Descriptions and its Use as a Rangeland Management Tool in Mongolia

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ABSTRACT

The concept of classifying any area into ecological sites, according to that area's productivity, based on varying soil, climatic and hydrological conditions, and its capacity to endure different intensities of use and to recover from degradation, and of using this classification as a basis of rational use of natural resources is more and more recognized internationally.

Since 2009, the Green Gold Project funded by the Swiss Agency for Development and Cooperation (SDC) has been exploring opportunities to develop the ecological site description (ESD) concept for Mongolian rangelands and use it as an essential tool of rangeland management. Based on soil, vegetation and geomorphological data collected from approximately 500 points representing nationwide environmental zones, we developed the ESD concept for the Mongolian context. According to this concept Mongolian rangelands are divided into some 20 zones, representing distinct ecological potentials. Based on these plot data and state and transition models a preliminary conclusion is made that over 65 percent of Mongolian rangeland has, with varying degrees, altered from its reference state, and 80 percent of this area has potential to recover through changes in rangeland management.

The main objective of this research was to identify, for each environmental zone, the main factors that determine rangeland ecological potential, to develop the ESD concept and to test the possibility of using it in rangeland management. The novelty of this study, as well as its scientific and practical significance, lie in development and testing of a more detailed classification based on ecological potential within Mongolian ecological zones and geo botanical regions. This approach is significant because the classification may be used as an essential tool for rangeland use planning, implementation and monitoring, as well as for regulating rangeland use agreements.

Keywords: rangeland ecological potential, rangeland state and transition models, rangeland recovery class classification

STUDY SITES

Field research for determining rangeland ecological potential (ESDs) and the main defining factors was conducted between 2009-2012, at approximately 500 points representing nationwide ecological zones. The monitoring research for the purpose of testing proposed versions of the concept of ecological capacity was undertaken between 2012-2014, in four *soums* representing a range of environmental zones in Mongolia, under the auspices of Pasture Users Groups or PUGs formed in the frame of Green Gold Project.

METHODS

At each point we collected data on soil (soil texture, clay content, color, texture and carbon property, and gravel stone content), vegetation data (coverage and species composition, the basal cover, ground cover, basal gap of perennial vegetation, and harvest) using line-point intercept and perennial vegetation basal gap methods, and geomorphological data (altitude, slope, aspect, landform and geographic location) (Herrick et al., 2009; Guideline for meteorology and environmental monitoring, 2011; Caudle et al., 2013).

Topsoil structure, water holding capacity and exposure to erosion were evaluated separately using rangeland health assessment methodology.

We analyzed soil and vegetation data using Detrended Correspondence Analysis (DCA) and Principal Components Analysis (PCA). The classification by division into ecological zones for every environmental region was reflected into a Mongolian soil and vegetation map and “Rangeland monitoring validation” reports and was brought up for discussion by researchers, rangeland specialists and herdes representatives. This classification is currently in the finalizing stage.

The opportunity to use rangeland ecological capacity data as a basis for rangeland management was experimentaly researched in four *soums* representing a range of ecological zones. The following indicators were studied: 1) PUG herders’ and local specialists’ participation and initiative, 2) rangeland use plan realization rate, 3) impact of rangeland management on total and dominant plant species’ cover, and 4) the budget amount invested in rangelands locally.

RESULTS

The results of statistical analysis show that the main factor of determining Mongolian rangeland ecological capacity is the level of moisture in the soil used by vegetation. The principal factors that define soil moisture levels include soil texture, elevation, and landform. These in turn strongly influence vegetation community structure and productivity (Bulgamaa et al., 2013; Budbaatar et al., 2014).

According to the DCA analysis, most of the variation in plant species was explained by first two axes (Figure 1), with eigenvalues of 0.56 and 0.27 respectively. In the first axis the variation in plant species is the most dependent on elevation according to which the points differ from each other. From the Figure 1, it is seen that the major indicators of determining vegetation structure and composition (capacity) of points are soil texture and land form, the indicators which actually define rangeland ecological capacity (Sumjidmaa, 2014).

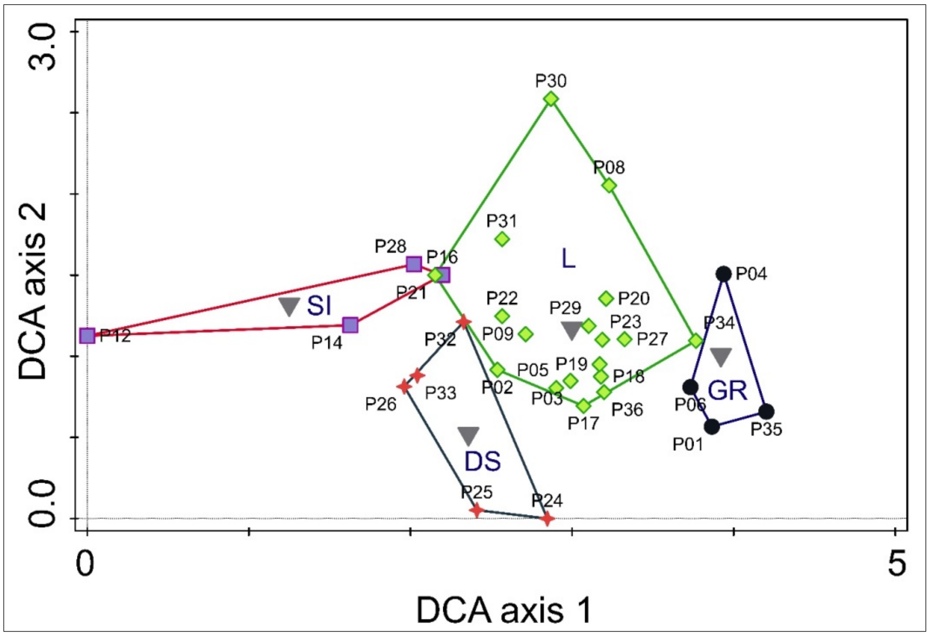

Figure 1. The results of DCA analysis that was done using vegetation cover and ecological site groups classification of the research of steppe zones representative points. In the diagram points marked with circle shapes represent Gravelly hills ecological site group, diamond shapes represent Loamy fan and mountain valley ecological site group star shapes represent Deep sandy ecological site group in mountain valley, and square shapes represenent high water table ecological site group. Downward triangle shapes represent ecological sets as follows: SI = Meadow, moist soil set; DS = Mountain lower slope and valley, grainy sand soil set; GR = Mountain and hill, stony soil set; L = Mountain lower slope and valley, clay soil set.

Mongolian rangeland, based on its ecological potential is classified into following ecological site groups (ESGs):

1. Gravelly hills ESG (in the forest steppe and the steppe zones)
2. Loamy fan and mountain valley (in the forest steppe and the steppe zones)
3. Sandy loam plain ESG (in the forest steppe zone)
4. High water table ESG (in the forest steppe and the steppe zones)
5. Deep sandy alluvial plain ESG (in the steppe zone)
6. Sandy plain ESG (in the desert and semi-desert steppe zones)
7. Gravelly hills ESG (in the desert and semi-desert steppe zones)
8. Lowland meadow salt marsh soil set (in the desert and semi-desert steppe zones)
9. Salt marshes (in the desert and semi-desert steppe zones)
10. Wet depressions (in the desert and semi-desert steppe zones)

From the ecological site groups' rangeland state and transition patterns we observed that in the forest steppe and steppe zones, relatively many ecologically unstable systems emerge, while in the desert and semi-desert zones, there are relatively few variations in systems. In other words, the forest steppe and steppe zones state shows that these zones are highly influenced by use, and consequently show more change.

According to the results of PCA analysis, based on four vegetation species cover, which are the dominant species in Mountain lower slope and valley, clay soil zone where the Krylov's feather grass community is present, the first two axes explain the most variation (Figure 2). Also according to the second axis, the livestock grazing is likely to influence, and as a result of the cover of main community function plants, such as *Stipa krylovii, Artemisia frigida, Carex duriuscula* and *Artemisia adamsii*, and their involvement particular rangeland state is being changed and transformed (Chognii, 1978; Ankhtsetseg et al., 2014; Sumjidmaa, 2014).

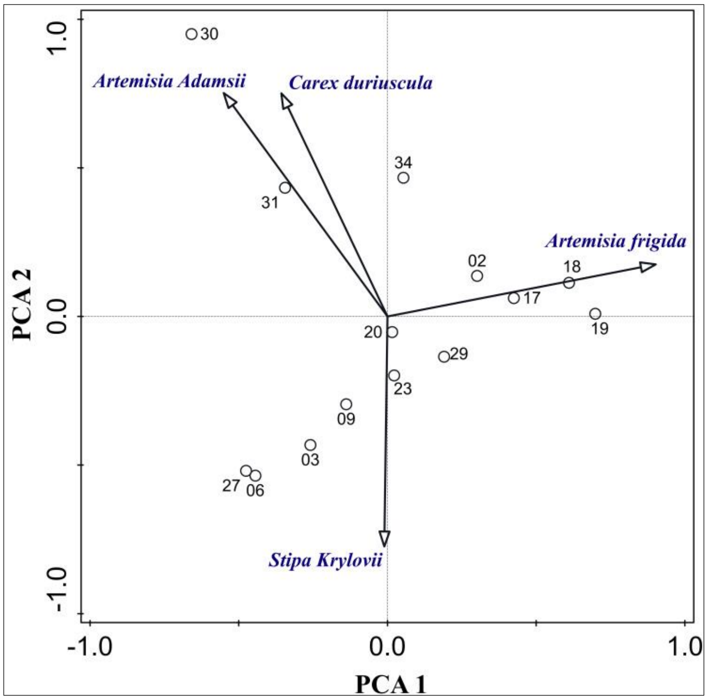

Figure 2. The results of Principal Correspondence Analysis (PCA), based on four vegetation species cover which are dominant in the Steppe zone with Krylov's feather grass community.

Based on the assessment all points of rangeland monitoring according to the concept of rangeland ecological capacity, and transition patterns, the preliminary conclusion is made that over 90 percent of the Mongolian rangeland has shifted from its original state, most of which has high capacity to naturally recover and regrow, having not yet crossed an ecological threshold (National Report of Mongolian rangeland state, B.Bestelmeyer, 2014).

The research of opportunity to use rangeland ecological capacity data as a basis for rangeland management was done and according to its results, the participation and initiative of local specialists and herders, that are involved in planning, implementation and monitoring of the impact of implementation works, have substantially increased. Also along with it the rate of realization of rangeland use plans, compared to the previous years, has grown up to 35-43 percent, and budget amount invested into rangeland locally equaled 30-80.0 million tugriks. This suggests a beginning of a positive tendency which provides hope of rangeland ecological capacity data being used as a basis for rangeland management.

IMPLICATIONS

Mongolian rangelands are divided into around 20 ecological site groups, based on their productivity and capacity to endure different intensities of use, and to recover and regrow after being used. In general the Mongolian rangeland has considerably high capacity to recover and regrow.

Rangeland ecological capacity data is not only an essential tool used in rangeland management, but also can be an instrument for the establishment of appropriate natural resource use, protection and restoration.

The rangeland ecological capacity, including rangeland state, transition patterns can be used as a basic document for regulating relationships between rangeland users and lessee parties.

ACKNOWLEDGEMENTS

Our deep gratitude to the donor of this research program, the Swiss Agency for Development and Cooperation in Mongolia and to cooperating specialists from USDA Agricultural Research Service Jornada Research Station for providing study and guidance on methods.

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Towards a National GIS Model to Map Terrestrial Ecosystems in Mongolia: A Pilot Study in the Gobi Desert Region

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ABSTRACT

In Mongolia, partners from national and aimag governments, academia and NGOs have developed regional conservation plans that balance the government commitment to protection of natural habitats with planned development of mineral resources and related infrastructure. A key input is a mapped classification of major habitat types, or ecosystems, to represent the range of natural habitats and function as a surrogate for biodiversity. We developed a GIS model to map ecosystems across the Mongolian Gobi Desert region by comparing the distribution of plant communities and major vegetation types, taken from field surveys and national maps, with patterns of above-ground biomass, elevation, climate and topography derived from remote sensing. The resulting mapped classification is organized as a hierarchy of 1) biogeographic regions, 2) terrestrial ecosystem types based on vegetation, elevation and geomorphology, and 3) landforms. This provides a first-iteration map to support landscape-level conservation planning and a model framework that can support field surveys and future model revisions, with other applications to land use planning, research, surveys and monitoring. To facilitate that, the GIS results are

publicly available either for download or to view and query in a web-based GIS available at:
<http://s3.amazonaws.com/DevByDesign-Web/MappingAppsVer2/Gobi/index.html>.

Keywords: ecosystems, ecological classification, ecological delineation, GIS, remote sensing, conservation planning

INTRODUCTION

In collaboration with national and provincial governments, Universities and NGOs, TNC has produced landscape level conservation plans for Eastern Mongolia and the Gobi Desert region to guide protection and mitigation (Heiner et al., 2013; Kiesecker et al., 2010). A third assessment of the remaining Central and Western regions will finish in July 2015. A key component of landscape-level conservation planning is a mapped classification of major habitat types, or ecosystems, to represent the range of natural habitats and function as a surrogate for biodiversity.

Since the 1970s, extensive field surveys by joint Mongolian-Russian expeditions have produced several national and regional maps of vegetation and ecosystems (e.g. Vostokova and Gunin, 2005; Yunatov et al., 1979) at map scales of 1:1 to 1:2 million. The applications of these maps are limited by the coarse spatial scale. In recent years, several advances in remote sensing products and tools have enabled vegetation mapping and landscape classification at a finer spatial scale, based on documented, replicable quantitative methods and field data. These include Landsat TM (NASA, 2011) for high spectral resolution image classification, the Normalized Difference Vegetation Index (NDVI) (e.g. MODIS; NASA, 2012) to measure above-ground biomass at a range of spatial and temporal scales, and digital elevation models (DEMs) (e.g. SRTM; NASA, 2005) for measuring elevation and classifying topography or landforms. One advantage of a data-driven modeling approach is that the source data and model can be iteratively revised as new field data becomes available, and initial results can guide spatial sampling of survey design to inform revisions.

In Mongolia, there is a need for a regional-level mapped classification of vegetation and physical habitat that is accurate at a coarse but consistent spatial scale and based on transparent, well-documented methods and source data. Several vegetation maps have been developed using Landsat 5 TM images for National Protected Areas in the Gobi Desert study area (von Wehrden et al., 2006a; von Wehrden et al., 2006b; von Wehrden et al., 2009a). A Landsat-based approach is not feasible for a study area as large as the Gobi Desert region. We developed a GIS model to map ecosystems across the Gobi region by comparing the distribution of plant communities and major vegetation types, taken from field surveys and national maps, with patterns of above-ground biomass, elevation, climate and topography derived from remote sensing. The result is a first iteration mapped classification of the Gobi Desert region to support landscape-level conservation planning, as well as other applications including land use planning, research, surveys and monitoring.

STUDY AREA

The study area is the Mongolian portion of the Central Asian Gobi Desert ecoregion, as delineated by the World Wildlife Fund (WWF) Mongolia Programme Office for the National Gap Assessment (Chimed-Ochir et al. 2010). This region covers 510,000 km^2, or the southern third (32%) of the country, and is a cold desert with a continental climate and long, cold winters. Mean annual precipitation ranges from less than 40 mm in extreme arid areas to over 200 mm in the Gobi-Altai mountains (Hijmans et al., 2005) and inter-annual variation is high.

METHODS

Our approach to developing a mapped ecosystem classification is based on regional mapped classifications of ecological systems developed in the United States and Latin America that define ecological systems as groups of biological communities occurring in similar physical environments and influenced by similar ecological processes. This framework is organized by biogeographic regions (e.g. ecoregions) and four categories of spatial pattern or patch type: matrix, large patch, small patch and linear. As such, this framework considers multiple scales of organization, environmental patterns and processes that influence habitat structure and function, and the classification units are practical to map and identify in the field, thereby addressing a critical need for practical, medium-scale ecological units to inform conservation and management decisions (Comer et al., 2003). For the Gobi Desert region, we developed a terrestrial ecosystem classification that is a hierarchy of 1) biogeographic regions, 2) terrestrial ecosystem types based on vegetation, elevation and geomorphology, and 3) landforms.

1. Biogeographic regions. Biogeographic regions represent broad, regional patterns of climate, physiography and related variation in species and genetics. For most ecosystem types distributed across the study area, stratification by biogeographic zone may capture regional differences in species composition and environmental patterns. To define and map biogeographic zones, we chose the four ecoregions delineated by the National Gap Assessment (Chimed-Ochir et al., 2010): Eastern Gobi, Gobi-Altai Mountain Range, Southern Gobi-Altai and the Dzungarian Gobi Desert. To capture the unique biogeography of the Trans-Altai Gobi Desert in southwestern Mongolia (N. Batsaikhan, pers. comm.), we further divided the Southern Gobi-Altai ecoregion based on the Trans-Altai Gobi Desert Landscape-Ecological zone delineated by Vostokova and Gunin (2005).

2. Ecosystem types. We defined the set of focal ecosystem types based on botanical studies (Grubov, 1982; Hilbig, 1995) and national maps of vegetation and ecosystems (Yunatov et al., 1979; Chimed-Ochir et al., 2010) and developed a GIS model that functions at two levels, or spatial scales. First, matrix-forming types, such as desert steppe, are broadly distributed and mapped here according to coarse-scale patterns of annual productivity, elevation and precipitation. Second, patch-forming types, such as oases or wet depressions, form distinct patches and are mapped here at a relatively fine scale based on topography, surface hydrology and satellite imagery. Source data and mapping methods are listed in Table 1.

Matrix-forming systems cover most of the land area and follow broad patterns of climate and precipitation. These include extreme arid desert, true desert, semi-desert, desert steppe, dry steppe and mountain steppe. In the Gobi Desert region, precipitation, vegetation productivity, and the spatial distribution of plant communities are highly correlated (von Wehrden and Wesche, 2007). Based on this strong relationship, we developed a predictive model of the distribution of general steppe and desert types based on above ground biomass, annual precipitation, and elevation sampled with 1,145 survey records of diagnostic plant communities collected by von Wehrden et al. (2006c, 2006d, 2006e, 2009b) and Wesche et al. (2005). Above-ground biomass is the 11-year (2000-2011) mean NDVI during the growing season (June through September) from MODIS 13A3 (NASA 2012). Precipitation values are 50 year (1950-2000) monthly averages from WorldClim (Hijmans et al. 2005). Based on the results (Figure 1), we chose NDVI thresholds to define six classes of biomass, combined with elevation and landforms to map the predicted distribution of eight matrix-forming vegetation types: barren, extreme arid desert, true desert, semi-desert, desert steppe and steppe. We further divided steppe into dry steppe and mountain steppe based on elevation, and mountain rough terrain based on landforms.

Patch-forming systems include five general types and sets of mapping methods, described below. These five types were identified by experts and in literature (Grubov, 1982; Hilbig, 1995) as important habitat and sources of water and forage that have high value for wildlife, livestock and people. All are groundwater-dependent ecosystems, with sparse and patchy distribution following groundwater hydrology. These systems support high species diversity and provide critical habitat, particularly for small mammals, reptiles and birds, and provide valuable forage for large desert mammals.

- *i.* *Wet depressions*: dry river beds or salty depressions with shallow water table following broad drainage patterns. These areas typically support distinct vegetation types including Saxaul (*Haloxylon ammodendron*) forest stands and Siberian elm (*Ulmus pumila*) and contain physically diverse soil types due to near-surface groundwater and hydrology. We mapped these features using a GIS topographic model that delineates potential riverine wetlands based on regional flow accumulation and local topography of the stream channel (Smith et al., 2008), as derived from a hydrologically conditioned digital elevation model (DEM) at 3 arc-second (77m) resolution (Lehner et al., 2008).
- *ii.* *Dense vegetation*: large patches of closely-spaced tall shrubs and trees, typically near oases, including Tamarisk (*Tamarix ramosissima*), Poplar (*Populus diversifolia)*, Elm and Saxaul. We mapped these features with a soil-adjusted total vegetation index (SATVI) (Marsett et al., 2006) derived from Landsat 5 TM satellite imagery (NASA, 2011) with acquisition dates between June 15 and September 28, 2011. The SATVI was developed specifically to measure above-ground biomass of aridlands vegetation. Dense vegetation in an arid desert setting produces distinct high SATVI values. We classified areas with high SATVI values as dense vegetation, and separated the results by likely water source or hydrology into patches occurring in either a) dry stream beds and wet depressions (described above) or b) spring-fed seeps.
- *iii.* *Ephemeral water bodies*: we digitized the boundaries and point locations of 1,200 water bodies at map scale 1:200,000 through manual interpretation of the 2011 Landsat 5 TM satellite imagery described above.
- *iv.* *Sand massives:* large areas of sand dunes that we digitized manually from 1:200,000 scale topographic maps. The unique hydrology of sand dunes often creates small wetlands that support distinct plant communities and habitat with high species diversity.
- *v.* *Mountain valleys:* mapped as valley bottoms, per the landform classification (described below), in mountain steppe or rugged mountain vegetation, per the matrix-forming ecosystem classification.

3. Landforms. Matrix-forming ecosystem types form a heterogeneous, patchy mosaic of plant communities formed by topography, disturbance regimes and successional cycles. Within these ecosystem types, patterns of plant species composition generally follow topographic environmental gradients. To capture this ecological, environmental and genetic diversity, we stratified these widespread ecosystem types by landforms defined and mapped according to a cluster analysis of a topographic soil moisture index, insolation and terrain ruggedness, derived from a hydrologically conditioned DEM at 3 arc-second (77m) resolution (Lehner et al., 2008), as described in Table 1.

RESULTS

The GIS model maps 15 ecosystem types across 5 biogeographic zones, producing 67 unique combinations of biogeographic region and ecosystem type. Stratifying matrix-forming ecosystem types by landforms produces 193 unique combinations of biogeographic region, ecosystem type and landform. The source data and mapping methods are listed in Table 1 and the result is shown in Figure 2.

A validation using 285 field survey records collected in 2012 yielded an overall accuracy of 65%. These records were collected during three surveys in 1) Gobi-Altai Aimag, 2) Alashan Gobi Desert (Southern Ovorkhangai, Omnogobi around Gobi Gurvansaikhan

National Park, and Dundgobi) and 3) Eastern Gobi Desert (Eastern Omnogobi and Dornogobi). Most of the errors were misclassification of matrix-forming types, and specifically misclassification of true desert as semi-desert in Gobi-Altai Aimag and desert steppe as semi-desert in the Alashan Gobi Desert. The model performed best (80%) in the Alashan Gobi Desert. The error matrix is shown in Table 2.

DISCUSSION

This demonstrates a method for defining and mapping ecosystems across a large region based on limited survey data and globally-available datasets. As such, this type of GIS model can be developed and updated relatively quickly, and the results are appropriate to support landscape-level conservation planning as well as regional land use planning, research, surveys and monitoring. A key assumption is that it is possible to accurately predict and map the distribution of major vegetation types at a simple thematic (formation) level based on globally-available datasets measuring above-ground biomass, elevation and climate factors. The initial validation results appear to support this.

Ecological classification is an iterative process. Additional field validation is a critical next step to test and revise the model using a combination of methods and datasets, including 1) field surveys, 2) research plots established by several long-term rangeland studies, and 3) fine-scale vegetation maps developed for smaller areas within the Gobi Desert study area. The current model results can guide the spatial sampling design of field surveys that will inform future revisions.

All the patch-forming types defined and mapped by this model are groundwater-dependent systems that have high value for wildlife, livestock and people. The model result includes only large patches, due to the coarse spatial scale, and generally does not capture small water sources such as small oases or springs. These features have been mapped in existing 1:100,000 topographic maps, but are often ephemeral.

The model does not explicitly define or map Saxaul forest, which is a unique and productive habitat type and also groundwater-dependent. However, the ‘wet depression’ type may be a useful predictor of Saxaul forest occurring in areas with near-surface groundwater, based on descriptions of Saxaul ecology and site characteristics (Hilbig, 1995) and our field surveys. Saxaul forests have been delineated across Mongolia at a coarse scale for the National Atlas (Dorjgotov, 2009).

The model is based on relationships between spatial distribution of ecosystems and environmental gradients, and does not consider interactions between factors. Many multivariate methods exist for future iterations, including Classification and Regression Tree (CART) analysis and cluster analysis (e.g., hierarchical agglomerative clustering, fuzzy C-means clustering). These methods require field data well-distributed across the study area.

A similar ecosystem mapping and conservation planning process in Western and Central Mongolia will be complete in July 2015. We hope to produce one national GIS model, based on a multivariate model and field survey data, by combining and revising the results from the Gobi Desert region and Eastern, Central and Western Mongolia. That will require a major data mining and data sharing effort among the National University of Mongolia, the Mongolian Academy of Sciences, international researchers and non-governmental organizations (NGOs). One challenge will be classifying and mapping matrix-forming steppe types, including dry-, meadow- and forest-steppe, for which NDVI-derived biomass is not a reliable predictor of plant community composition. To map forest, a promising data source is a high-resolution global dataset predicting percent forest cover derived from Landsat TM (Hansen et al., 2013).

IMPLICATIONS

In the face of rapid development of natural resources, landscape-level biogeographic information is a critical reference for guiding protection, management and mitigation actions. Our results indicate that for arid lands, it is possible to map major vegetation and habitat types according to gradients of biomass and physical environmental factors using globally available datasets and in a relatively short time frame. This information can be the basis for landscape-level conservation planning that is a critical input to effective mitigation of mining and energy development, and can also inform land use planning, research and monitoring.

ACKNOWLEDGEMENTS

The Gobi ecoregional assessment was funded by a generous grant from Rio Tinto to Joseph Kiesecker and Bruce McKenney. The authors wish to thank Munkhzul Ganbaatar and Odonchimeg Ichinkhorloo of the TNC-Mongolia Gobi Desert ecoregional assessment team, the other authors of the assessment report, the project science advisory group and the editorial committee for their valuable advice and input throughout the project.

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Table 1. Terrestrial Ecosystem Classification: Source datasets and mapping methods. The ecosystem classification is organized as a hierarchy of (i) biogeographic zones, (ii) ecosystem types based on vegetation and (iii) landforms.

Biogeographic Regions

Djungarian Gobi, Gobi-Altay, Southern Gobi, Eastern Gobi (Chimed-Ochir et al. 2010)

Trans-Altai Gobi: N. Batsaikhan pers. comm. Digitized from Vostokova and Gunin (2005).

Ecosystems - Matrix-forming follow broad patterns of climate and elevation

barren *extreme arid* * *true desert* * - characteristic desert shrubs, Haloxylon and Rheaumaria, dominate. *semi desert* * - grasses appear, mixed with desert shrubs. *desert steppe* * - Stipa grasses dominate. steppe	• NDVI (MODIS 13A3, 1 km resolution) above ground biomass, growing season (June – Sept.), 11 year mean (2000-2011), classified according to 1,145 survey records of diagnostic plant communities. • elevation • landforms (see below)

dry steppe *: elevation < 1400

mountain steppe (pediments and gentle slopes): elevation > 1400 AND Landform = flat or gentle slopes

mountains rough terrain: elevation > 1400 AND Landform = hills or steep slopes

Ecosystems - Patch-forming follow finer-scale patterns of hydrology and soil types and microclimate.

Wet depressions: dry river beds or salty depressions with shallow water table following broad drainage patterns

small basins: drainage area < 1,000 km^2 large basins: drainage area > 1,000 km^2 mountain valleys: elevation > 1400 m	• DEM-derived topographic model (Smith et al. 2008) at 3-arc second (78m) resolution. • elevation

Dense vegetation: large patches of closely-spaced tall shrubs and trees, typically near oases, including Tamarisk, *Populus*, Elm and Saxaul

seeps: spring-fed dry river beds: shallow water table	• Soil-adjusted total vegetation index (SATVI) from Landsat 5 TM (July -September 2010 and 2011), resampled to 3 arc-second (78m) resolution. • DEM-derived topographic model (Smith et al. 2008) at 3 arc-second (78m) resolution.

ephemeral water bodies	digitized manually from Landsat 5 TM satellite imagery
sand massives	digitized manually from 1:200k topographic maps

Landforms capture finer-scale variation in plant communities following patterns of hydrology, soil types and microclimate. They are used here to stratify five matrix-forming ecosystem types (* labeled above).

rough steep N-facing rough steep S-facing hills N-facing hills S-facing upland low flat depression valley, water track	mapped by cluster analysis of three DEM-derived topographic indices at 3-arc second (78m) resolution: • Topographic moisture index (CTI; Moore et al. 1991) • Insolation (SolarFlux; Rich et al. 1995) • Terrain ruggedness (VRM; Sappington et al. 2007)

Table 2. Accuracy assessment results. Error matrix cross-tabulating observed and modeled ecosystem types to measure producer's accuracy, user's accuracy and overall accuracy based on data from three field surveys. Results varied by region:

1) Gobi-Altai Aimag: n = 94, overall accuracy = 59%.
2) Alashan Gobi Desert (Southern Ovorkhangai, Omnogobi around Gobi Gurvansaikhan National Park, and Dundgobi): n = 70, overall accuracy = 80%.
3) Eastern Gobi Desert (Eastern Omnogobi and Dornogobi): n = 121, overall accuracy = 61%.
4) combined: n = 285, overall accuracy = 65%.

	FIELD SURVEY													
	barren	extreme arid	true desert	semi desert	desert steppe	dry steppe	mountain steppe	wet depression	mountain valley	dense veg riparian	dense veg spring	sand massive	row total	user's accuracy
GIS MODEL														
barren														
extreme arid	1	2	2										5	40%
true desert		5	26	1	2								34	76%
semi desert			20	34	14	2							70	49%
desert steppe				9	54	8	1						72	75%
dry steppe					3								3	0%
mountain steppe					2	1	7						10	70%
wet depression	1		3	7	8			35					54	65%
mountain valley						2			3				5	60%
dense veg riparian					1			3		8			12	67%
dense veg spring								1		1	9		11	82%
sand massive					2							7	9	78%
column total	2	7	51	51	86	13	8	39	3	9	9	7	overall accuracy: 65%	
producer's accuracy	0%	29%	51%	67%	63%	0%	88%	90%	100%	89%	100%	100%		

Figure 1: Vegetation classification based on biomass of diagnostic plant communities.

This box plot shows the distribution of plant community survey records (n=1,145) across the range of 11-year mean NDVI values. Based on the distribution of several diagnostic plant communities, we chose thresholds of NDVI to define six classes of above ground biomass and map matrix-forming ecosystem vegetation types.

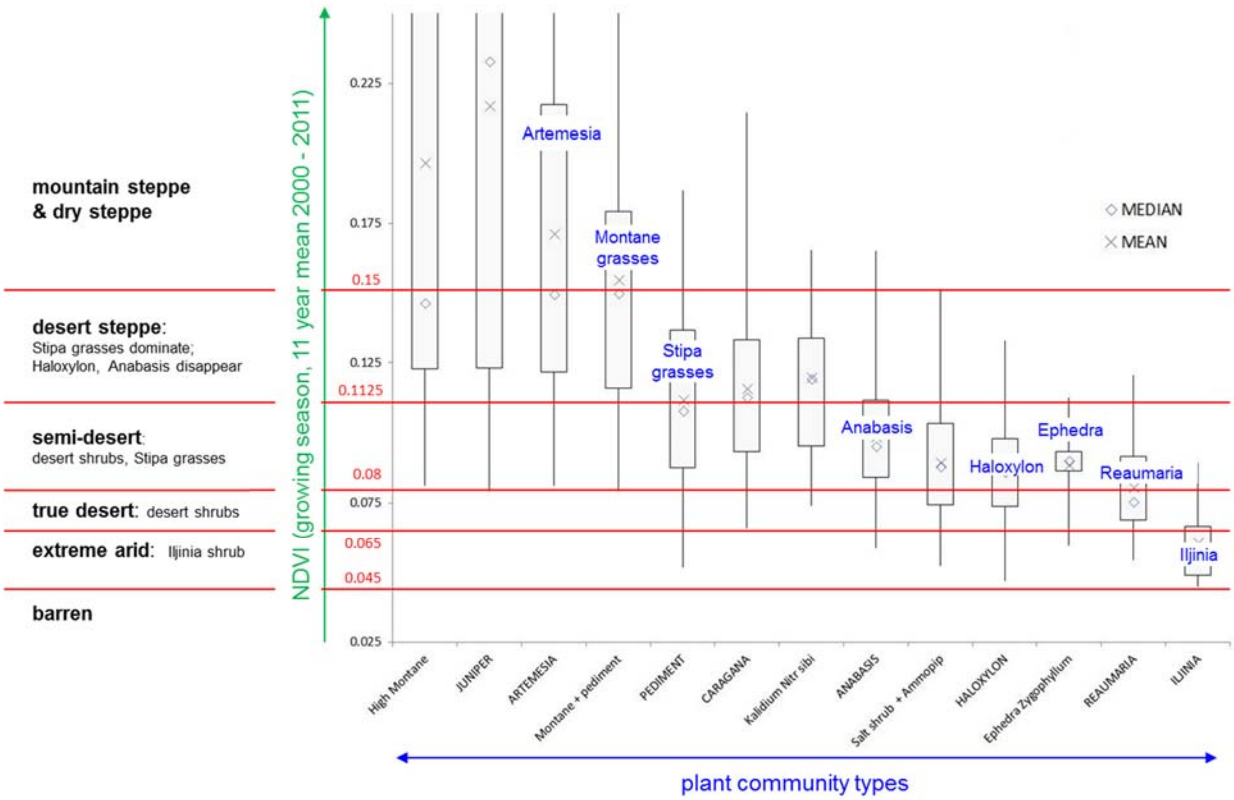
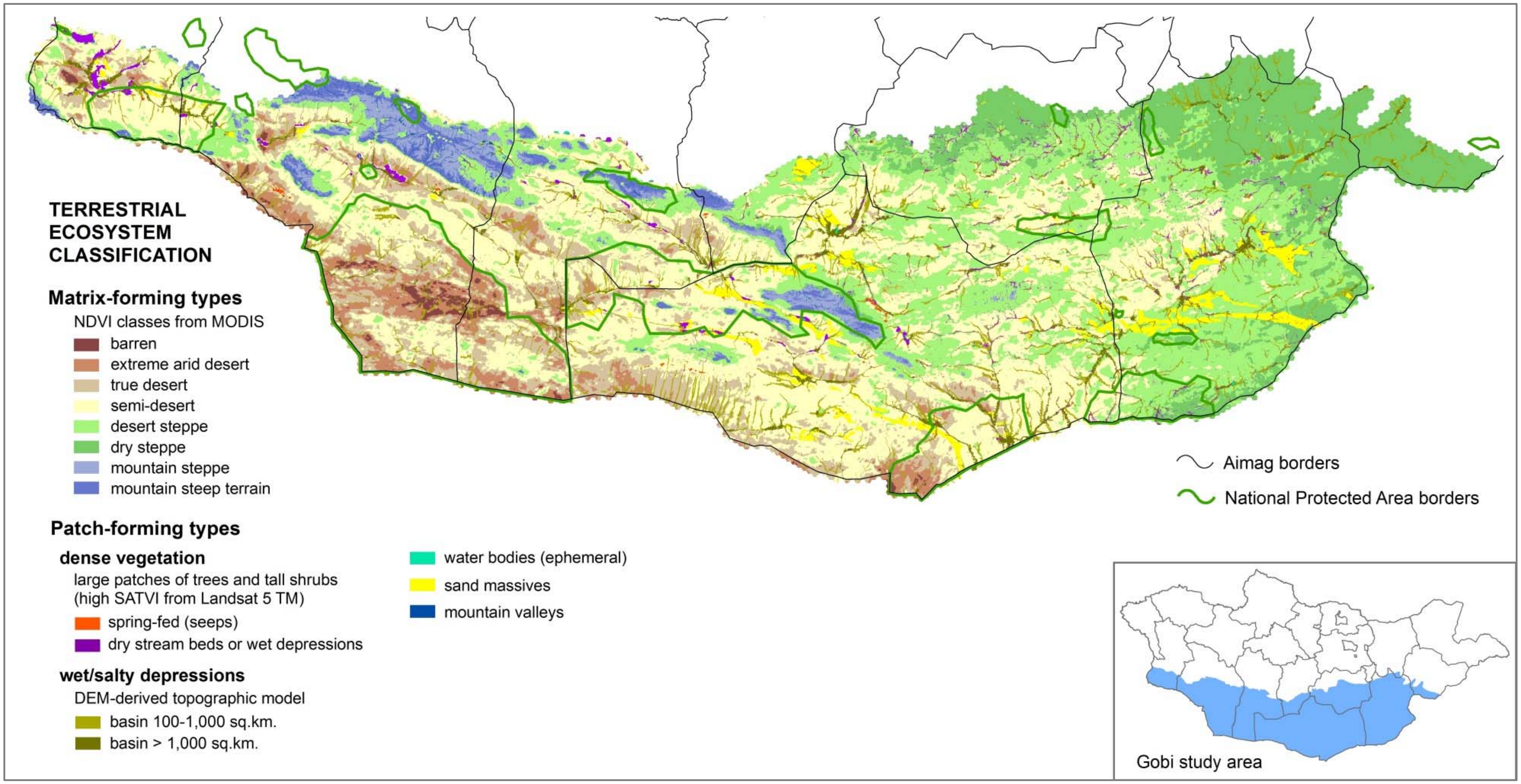


Figure 2: Terrestrial Ecosystem Classification

Map showing GIS model result.



Is Overgrazing A Pervasive Problem Across Mongolia? An Examination of Livestock Forage Demand and Forage Availability from 2000 to 2014

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ABSTRACT

Pastoral livestock production is considered a pillar of the Mongolian economy. Since the early 1990's, Mongolia has transitioned to a market economy, and livestock numbers have trended upward. Recent remote sensing studies have indicated widespread overgrazing; however, to date, no studies have examined grazing pressure on a national scale to assess the pervasiveness of overgrazing. We conducted a spatial and temporal analysis of grazing pressure by analyzing the relationship between livestock forage availability and forage demand across soums during 2000 to 2014. To estimate livestock forage demand (kg/ha/yr), we converted soum livestock densities to sheep forage units and calculated forage intake on an area basis. Forage availability was estimated using a regression relationship between herbaceous biomass and 250-m resolution MODIS NDVI (r^2 = 0.70). The regression was applied to yearly maximum NDVI images to create surfaces of available forage (kg/ha/yr). Percent use (PU) of forage, which is the ratio of forage demand to forage available, was used as an indicator of grazing pressure. 50% use is generally recommended on rangelands for promoting forage regrowth and soil protection. Thirteen percent of the rangeland across Mongolia had PU that exceeded 50% during the entire time series, while 37% had 10 or more years with >50% use. Grazing pressure was higher in the central and western aimags, and lowest in the eastern aimags. Dzuds (winter disasters) in 1999-2002 and 2010 resulted in 35% and 22% reductions in livestock numbers nationwide. Grazing pressure exceeded 50% in over half of the country prior to and during dzuds due to the effect of summer drought on forage availability and high animal numbers. Grazing pressure was lowest after dzuds due to lower livestock numbers and forage response to higher rainfall. Our results indicate that heavy stocking (>50 PU) appears to be pervasive in about 32% of the country and consistent overgrazing (>=10 years with PU>=70) occurs on approximately 11% of the land area. During individual years, land areas having overgrazing are variable due to extreme climate events and linear increases in livestock numbers, regardless of forage availability, during periods between dzuds. The spatially explicit and temporal nature of these results will aid in disentangling effects of changing climate and management, and assessing the resilience of these rangeland systems in Mongolia.

Keywords: overgrazing, forage demand, forage availability, Mongolia

INTRODUCTION

In Mongolia, pastoral livestock production is considered a pillar of the economy and a large portion of the rural population depends on livestock production for their livelihood. Livestock producers are generally semi-nomadic herders who extensively graze their animals in surrounding regions during the spring, summer, and fall, then return to protected camps for the winter months (Bedunah and Schmidt, 2004). Sheep and goats are the predominant kinds of livestock, followed by cattle, horses, yaks and camels. Since 1991, Mongolia has been transitioning to a market economy and livestock numbers during this period have generally increased each year with the exception of 1999-2002 and 2010 where large-scale drought and winter disasters (Fernández-Giménez et al., 2012) resulted in 35% and 22% reductions in livestock numbers nationwide (National Statistical Office of Mongolia, 2015).

Recent remote sensing studies, using proxies for vegetation biomass such as the Normalized Difference Vegetation Index (NDVI), have indicated that widespread overgrazing and changing climate in Mongolia are leading to land degradation (Liu et al., 2013; Hilker et al., 2014). In these studies, overgrazing was generally attributed to increases in animal numbers; however, no evaluations were conducted to assess whether the vegetation could support the number of animals measured in annual statistical surveys, and numbers for each species of livestock were not converted to a common forage intake unit (e.g., a sheep) to account for forage intake differences across species so that forage demand and grazing pressure could be interpreted correctly. To date, no studies in Mongolia have examined grazing pressure on a national scale to assess temporal and spatial trends in overgrazing over a period of 10 or more years. An understanding of these trends is important for evaluating how changing climate and livestock management influence vegetation change and resilience in these systems. For this study, our overall goal was to conduct a spatial and temporal analysis of grazing pressure by analyzing the relationship between livestock forage availability and livestock forage demand across soums (similar to districts) in Mongolia during the period from 2000 to 2014. Our objective was to define land areas having grazing pressure indicative of overgrazing, and to examine trends in grazing pressure over time to identify areas that have had prolonged overgrazing that could result in rangeland degradation.

STUDY SITE

Mongolia is a landlocked country in east-central Asia. The political administration in Mongolia is divided into 21 *aimags* (similar to provinces), which are further sub-divided into *soums.* Each year, the National Statistics Office of Mongolia conducts surveys in each soum to determine the number and species of livestock.

METHODS

In order to assess grazing intensity over time, we compared the forage demand (based on livestock density and herd composition) to forage availability during the 2000 to 2014 period. Livestock census data, by *soum*, were acquired from the National Statistics Office of Mongolia for the period from 2000 to 2014 (National Statistical Office of Mongolia, 2015). Livestock species numbers we converted to sheep forage units (SFU) using conversion factors of 1, 0.9, 6, 7, and 5 sheep forage units for sheep, goats, cattle, horses, and camels, respectively (Bedunah and Schmidt, 2000).

Forage demand was calculated by multiplying the SFU densities in each district by the forage intake of an individual SFU (i.e., 365 kg of forage intake/yr) (Bedunah and

Schmidt, 2000). The forage demand for each district was then divided by the total hectares in each district to derive livestock forage demand per hectare for each year.

Forage availability was estimated using a linear regression relationship between herbaceous biomass and the 250-m Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) (Huete et al., 2002). The herbaceous biomass data were collected from plots that were clipped along vegetation transects as part of a forage monitoring study conducted in Mongolia during 2004 to 2010 (Angerer, 2012). Transect locations were collocated with NDVI pixels and NDVI values were extracted from MODIS scenes for the time periods when biomass data were collected. The resulting regression had an r^2= 0.70 and a root mean square error of 164 kg/ha. The regression was used to predict herbaceous biomass for the maximum NDVI that occurred for each 250-m pixel within the district boundaries for each year (2000 to 2014). Spatial statistical tools were used to calculate the total herbaceous biomass in each *soum*. The total herbaceous biomass was divided by the number of hectares in the *soum* to derive forage available for livestock per hectare.

Percent use (PU) of forage was used as an indicator of grazing pressure. PU was calculated as the forage demand divided by the forage available multiplied by 100. Because grazing is not always efficient and vegetation is lost through trampling, soiling, insects, and natural senescence (Smart et al., 2010), a loss factor of 20% of the available forage was included in the calculation of percent use. As a general rule, PU values of 50% will leave enough standing forage biomass to protect the soil and allow plants to regrow; however, research in arid and semi-arid regions of the United States indicate that percent use values of 25 to 45% are need to prevent overuse in these areas, whereas values of 50 to 60% are reasonable in more humid areas or annual grasslands (Holechek, 1988). For this analysis, PU values exceeding 50% were used to indicate heavy stocking, and values exceeding 70% use were used to indicate overgrazing. Values approaching 100% can indicate removal of all forage biomass.

RESULTS

Total SFUs approached 64 million in 2000 and declined in both 2001 and 2002 to 45 million due to drought and winter disasters (dzud). After 2003, SFUs increased steadily each year until 2010, when drought conditions in 2009 and dzud in early 2010 resulted in a 21% decrease in SFUs. Since 2010, SFUs have increased more than 10% each year, and in 2014, SFUs approached 85 million.

Using PU values exceeding 50% as an indicator of vegetation overuse or heavy stocking rate, 13% of the rangeland across Mongolia had PU that exceeded 50% during the entire time series, while 37% of the rangeland area had 10 or more years with >50% use. Total land area in Mongolia that could be classified as overgrazed (>=70 PU) varied by year in the time series with the lowest percentage occurring during 2003 and the highest percentages occurring during 2007 to 2009 and in 2014. Land areas that had consistent overgrazing during the 15 year period totaled only 3%; however, this increased to 11% of the total land area if 10 years or more were included.

Grazing pressure was generally higher in the central and western *aimags*, and lowest in the eastern *aimags* (Figure 1a, b). Grazing pressure was lowest after dzuds due to lower animal numbers and an increase in forage production in response to higher rainfall in the year following the dzuds (Figure 1a). Within ecological zones, land area within zone boundaries classified as overgrazed was greatest for the mountain steppe zone, followed by the steppe zone and mountain forest steppe zone. Percent of overgrazed area varied over time, but was generally lowest for all ecological zones in 2003 and highest in 2014 (Table 1).

DISCUSSION

Changes in livestock numbers over time appeared to follow a boom-bust cycle with drought and dzud events reducing animal numbers nationally with linear increases in animal numbers following these events. There was no correlation between livestock numbers and forage availability indicating that herders were not adjusting herd size based on climatic factors such as rainfall. Land area classified as consistently overgrazed (>70 PU for 10 or more years) generally occurred in the steppe and the mountain and forest steppe ecological zones in the central and western portions of Mongolia (Figure 1b, Table 1). These zones are generally some of the most productive rangeland areas in Mongolia; therefore long-term overgrazing in these zones could lead to reduced productivity, irreversible degradation, and/or loss of resilience. A recent study of long-term vegetation trends in mountain steppe, steppe and desert steppe ecological zones in south-central Mongolia indicated that the interaction of climate and grazing pressure resulted in degradation in these zones, and that mountain steppe zones were most susceptible to degradation; however, their results indicated that the degradation was reversible and not permanent (Khishigbayar et al., 2015).

Results from this study do not show the degree of overgrazing indicated by recent remote sensing studies. Hilker et al. (2014) stated that their analysis of MODIS NDVI decline from 2002 to 2012 revealed widespread degradation across Mongolia and increases in animal numbers during this period were the primary cause of this decline. Results from this study indicated that only 11% of the total land area in Mongolia experienced overgrazing for 10 years or more, and 37% of the land area could be considered heavily stocked (> 50% PU); therefore, overgrazing would not be considered as widespread across Mongolia. In a study using MODIS Leaf Area Index data to assess vegetation productivity and use during the period from 2000 to 2006, Sekiyama et al. (2014) reported that overgrazing occurred over large portions of Mongolia in 2000 and 2001 due to low biomass availability. However, during the period from 2002 to 2006, overgrazing was limited to *soums* having increases in animal numbers, especially goats. Our analysis identified areas of heavy forage use in 2000 to 2001 similar to Sekiyama et al.; however, the area that we classified as overgrazed was much smaller.

Our results also indicate that opportunities for vegetation recovery do exist during periods after dzuds when forage demand is lower due to reduced animal numbers and higher rainfall that promotes vegetation growth. Additional research is needed to evaluate rates of recovery after reductions of livestock numbers in these regions.

IMPLICATIONS

The spatially explicit and temporal nature of these results provide a basis for identifying areas that are experiencing overgrazing and that may be on a trajectory for loss of productivity and resilience. These areas could be targeted by local community based rangeland management groups or aimag government for programs to reduce animal numbers and for conducting long-term rangeland health monitoring programs to identify changes in vegetation and soil conditions to avoid irreversible degradation. At the national level, the spatial analysis of grazing pressure and livestock numbers would be beneficial in developing pasture guidelines for stocking rates, determining the potential economic impacts of dzud, and for dzud disaster response. Lastly, the ability to define the degree of grazing pressure across Mongolia can aid in disentangling effects of livestock management and changing climate in assessing the resilience of these rangeland systems.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation under CNH Program Grant No. award BCS-1011 *Does Community-based Rangeland Ecosystem Management Increase the Resilience of Coupled Systems to Climate Change in Mongolia*? Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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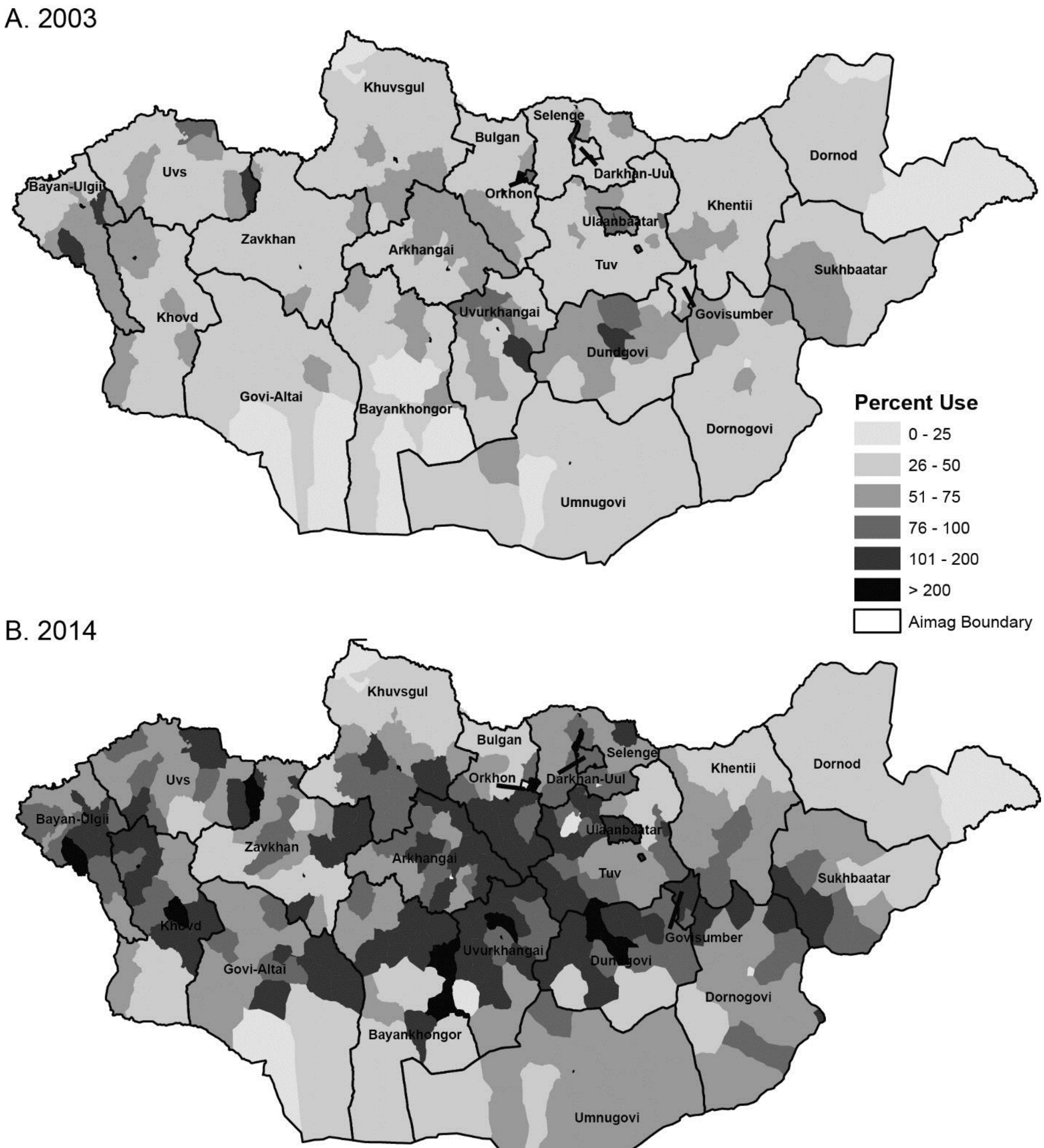

Figure 1. Percent use of forage by livestock within *soums* and *aimags* in Mongolia during 2003 (A) and 2014 (B).

Table 1. Percent of total land area, by year, within ecological zone classes having greater than 70% use of forage. Ecological zones boundaries were acquired from the from the Mongolia Information and Computer Center (ICC) Environmental Database vegetation map. http://www.eic.mn:8080/geonetwork/srv/eng/main.home)

		Year (%)							
Ecological Zone Class	Hectares	2000	2001	2002	2003	2004	2005	2006	2007
Desert	25,283,265	9.2	14.0	4.7	1.3	6.2	7.3	5.5	9.5
Desert steppe	34,123,871	18.8	19.4	9.4	3.8	13.6	15.3	13.5	21.7
High Mountain	7,192,755	18.0	15.1	6.9	4.5	8.3	10.0	14.1	31.9
Mountain desert steppe	2,690,406	12.3	11.3	4.3	1.6	6.3	8.0	7.4	33.1
Mountain forest steppe	33,413,359	15.8	13.6	10.3	3.7	9.4	10.2	12.8	31.3
Mountain steppe	8,426,857	25.0	29.8	15.4	6.3	21.9	26.4	28.8	50.9
Steppe and dry steppe	24,725,573	22.3	22.1	10.4	6.7	16.4	18.6	18.4	39.6
		2008	2009	2010	2011	2012	2013	2014	
Desert	25,283,265	13.2	26.3	3.6	3.8	3.6	19.9	16.7	
Desert steppe	34,123,871	23.9	33.0	9.9	10.8	11.4	28.2	36.5	
High Mountain	7,192,755	29.0	30.7	11.8	12.4	20.0	24.6	44.6	
Mountain desert steppe	2,690,406	18.1	27.5	8.2	6.1	10.2	14.7	30.4	
Mountain forest steppe	33,413,359	22.9	28.3	13.6	14.9	16.9	24.0	44.1	
Mountain steppe	8,426,857	39.7	42.2	21.8	18.1	22.2	34.2	54.8	
Steppe and dry steppe	24,725,573	31.3	35.7	18.1	16.7	20.4	32.3	48.9	

Distance-to-Well Effects on Plant Community Based on Palatability and Grazing Tolerance in the Desert-steppe of Mongolia

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ABSTRACT

Wells in grasslands are usually accompanied with increased traffic by humans and livestock. The purpose of this study was to detect whether plant community structure differs in spatial arrangement with different grazing gradients in the desert steppe of Mongolia. We found poor correlation between total coverage and distance-to-well in big-shrub and shrub-limited sites but strong correlation in the small-shrub site. Dominance of palatable plants along the transect appeared in the big-shrub site but that of palatable, grazing avoider and grazing tolerant plants appeared in other two sites. The results show that these communities might respond differently to grazing pressure. Livestock trampling was limited to near the well and then grazing might be effective far from the well, because all sites showed dominance of palatable herbaceous plants. Sub-dominance of Eurotia ceratoides appeared nearest to the well and followed Caragana spp. sub-dominance. Ajania spp. sub-dominance appeared more away than E. ceratoides and Caragana spp. Dominance of palatable herbaceous plants appeared near the well, compared with that of shrubs. In all sites, palatable herbaceous plant community was replaced by grazing tolerant plant community near the well and shrubs disappeared. This indicates that succession after grazing might be faster in herbaceous plant community than shrub one.

Keywords: grazing, trampling, palatable plant, grazing tolerant plant

INTRODUCTION

The Mongolian Plateau is one of Asia's largest biomes. With its highly diverse floral communities, environmental gradient across an extensive region, and long human impact, this area provides a unique opportunity to explore the interactions of the environment, plants, and humans in creating the diverse spatial pattern of this ecosystem (Hilbig 1995; Karamysheva and Khramtsov 1995). Generally, the south is characterized as drier and hotter than the north of Mongolia (Pyankov et al. 2000).Hence, plant species richness, diversity, and community structure can be different among natural zones (Fujita and Amartuvshin, 2013).

In the desert steppe, the effect of livestock grazing on plant community structure is generally weaker than interannual rainfall variability (Fernandez-Gimenez and Allen-Diaz, 1999; Stumpp et al., 2005).However, during dry seasons, drought-resistant shrub species such as *Caragana* spp. which can absorb water deep in the soil, are a good forage resource for livestock (Fujita et al., 2013), and succulent small-shrubs can also be grazed by livestock (Jigjidsuren and Johnson, 2003). In spite of primary role of climate in determination of desert-steppe plant community, livestock grazing might create a more heterogeneous spatial pattern of plant communities.

The purpose of this study was to detect whether plant community structure differs in spatial arrangement with different grazing gradients in the desert steppe region of Mongolia.

MATERIALS AND METHODS

We selected 3 sites which locate in same size of valleys in the desert steppe region of Mongolia. Each can be characterized with shrub types: big-shrub site (45°36'18.34"N, 100°46'29.21"E), small-shrub site (45°12'23.24"N, 101°06'33.67"E), and shrub-limited site (45°27'27.62"N, 101°07'11.96"E), respectively. We designated the big- and small-shrub sites where *Caragana* spp. and *Ajania* spp. co-exist with the second dominant of herb and grass, respectively, while the shrubs are not dominant in the shrub-limited site. Mongolia's climate is continental, with cold-dry winter and warm-wet summers (Fernandez-Gimenez and Allen-Diaz, 1999) but our study area was drier than the forest-steppe and steppe zones. Mean annual air temperature and precipitation are 4.8°C and 95 mm in the desert-steppe. Soil in our study area was desert-grey type (Sodnom & Yanshin, 1990) with dominant *Stipa gobica*, *S. glareosa* of grass, *Allium polyrrhizum*, *A. mongolicum* of forb (Fernandez-Gimenez, 1997) and *Caragana* spp of shrub (Fujita and Amartuvshin, 2012).

We performed a vegetation survey in July, 2014. Transect direction was selected along valley. A single transect was recorded for each well site. Species dominance was recorded at every 100 m interval away from the well, up to 1620 m. Three plots of 1 x 1 m at each 100-m interval were used in each well site. For each plot, the primary and secondary dominant species were identified and their respective coverage fractions were visually estimated and recorded. Each 1 x 1 m plot was considered a sub-sample and they are averaged to obtain the value for that location (Figure 1). We did not replicate transects within well-site, because of time limitation. So, all results in this study cannot be inferred to apply more widely than our specific sites.

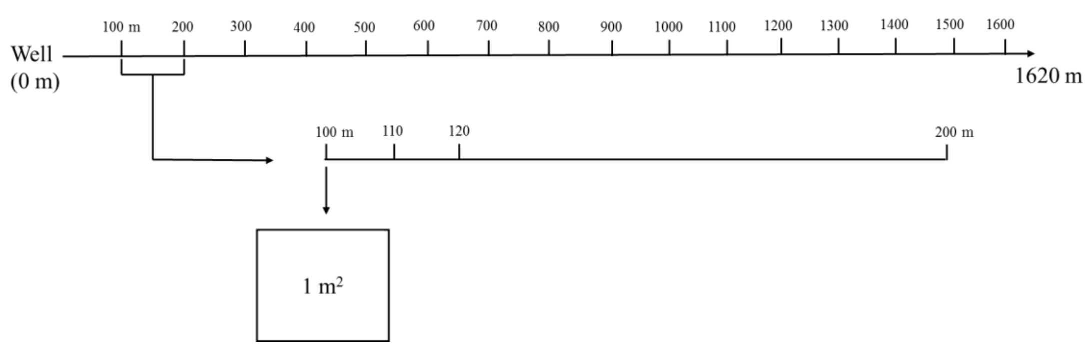

Figure 1. Well-transect design within site for field survey

Pasture plants are divided into two groups which are palatable and grazing tolerant (Jigjidsuren and Johnson, 2003). Fujita et al. (2002) reported plants which avoid grazing in Mongolian pasturelands, based on creeping and rosette growth forms. Dominant plant species observed through well-transects were divided into three groups: palatable, grazing avoider, and grazing tolerant.

We used Spearman Rank Correlation (Rs) to calculate correlation between coverage and distance from well and Tukey HSD test to compare coverage between different distances within transects showed poor correlation between total coverage and distance.

RESULTS

Total coverage in small-shrub site positively correlated with transect distance (Rs = 0.89, $p < 0.0001$) but significant patterns were not found at big-shrub (Rs = 0.3, $p > 0.05$) and shrub-limited sites (Rs= -0.2, $p > 0.05$). Big-shrub site showed densest coverage along the transect. Total coverage was denser in shrub-limited site than in small-shrub site within 400-420 m while it was denser in small-shrub site far from well (Figure 2). In the big-shrub and shrub-limited sites, coverage increased up to 300-320 m away from wells (Tukey HSD, $p < 0.05$) but decreased to 400-420 m ($p < 0.05$). Plots with grass and herb showed sparse coverage although plots with big shrubs showed dense coverage. Also, plots without shrubs at 200-220 m in big-shrub site showed dense cover.

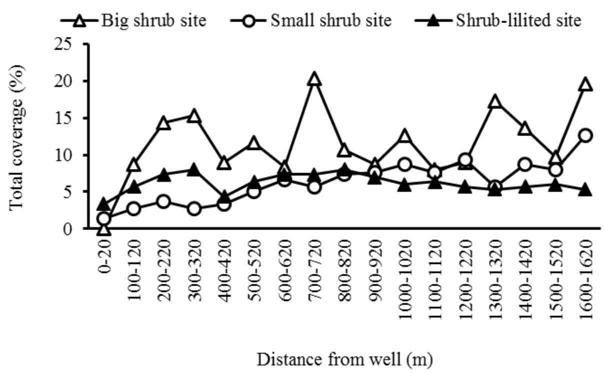

Figure 2. Changes of total coverage throughout transect from well in big and small-shrubs and shrub-limited sites.

Primary dominance of palatable grasses appeared along the transect in the big-shrub site, excluding one plot with grazing avoider species (600-620 m) but those were different in other sites. The primary dominance of grazing avoider species appeared near the well and palatable grass away from the well in the small-shrub site while tall grazing-tolerant species dominated near the well and palatable grass away from well in the shrub-limited site (Table 1). Sub-dominance of *Eurotia ceratoides* appeared nearest to the well and followed *Caragana* spp. sub-dominance. *Ajania* spp. sub-dominance appeared more away than *E. ceratoides* and *Caragana*spp (Table 2).

DISCUSSION

We found poor correlation between total coverage and distance-to-well in big-shrub and shrub-limited sites, over the full transect (1620 m), except within 200-220 m of the well, but strong correlation in the small-shrub site. Dominance of palatable plants along the transect appeared in the big-shrub site but that of palatable, grazing avoider and grazing tolerant plants appeared in other two sites. Previous studies reported that total coverage is poorly or moderately correlated with distance from water sources in the desert-steppe (Stumpp et al., 2005; Sasaki et al., 2005). Fujita et al. (2002) reported that livestock selectively graze palatable plants while grazing tolerant plants can resist grazing, chemically and morphologically. Also, they suggested that livestock mostly cannot graze low height plants, because of creeping or short culms. Our and other results suggest that these communities might respond differently to grazing pressure.

Both livestock trampling and grazing can affect plant communities (Fernandez-Gimenez et al., 2012). Our result showed that within 400-420 m of transect away from the well, creeping plants (*C. ammanii*) dominated in the small-shrub site. Trampling decreases the vertical height and increases basal diameter of plants (Xu et al., 2013). Also, increasing coverage of grazing tolerant plants up to 200-220 m indicate that trampling effect might be strongest in 0-20 m and then decrease up to 200-220 m, because livestock trampling damaged branches of grazing tolerant plants. The results indicate that livestock trampling was limited near the well and then grazing might be effective far from well, because all sites showed dominance of palatable herbaceous plants. Fujita et al (2012) reported that coverage of *A.mongolicum* is dense in shrub sites but *A. polyrrhizum* in non-shrub sites, because livestock selectively graze *A. mongolicum* better than *A. polyrrhizum* (Jigjidsuren & Johnson, 2003). We found co-existence of both *Allium* species near the well in big-shrub site but did not find their co-existence within dominants in other two sites.

Table 1. Primary dominance of herbaceous plant species along the transect in our study sites

distance [m]	Primary dominant		
	Big-shrub site	Small-shrub site	Shrub-limited site
0-20	-	*Convolvulus ammanii*	*Peganum nigellastrum*
100-120	*Allium mongolicum* *Allium polyrrhizum*	*Stipa gobica*	*Peganum nigellastrum*
200-220	*Allium polyrrhizum*	*Convolvulus ammanii*	*Peganum nigellastrum*
300-320	*Allium polyrrhizum*	*Stipa gobica*	*Stipa glareosa*
400-420	*Cleistogenes soongorica*	*Stipa gobica*	*Iris bungei*
500-520	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
600-620	*Convolvulus ammanii*	*Stipa gobica*	*Stipa glareosa*
700-720	*Agropyron cristatum*	*Stipa gobica*	*Stipa glareosa*
800-820	*Agropyron cristatum,* *Cleistogenes squarrosa*	*Stipa gobica*	*Stipa glareosa*
900-920	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1000-1020	*Cleistogenes soongorica*	*Stipa gobica*	*Stipa glareosa*
1100-1120	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1200-1220	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1300-1320	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1400-1420	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1500-1520	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*
1600-1620	*Stipa glareosa*	*Stipa gobica*	*Stipa glareosa*

Table 2. Sub-dominance of shrub species along the transect in our study sites

distance [m]	Secondary dominant		
	Big-shrub site	Small-shrub site	Shrub-limited site
300-320	*Eurotia ceratoides*	-	-
700-720	*Caragana bungei*	-	-
900-920	*Eurotia ceratoides*	-	-
1200-1220	-	*Ajania trifida*	-
1300-1320	*Caragana bungei*	-	-
1400-1420	-	*Ajania trifida*	-
1500-1520	-	*Ajania trifida*	-

E. ceratoides showed denser coverage near the water source (Stumpp et al., 2005) while *Artemisia schisinskii* (a palatable shrub) showed denser coverage with increasing distance from water source (Fernandez-Gimenez and Allen-Diaz, 1999). Similarly, dominance of *E. ceratoides* appeared near well while dominance of *Caragana* spp (a palatable shrub) far from well. It suggests that palatability of *E. ceratoides* might be lower than of *Caragana* spp. Also, dominance of small-shrub (*Ajania* spp.) appeared farthest, suggesting more sensitive to grazing than above mentioned shrubs. Dominance of palatable herbaceous plants appeared near the well, compared with that of shrubs.

Good palatable herbaceous plants grow well in the shrubs (Fujita and Amartuvshin, 2012). Fujita et al. (2012) suggested that *Caragana* spp keeps green biomass and is grazed by livestock during drought season but herbaceous plants keep underground storage and are grazed during wetter season. Our results indicate that livestock might weakly graze both herbaceous and shrub species along the transect in the big-shrub site but they might strongly graze those in shrub-limited site. Also, livestock might moderately graze those in the small-shrub site. In all sites, a palatable herbaceous plant community was replaced by a grazing tolerant plant community near the well but shrubs plant community disappeared. This indicates that succession after grazing might be faster in herbaceous plant community than shrub one.

The present study used few well-sites, limiting generalizability. Also, we did not count livestock in our study sites, due to time limitations, hence, this paper cannot evaluate grazing pressure in our study sites, even in desert-steppe zone. However our results can be used to improve pasture management in dry regions of Mongolia. It is necessary to make further comprehensive research on how vegetation communities respond to grazing pressure in desert-steppe zone.

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Changes in Soil Properties along Grazing Gradients in the Mountain and Forest Steppe, Steppe and Desert Steppe Zones of Mongolia

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ABSTRACT

Recent debates about the condition of Mongolia's rangelands and possible causes of rangeland change highlight the need for greater understanding of changes in grassland soil fertility and physical characteristics associated with grazing. As part of a large observational study of grazing effects on different Mongolian ecological zones and soil types (ecological sites), we studied soil characteristics along grazing gradients from winter shelters in the mountain and forest steppe, steppe and desert steppe ecozones of Mongolia. Our objective was to determine how grazing affects soil properties in winter pastures in different ecological zones and ecological sites within zones, based on grazing gradients. Our findings did not support our hypothesis that livestock grazing along a grazing gradient from winter shelters would lead to increased concentrations of nutrients (C, NO_3^-, P, K and humus) near the shelters. Instead, where soil chemical properties differed with distance, they were lowest close to winter shelters and higher with increasing distance. As hypothesized, we observed greater bulk densities nearer to winter shelters than farther away. Our hypothesis that grazing effects on soil properties would vary among ecological sites also was not supported. Further experimental and observational studies are needed to understand grazing effects on soil properties at different spatial scales and to examine feedbacks between livestock-induced changes in plant communities and soil quality.

Keywords: Mongolia, soil, nutrients, rangelands, degradation

INTRODUCTION

Mongolian rangelands cover over 75% of the country's territory, are an important part of Mongolia's ecology, culture and economy (Fernandez-Gimenez and Allen-Diaz, 1999; Gunin et al., 1999; Hilbig, 1995), and among the most intact temperate grasslands globally (Khishigbayar et al., 2015). Recent debates about the condition of Mongolia's rangelands and possible causes of rangeland change (Addison et al., 2012) highlight the need for greater understanding of changes in grassland soil fertility and physical characteristics associated with grazing. Milton et al., (1994) and Whisenant (1999) defined degradation as a continuum of conditions from reversible to irreversible changes in both biotic and abiotic indicators. Irreversible degradation in rangelands is associated with soil loss or changes in soil nutrients (Whisenant, 1999). Given mounting concern about the condition of Mongolian rangelands (Lui et al. 2013; Hilker et al., 2014), and the potential importance of soil quality as a criterion for determining the health of rangelands (NRC, 1994), it is important to understand the effects of livestock grazing on major soil chemical and physical attributes of Mongolian rangelands.

Large mammal grazers can affect soil characteristics directly and indirectly through interactions of trampling, herbivory and excretion in Mongolian rangelands (Augustine and Frank, 2001). Several past studies in Mongolia, Inner Mongolia and the Tibetan Plateau have investigated the effects of livestock grazing on soil physical and chemical properties using space-for-treatment designs based on grazing gradients (Fernandez-Gimenez and Allen-Diaz, 2001; Stumpp et al., 2005), inside and outside of grazing exclosure comparisons (Hirobe et al. 2013), experimental manipulation of grazing intensity (Deng et al., 2014; Xu et al., 2014; Lui et al., 2014; Sun et al., 2014), or experimental removal of grazing to observe whether soil properties respond to grazing removal (Pei et al., 2007; Steffens et al., 2008; Sarula et al., 2014). Results of past observational and experimental studies led to different conclusions about the effects of livestock grazing on soil chemical and physical properties. Two observational studies in Mongolian rangelands along grazing gradients from water points found that carbon (C), nitrogen (N), and phosphorous (P) increased with greater relative grazing pressure and livestock densities near water points and decreased with increasing distance from water (Fernandez-Gimenez and Allen-Diaz, 2001; Stumpp et al., 2005). In contrast, exclosure and experimental studies of the effects of grazing on soils found declines in soil organic matter (SOM), soil organic C, and total soil N with increasing grazing intensity, with the highest levels of SOM, C , N, mineralization and nitrification in ungrazed exclosures (Pei et al., 2007; Steffens et al., 2008; Deng et al., 2014; Sarula et al., 2014; Xu et al., 2014; Wang and Batkhishig, 2014; Lui et al., 2014; Sun et al., 2014; and Hirobe et al. 2013).

As part of a large observational study of grazing effects on different Mongolian ecological zones and soil types (ecological sites), we studied soil characteristics along grazing gradients from winter shelters in the mountain and forest steppe, steppe and desert steppe ecozones of Mongolia. Our objective was to determine how grazing affects soil properties in winter pastures in different ecological zones and ecological sites within zones, based on grazing gradients.

Based on findings from previous observational studies we, hypothesized that soil total C, soil nitrate (NO3-), SOM (humus), and P and potassium (K) would be higher in heavily grazed sites due to nutrient redistribution through livestock trampling, herbivory and excretion (Fernandez-Gimenez and Allen-Diaz, 1999; Augustine and Frank, 2001; Stumpp et al., 2005). We hypothesized that soil bulk density would be highest close to winter camps due to higher livestock densities and trampling (Avaadorj and Baasandorj, 2006), and that bulk density would decline with distance from the camp. Finally, we expected that the relationship between grazing intensity and soil properties would vary on ecological sites (different soil types) within a given ecological zone.

STUDY SITE

We sampled soils in three mountain and forest steppe *soums* (Bayangol and Saikhan *soums* in Selenge *Aimag*; Erdenetsogt *soum* in Bayankhongor *Aimag*), four steppe *soums* (Bayan, Bayantsagaan, Erdenesant, and Undurshireet *soums* in Tuv *Aimag*), and four desert steppe *soums* (Bayantsagaan, Bayangobi, Bayan Undur and Jinst *soums* in Bayankhongor *Aimag*)..

STUDY METHODS

In each study area, we sampled soils in winter pasture areas along grazing gradients with plots located at 100m, 500m and 1000m from winter camps in each zone. We sampled 13 gradients (39 plots) in the mountain and forest steppe, 18 gradients (54 plots) in the steppe, and 17 gradients (51 plots) in the desert steppe. Soils were collected from 0-20 cm in depth from one point at the center of each plot. A soil pit was dug and full soil description was made at this point, with one soil sample collected for laboratory analysis from each pit.

Laboratory analyses of soil chemical and physical characteristics was carried out at the Soil Ecological Laboratory of the Geo-ecology Institute of the Mongolian Academy of Sciences, Ulaanbaatar according to the Mongolian Standard Soil Testing Procedures. Soil pH was determined using Thermo Orion 370 pH meter (Thermo Fisher Scientific Inc., 2008). Soil organic matter and total carbon were determined using Tyurin's method (Bel'chicova, 1965). Soil nitrate amount was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Mobile P and K were determined using Machigin's method (Machigin, 1952; Kheifet, 1965). Soil bulk density was determined by weight and volumetric analyses (Baatar et al., 1994).

Data were inspected for normality and tested for homogeneity of variances using Mauchly's test of sphericity. Initially we used multivariate analyses with distance and ecological sites as fixed factors and looked at their interaction terms to test our 3-rd hypothesis. Interaction terms were not significant in all three ecological zones, therefore we combined data over all ecological sites within each ecozone and examined the distance effect for each variable. We used ANOVA to access changes in soil characteristics with distance from winter camp in each ecological zone. Humus, C, NO_3^-, P, K, bulk density (BD), and pH were dependent variables, distance (3 different distances from winter camp: 100m, 500m, 1000m) was considered a fixed factor, winter camp was considered a random factor, and we used a type III model. We used Bonferroni's multiple-comparison correction to determine which pairs of distances differed. Statistical tests were performed using SPSS statistics 22 (IBM Corp, 2013) and were considered significant at $p =< 0.05$.

RESULTS

In the mountain and forest steppe, humus, C, and NO_3^- were all significantly less at 100m than at the 500m and 1000m distances (Figure 1a and 1b). There was no significant difference between 500m and 1000m distances. P and K had similar patterns but were not significant except K at 100m was significantly less than 1000m. Bulk density was highest at the 100m distance and was significantly greater than BD at 500m and 1000m distances (Figure1a). Soil pH did not differ significantly over the gradient (Figure 1b).

In the steppe zone, humus, C, and P were all significantly less at 100m than at the 500m and 1000m distances (Figure 2a) but there was no significant difference between 500m and 1000m. NO_3^- was significantly different from each other at all distances: lowest closer to the winter camps. K had similar pattern but 100m and 500m both were significantly lower than 1000m (Figure 2b). BD (500m and 1000m was not significant) and pH both significantly decreased with increasing distance from the winter shelters (Figure 2a and 2b). The same pattern was observed in the desert steppe, where humus and total C both increased significantly with each distance from the winter shelter (Figure 3).

DISCUSSION

Our findings did not support our hypothesis that livestock grazing along a grazing gradient from winter shelters would lead to increased concentrations of nutrients (C, NO_3, P, K and humus) near the shelters. Instead, where soil chemical properties differed with distance, they were lowest close to winter shelters and higher with increasing distance. As hypothesized, we observed greater bulk densities nearer to winter shelters than farther away. Our hypothesis that the relationship between grazing effect and soil properties would vary on ecological sites (different soil types) within a given ecological zone was not supported.

Our results contrast with past observational studies of soils along grazing gradients in Mongolia, but align with experimental and exclosure studies that show declining soil quality with increasing grazing intensity. Further experimental and observational studies are needed to determine the effects of grazing on soil characteristics at different spatial scales, and to identify meaningful and efficient indicators of rangeland change and degradation based on soil characteristics. In particular, feedbacks between soils quality changes and changes in vegetation must be further explored in order to understand how grazing- and trampling-induced changes in plant community composition may influence soil quality, and how livestock-induced changes in soil physical and chemical properties influence plant communities.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation under CNH Program Grant No. BCS-1011 Does Community-based Rangeland Ecosystem Management Increase the Resilience of Coupled Systems to Climate Change in Mongolia? We thank our MOR2 field team for their assistance and Institute of Geo-Ecology soil laboratory team for completing our soil analysis.

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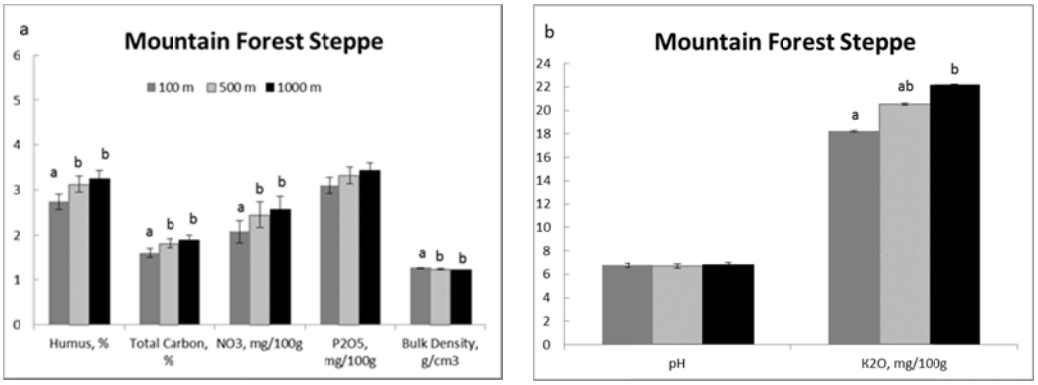

Figure 1. Mountain Forest Steppe soil characteristics: a) humus, C, NO_3^-, P, BD and b) pH and K.

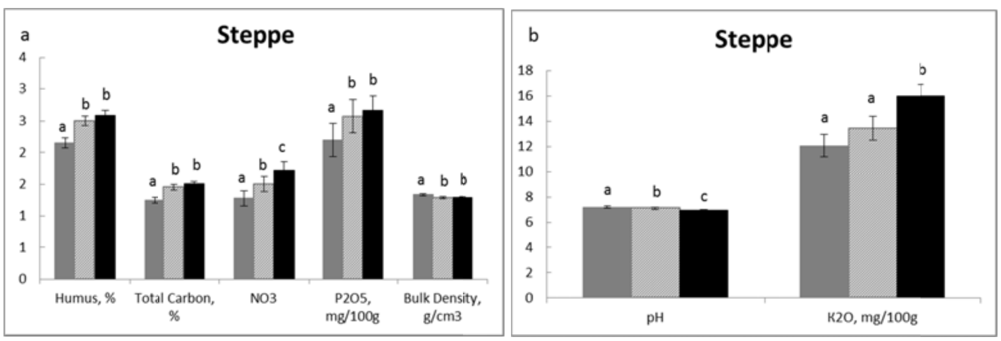

Figure 2. Steppe soil characteristics: a) humus, C, NO_3^-, P, BD and b) pH and K.

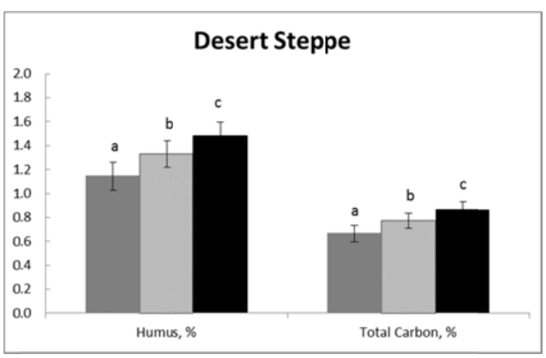

Figure 3. Desert Steppe soil characteristics: humus and total carbon.

Land Degradation Assessment in Gobi-Altai Province

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ABSTRACT

Remote Sensing and GIS analyses were embedded to monitor interactions and relationships between land use and land cover changes in the regional ecological space of Gobi-Altai province (Western part of Mongolia). In the last 76 years, Mongolia has experienced a combination of societal and governance system changes in transitioning from the feudal system to socialism and then from the socialist system with centrally planned economy to market. Each of these resulted in changes natural resources use throughout the country. Using GIS processing of data such as climate data (precipitation, air temperature) and vegetation, socio-economic data (livestock numbers, population density) were analyzed. We focused on developing a modeling approach for monitoring land degradation using GIS and Remote Sensing tools by merging climate and quantitative socio-economic data. The Modified Soil Adjusted Vegetation Index (MSAVI) from SPOT/VEGETATION was used to define vegetation cover change for the period from 2000 to 2013. GIS conditional functions were applied for mapping and analyzing climate and socio-economic driving factors, both of which affect land degradation. Conditional functions such as MAP-Algebra from ArcGIS were developed using ground truth data and data from National Administrative Department of Statistics. Remote sensing data were useful diagnostic tools for providing gross impressions on broad-scale spatial heterogeneity, to assist in land degradation monitoring. This paper defines that study area is affected by land degradation caused by climate and socio economic impacts.

Keywords: socio-economic change, climate impact, biodiversity, grassland degradation, MSAVI

INTRODUCTION

Mongolia is now experiencing many social and ecological issues such as population density, urban expansion and an increase of livestock will be affect the environment. The territory is susceptible to climate change due to its geographic location, vulnerable ecosystems and an economy that is highly dependent on seasonal climates. In the past

40 years, climate change and other anthropogenic activities have had a significant impact on the Mongolian ecosystem, resulting in desertification, increased occurrences of drought, water source depletion, and a decrease in biological diversity as well as affecting the well-being of local communities. Several quantitative studies using the methods outlined in the UN's Convection to Combat Desertification (UNCCD) has shown that approximately 90% of pastureland in Mongolia lies within vulnerable regions that are susceptible to desertification (Banzragch and Enkhbold, Chapter 3.3) Kappas and Propastin et al. (2008) estimated that drivers can determine both anthropogenic (e.g. demographic change) and natural forces. Human induced activities can be changed by socio-economic factors, which increase or diminish pressures on the environment. The Gobi region of Mongolia remains a place where nomadic pastoralism has been practiced for millennia and continues to provide livelihoods for 30% of the rural population (Sternberg et al., 2009; Ulambayar and Fernandez-Gimenez, 2013). A limited amount of research has been conducted on land degradation in Mongolia, and information on factors that influence land degradation in areas such as in the Mongolian Gobi-Altai region are lacking. The objective of this research is to assess current trends in degradation and identify the driving factors affecting the land degradation in the Gobi-Altai province of Mongolia. Furthermore an understanding of the factors and drivers that cause degradation will be useful for monitoring and mitigation of degraded lands and assist in developing policies for land use management local and regional levels.

STUDY SITE

Mongolia is a unitary state and divided administratively into 21 *aimags* (provinces) and the capital city of Ulan Baatar**.** The work in this study focused on determining the land degradation drivers in 18 *soums* (administrative units) in Gobi-Altai province. Gobi-Altai province is situated in the western part of Mongolia. It borders the Zavhan *aimag* to the north, Bayankhongor *aimag* to the east, Khovd *aimag* to the west and China to the south. The total area is 141,448 km^2. The Gobi bears, wild camels, ibex and snow leopards are protected species in several national parks located in the province. Vegetation is scarce in this zone of sand dunes, drifting sands, while shrubs are common for this region.

METHODS

We developed methodology to characterize and to monitor land degradation using remote sensing imagery, in addition to socio-economic and climate factors. We applied MSAVI indexes to monitor vegetation change between 2000 and 2013. In order to analyze socio-economic and climate factors, conditional function MAP-Algebra from ArcGIS was applied. We used the CON function inside ArcGIS to compute the influence of driver combinations. We acquired Spot 4 Vegetation data at 1km resolution data served as the data source for vegetation greenness and its spatial occurrence. Using the SPOT 4 data, we calculated the Modified Soil Adjusted Vegetation Index (MSAVI) for each of the images. Huete (1998) first described the soil adjusted vegetation index (SAVI) which was designed to minimize the effect of the soil background. A further development of the SAVI is an iterated version of this index, which is called MSAVI modified soil adjusted vegetation index (Qi et al. 1994a, 1994b):

$$SAVI = \frac{NIR - RED}{NIR + RED + L} * (1 + L) \quad MSAVI\,2 = \left[2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - RED)}\right] / 2$$

where RED is the red band reflectance from a sensor, NIR is the near infrared band reflectance, and L is the soil brightness correction factor. The difference between SAVI and MSAVI, comes in how L is calculated. In SAVI, L is estimated based on how much vegetation there is (but it's generally left alone at a compromise of 0.5). The parameter L varies between 0 and 1 with lower values indicating denser vegetation conditions. The impact of socio-economic factors on land degradation was defined by looking at the number of livestock from statistical data (e.g. sheep's, horses, goats, and camels), the human population figures, and climate impact from Metrological data (precipitation and temperature variation). The MSAVI, livestock and human population and temperature variables were used in a GIS model to calculate an index of land degradation. Using ESRI ArcGIS software, we developed a tool to calculate the index using Algebra functions and conditional operators. The condition function (CON) in ArcGiS was employed for indexing the socio-economic factors. The (CON) function is basically a "true-false' statement that evaluates a true-false condition in each pixel cell of a raster and does different calculations based on whether the condition is true or false. The Con-function statements can be nested to examine multiple conditions. We employed this method for our degradation indexing. The nested conditional functions used in this study are shown in (Table 1). From the field experience we selected the most degraded areas. Four *soums* Tsogt, Altai, Delger, Bugat were selected as being the most degraded area in the province and average data from *soums* were used to construct a degradation function. In formula (i), if the number of livestock was greater than 130000, (in soum level 2013) then the output was assigned a value of 1. A value of 1 is defined as an indicator of land degradation. If these conditions were not met, the output was assigned a value of 0, and then land degradation was not significant. In formula (ii), if the MSAVI was less than 0.15 then the output was assigned a value of 1. A value of 1 signified land degradation. In formula (iii), if the temperature was higher than 18°C, during the vegetation season (August), the output was assigned a value of 1 which signified land degradation. In formula (iv), if the precipitation was less than 10 mm per vegetation period, then the output was assigned a value of 1. A value of 1 signified land degradation. If these conditions were not met, the output was assigned a value of 0, and then land degradation was not significant. In formula (v), if the population was greater than 2637, then the output was assigned a value of 1, which signified land degradation. If these conditions were not met, again the output was assigned a value of 0. Finally, possible output cell values ranged from 0 to 5, illustrating different intensities of land degradation conditions. If an output cell indicates a value of 5 that means all of the 5 factors have an influence on land degradation. If an output cell indicates 0 it means there is no land degradation detectable according to this simple valuation method.

RESULTS AND DISCUSSION

Figure 1 shows the MSAVI changes for the period 2000 to 2013. We observed that MSAVI values were decreased in 2006 from 0.95 to 0.74 and increasing in small values in the last years. The main climatic factors are precipitation development and temperature increase over the growing period. However, there is virtually little change over the 13 years for the study area. It describes that MSAVI variation is not sufficient to assess the land degradation process. The result indicates that the assessment of vegetation greenness alone is not a major indicator for land degradation evaluation in the study site.

Figure 2 presents results showing the GIS analysis were completed to describe which *soum* is affected most by driving factors. We considered here "Tsogt" *soum* had the largest number of degradation degradation drivers of all study sites. During the 13 year period (2000-2013) there is influence from climate and increasing number of livestock as we defined 3-4 conditions are overlaying. We assumed that climate and socio-economic factors are the main affected factors for this site. GIS condition function analyses shows that the highest land degradation has been occurred in 2007 encompass Bayanuul, Tseel, Tsogt and Altai *soums*. The simple map algebra approach allows us to estimate which driving forces exist in the most degraded areas of the single *soums*. According to the National Report 2014 in Mongolia 77.8% of the Mongolian landscape has been degraded at some level. This paper contributes to the studies which involves policy makers and stakeholders defining and negotiating relevant scenarios with participatory approaches in the local area as well as to the studies which link people to the environment. Our prospective scenarios will be more focused on how this interacts and merges with other data platforms that could be more reliable and sufficient for the land degradation process. In conclusion, we describe that the basic modeling approach can be used in other dry land regions in order to determine the precise driving factors of land degradation.

ACKNOWLEDGEMENTS

The authors would like to thank and National Metrological center in Mongolia and SPOT /VEGETATION data center for providing satellite data. We are also grateful to the Areas+ Project for supporting O.V.'s PhD research in Germany and to the members of the Department of Cartography, GIS and Remote Sensing, Institute of Geography at George-August University of Göttingen for hosting O.V. as a researcher.

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Table 1. Conditional function key and related trends in study *soums*.

Indexes	Variables	Description
1	condition	([Livestock number] > 130000, 1, 0)
2	condition	([MSAVI] < 0.15, 1, 0)
3	condition	([Temperatura] > 18, 1,0)
4	condition	([Precipitation] <10,1, 0)
5	condition	([Population] > 2637, 1, 0)
1	True	
0	**False**	

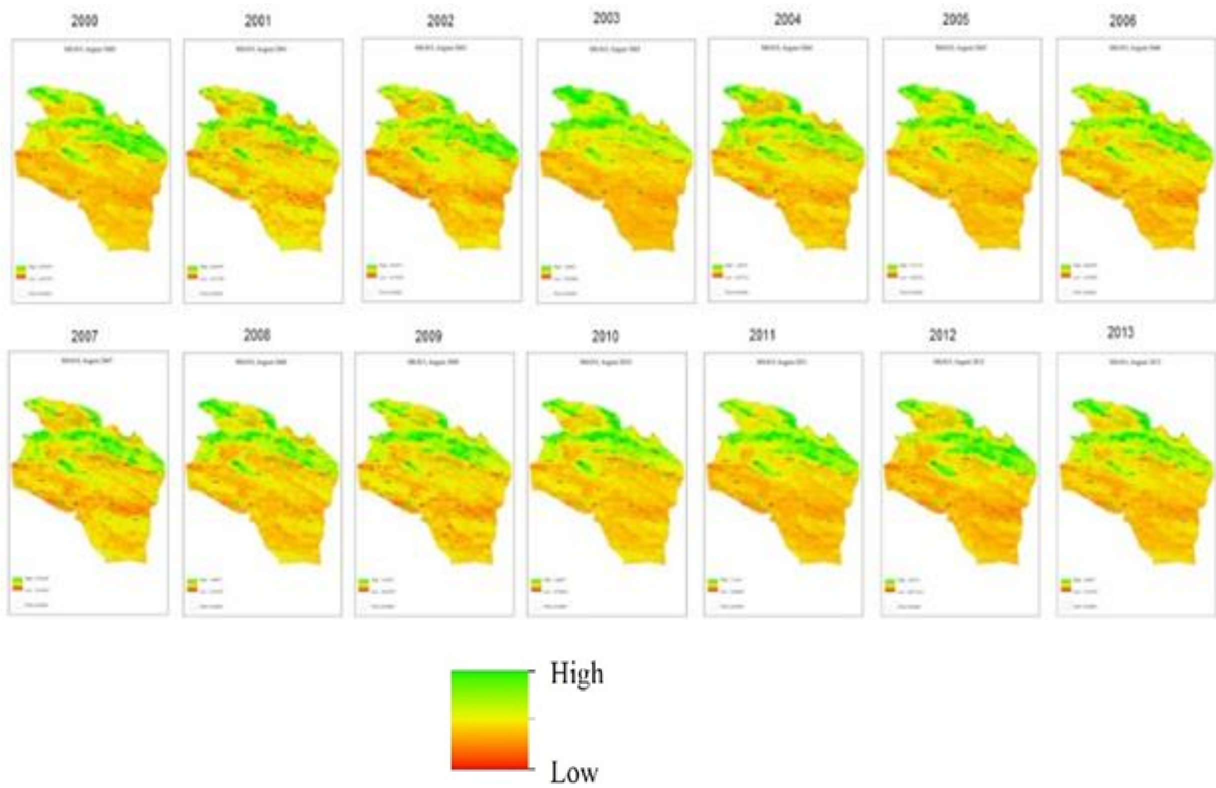

Figure 1. MSAVI change map from 2000 to 2013

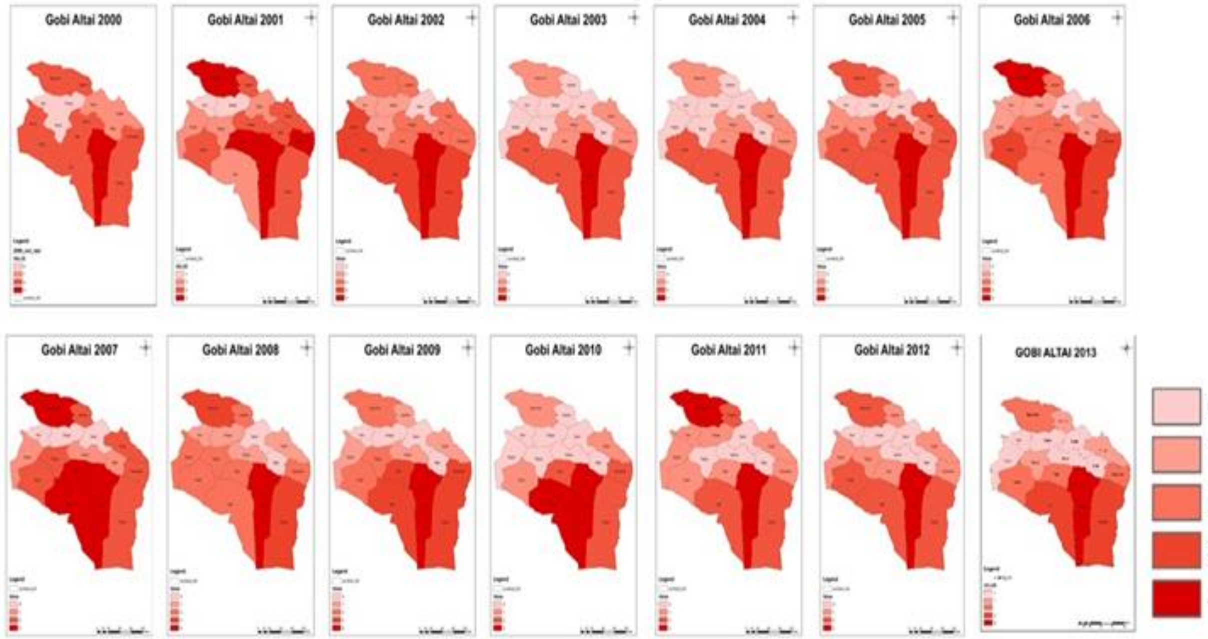

Figure 2. Land degradation change map from 2000 to 2013

Satellite-based Assessments on Regional Summer and Winter Conditions Triggering Massive Livestock Loss (*Dzud*) in Mongolia

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ABSTRACT

Dzud is a term referring either to conditions when melting snow refreezes to form an icy layer covering the grass, or to unusually heavy snow falls in Eurasian arid and semi-arid regions. Under *dzud* condition, animals cannot obtain food under snow or ice layer, which sometimes results in a *dzud* disaster, i.e. massive livestock kills. It has been recognized that the *dzud* disaster is directly induced by the harsh winter conditions but often influenced by drought in the previous summer. In this study, a data-intensive reanalysis on regional determinants of *dzud* disaster was conducted for more than 300 *soums* (an administrative unit equivalent with county in US) in Mongolia. Various climatic, hydrological, and vegetation variables were developed from satellite remote sensing (RS) data, which includes daily mean air temperature, dew-point temperature, and evapotranspiration, monthly precipitation, and 16-day NDVI from 2003 to 2010. Annual livestock census data were collected for every *soum* in Mongolia. Each variable was standardized to z-score and utilized for stepwise multiple regression analysis to identify factors statistically significant for explaining *soum*-level livestock mortality. The regression models were successfully constructed for two-third of total *soums*. Considerable spatial variability in the determinants of livestock mortality were found across *soums* in Mongolia. As the primary determinants, summer NDVI and dryness equally explained 22% of the *soum* mortality, while 33% and 16% of the mortality were explained with winter temperature and precipitation, respectively. Spatial patterns were also identified with winter precipitation and temperature being primary determinants in mountain regions and northern cool and semi-arid regions, while summer NDVI and dryness were important in southern hot and arid regions. Our results indicate combined efforts of monitoring RS-based summer NDVI and dryness and forecasting winter temperature and precipitation can provide useful tools for *dzud* disaster early warning.

Keywords: livestock loss, satellite, precipitation, temperature, aridity, time-integrated NDVI

INTRODUCTION

In arid regions, severe climatic constraints on water resources caused by low precipitation but high potential evapotranspiration have drawn priori attentions in both local and global societies because of increased awareness on the relationships between drought, land degradation and yellow dust occurrence in many regions of arid environments (Zhang et al., 2003). Besides climate-induced drought, desertification, and dust occurrence, certain climatic conditions resulted in multifaceted disasters that result in socio-economic problems, especially in arid regions lacking social infrastructure. *Dzud* is the case of climate-induced socio-economic disaster in widespread dry regions of Central Asia, creating conditions in which livestock mortality is abnormally high due to harsh winter condition and/or summer drought (Middleton & Sternberg, 2013; Sternberg, 2010; Tachiiri et al., 2008). *Dzud* was described by the United Nations and Government of Mongolia (2001) as a winter disaster that involves the mass debilitation, starvation, and death of livestock that seriously damages the livelihoods of the herder households who depend upon them. The spatially evaluation on *dzud* mechanisms was conducted by Tachiiri et al. (2008) at the country scale using *aimag*-level data. As well, Fernandez-Gimenez et al. (2012) analyzed *dzud* mechanisms in detail for two mountain-steppe and two desert-steppe districts in Mongolia. There, however, exists lacks of our knowledge on region-specific mechanisms and main factors causing regional livestock losses across Mongolia.

This study aimed to fill the gaps in knowledge about region-specific *dzud* mechanisms to identify potential climatic and biotic factors that influence on livestock mortality in Mongolia, by building a conceptual model of *dzud* occurrence. We sought to evaluate the conceptual model statistically using satellite-based data of the potential factors that could influence *dzud* and stepwise multiple regression analysis of the most important factors that influenced *dzuds* at the *soum* district scale across Mongolia. In particular, this study examined seasonal links between livestock mortality and the climatic and biotic factors to identify the main seasonal factors or combined factors that influence livestock losses.

METHODS

Datasets collected in this study include national census data of livestock number for more than 300 *soums*, 25 km monthly precipitation data from Tropical Rainfall Measuring Mission (TRMM) (Goddard Distributed Active Archive Center, NASA), 5 km daily mean temperature and 1 km daily evapotranspiration (ET) from Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) (Jang et al., 2013, 2014), and 1 km 16-day normalized difference vegetation index (NDVI) from MODIS (Huete et al., 2002). Additionally, monthly mean temperature and total precipitation observed from national weather stations (NWS) of Mongolia were collected for evaluating uncertainties in MODIS/AMSR-E temperature and TRMM precipitation, respectively. The datasets collected differed in data periods since 1991 for livestock census data, 1998 for TRMM precipitation, 2000 for MODIS NDVI, 2003 for MODIS/AMSR-E temperature, and 1940 for NWS monthly data. In addition, we collected extensive aboveground biomass data from 2006 to 2010, collected by the Livestock Early Warning System (LEWS)-Mongolia project. In this study, we focused on analyses for a common data period from 2003 to 2010. Each data was spatially aggregated for each *soum* to produce *soum*-level dataset for multiple regression analysis. Before the regression analysis, the various *soum*-level data, except for livestock census data, were standardized to z-scores in which the 8-year data from 2003 to 2010 provide mean values. Livestock change rate (%) was utilized as the dependent variable of multiple regression analysis.

RESULTS

Among 337 *soums*, regression analysis was conducted for 291 *soums* where all input data are available. Multiple regression models were successfully produced at 203 *soums*, equivalent to 70% of the studied *soums*. The regressions explained on average 82% of annual livestock change with a range from 57% to 100%. Summer and winter conditions appeared equally important factors affecting livestock growth and mortality. Major controlling factors are summer NDVI (22%) and aridity (i.e. both P_s and ET_s/P_s, 22%), and winter temperature (33%) and precipitation (16%), respectively. Spatial pattern of primary factors was not randomly distributed but showed certain regionality (Figure 1). Aridity appeared as the most popular primary factor of Gobi regions, while NDVI was the primary factor in typical steppe regions. In north, winter or summer temperature explained the inter-annual livestock change primarily. Whereas, winter precipitation appeared the primary factor in parts of Khangai and Altai ranges.

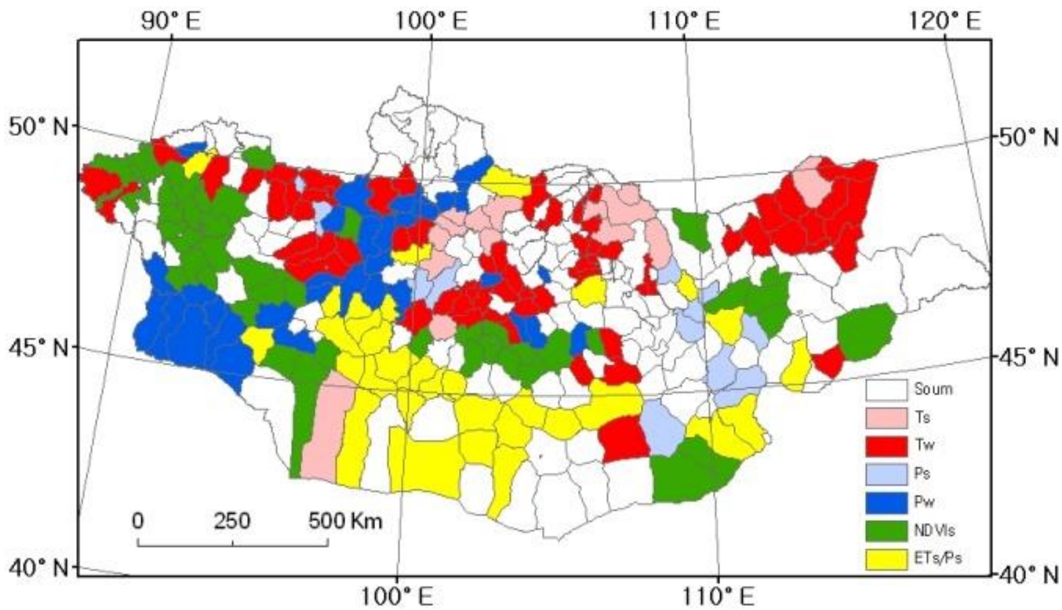

Figure 1. Biophysical variables of determining inter-annual livestock change for the period of 2003-2010: primary independent variables included in *soum*-level regression models. Ts and Tw, summer (JJA) and winter (DJF) mean temperature, Ps and Pw; summer (JJA) and winter (DJF) total precipitation; NDVIs, summer mean Normalized Difference Vegetation Index from MODIS; ETs/Ps, dryness index of ratio between summer evapotranspiration and precipitation. Seasonal temperature and precipitation were derived from daily and monthly data from MODIS and TRMM, respectively. Summer ET was a sum of daily ET derived from MODIS and AMSR-E data.

DISCUSSION

This study provided a conceptual model how various biophysical variables are linked with each other to regulate livestock growth and mortality. The model emphasizes critical roles of vegetation production and accessibility to foraging resources in determining livestock mortality. Summer and winter climate conditions act as external forcing variables to control summer vegetation production and winter livestock accessibility to standing dry grass. The seasonal perspectives on climate and vegetation growth were already conceived importantly in earlier studies, albeit verbally (Tachiiri et al., 2008). Our schematic model refines the verbal perspectives to have better mechanistic meanings by introducing seasonal biophysical variables and their interacting processes, which enabled us to investigate how the biophysical variables affect livestock dynamics quantitatively.

Among the six types of *dzud* identified in earlier studies (Fenandez-Gimenez et al., 2012), white, black, and combination *dzud*s can be semantically linked with factor(s) corresponding to winter precipitation (P_w), winter temperature (T_w) , and any combination from respective summer (P_s, T_s, ET_s/P_s, $NDVI_s$) and winter variables (P_w, T_w), respectively. Whereas, storm, iron, and hooped *dzud*s are not detectable in our study because those requires finer temporal-unit (such as daily) climate data or additional information on *otor* migration (Fenandez-Gimenez et al., 2012). In this study, roughly one half of *soums* with regression models were linked with the white (24 *soums*), black (51), and combination (38) *dzud*s, respectively. Though some studies verbally described the combined *dzud* as the most sever *dzud* case, this study showed equivalent mortality of the three types of *dzud*s in year 2010.

Our results indicate that summer and winter variables appeared equally important in influencing inter-annual changes in livestock numbers. Primary factors showed lumped regional patterns that corresponded well with regional climate constraints in ecological processes. Those results indicate that Mongolian pastoralism is highly vulnerable to climate change and variability and there are still many passageways for enhancing adaptive capacity such as herder's preparedness and governance.

Our multiple regression analysis may give benefits to determine overriding target variables in *soum* or region-level adaptation plans for *dzud* disasters. This should be however done carefully because our analysis were based on only 8-year data and hence, our results can be biased with the certain extreme conditions, such as 2009 summer drought and 2009-2010 harsh winter conditions resulting in 2010 massive *dzud* disasters in Mongolia. In turn, this suggests our regression models are more appropriate diagnostic analysis on which factors were mainly associated with controlling livestock survival or mortality rate during 2003-2010, rather than application to future projections of livestock change caused by climate change. Nevertheless, the conceptual model and statistical analysis done in this study provide useful framework for future development of process-based model on *dzud* hazard vulnerability and adaptation plans.

ACKNOWLEDGEMENTS

This work was supported by research grants from the Korea Forest Service (No. S211212L06031) and the National Research Foundation of Korea (NRF-2013R1A1A4A01008632).

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Phenology of *Stipa krylovii* Roshev. and *Stipa tianschanica* var. *klemenzii* Roshev., Species Dominating the Vegetation Communities of Hustai National Park

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ABSTRACT

Hustai National Park (HNP), which is one of the important parts of the Mongolian Special Protection Areas network, was founded in 1992 with the purpose of reintroducing the Takhi horse (*Equus ferus przewalskii*). HNP vegetation phenology research was first done in 1999 and since 2003 has been conducted each year between 24th of April and 24th of September, every 10 days. The purpose of this study is to identify, with the help of dominant species, the response of vegetation growing period to climate changes and to clarify features of species' phenology changes. As a result of the research we identified and recorded general trends of dominant vegetation phenology stages and how these changes respond to environmental factors (air temperature and precipitation). Comparison of the phenology stages of the two grasses dominant in the mountain steppe and steppe communities, *Stipa tianschanica* var*. klemenzii* Roshev. and *Stipa krylovii* Roshev. identified that the May and June precipitation amount had a significant effect on the beginning of the species' spring growing period ($p<0.027$). The results show that the vegetation growing period of the species has been increasing in the mountain steppe communities.

Keywords: phenology, growing period changes, Kryllov's feather grass, Klement's feather grass

INTRODUCTION

Research on the growing season regime and phenology studies help to identify relationships between species and their natural environment (Donnelly, 2006). Along with detecting the regularity of each year's seasonal changes, phenology studies also evaluate the normality of particular vegetation development by clarifying the extrinsic factors that influence it (Schwarts, 2003). Vegetation development stages generally happen in the same order each year and with the same regularity, but phenological stages occur in relatively different time periods depending on each species' geographical location, the local climate condition and the individual age structure in the population

(Beideman, 1960). Phenology data is used to detect the impact of climate changes in vegetation, but there are few long term studies. The beginning of vegetation growth, flowering and fruiting periods are sensitive to the air temperature and moisture levels, and climate changes is likely to impact the phenology trends of community-level reproduction (Donnelly, 2006). Conducting research beginning from initial growth in spring until withering in autumn, making measurements once every 10 days is an easy way to identify particular vegetation's annual phenology dynamics.

The purpose of our research was (1) to determine the phenology period of dominant species in each community of Hustai National Park (HNP), and (2) to analyse weather data from each observation period to identify the influence of particular environmental conditions on vegetation phenology.

The two species of feather grass (*Stipa*) which we chose for our research are both thick bushy, perennial species which are dominant in a particular community. Krylov's feather grass (*S.krylovii* Roshev.) occurs in all Mongolian vegetation-geographical regions except for the Transaltai Gobi region and Alashaa Gobi region. Globally, it occurs in Russia, Kazakhstan, Kirgizstan, Uzbekistan and China. It grows in dry and stony steppe and mountain steppe. Klement's feather grass (*Stipa tianschanica* var. *klemenzii* Roshev.), which is one of three tianschanica feather grass (*Stipa tianschanica*) variations, occurs in all vegetation-geographical regions of Mongolia except for Khuvsgul, Khentii, Khovd and the Mongolian Altai. Globally, it occurs in the northern areas of China, in Russia along the Mongolian border, in Kazakhstan, Kyrgyzstan and Uzbekistan. It is adapted to dry environments (xerophytic), and grows in dry mountain steppe, pure steppe and Gobi desert habitats (Grubov, 1982; Urgamal et al., 2014; eFloras.org, 2015).

FEATURES OF RESEARCH SITE

Hustai NP was founded in 1992 for the purpose of reintroducing the Takhi (*Equus ferus przewalskii*), which is rare and critically endangered species globally and regionally. HNP is a part of the National Special Protection Areas (NSPA). HNP is located in the semi-cold sub-zone of the semi-dry and temperate climate zone (Tsegmid, 1969). As the area contains mountains, hills, and wide and narrow valleys between the mountains and plains, the range of micro-climates means there are many different characters, such as steppe, mountain steppe and forest steppe vegetations. Ninety-five percent of total area is considered suitable for grazing (Bolormaa, 2004). In the recent years the forest steppe of HNP has dried considerably and changed its landscape appearance (Bayarsaikhan et al., 2009; Enkhsaikhan, 2009; Tuvshintogtokh, 2013) which indicates the need to observe and study the future vegetation trends in the area (Figure 1).

From the climate diagram developed by Walter's method using multiyear reports from Hustai hydrological observers (Munkhbat, 2014), the general trend in HNP shows suitable conditions for vegetation growing during summer, with a drying trend in September. However, rainfall is delayed for longer periods in some years which leads to semi-drought conditions. Annual precipitation is an average 228 mm, out of which 70% (156±30 mm) falls in the warm season (in June, July and August) (Munkhbat, 2014). Excessive hot weather in the middle of July of some years leads to an interruption of vegetation growth and subsequent early withering (Sergelen, 2007). The trend of temperature variations increase and cooling trend in April or at the beginning of vegetation growing period is being observed since 1995. However, according to the recent 10 year average, the there is a trend of increasing growing period, which is vegetation growing period after May, with an increase of days with regular temperature above +5 ^{0}C.

MATERIALS AND METHODS

Vegetation monitoring in HNP has been conducted each year since 2003, from the 24th of April until the 24th of September, on the 4th, 14th, and 24th of each month. On each occasion, species composition, cover, plant height, phenology stages were recorded. In this paper we have focused on records of two chosen species. Phenology stages of dominant species were recorded in consistence with bio-morphological characteristics. Our research principle is based on Beideman's (1960) method. We measured basic stages such as beginning to grow, seedhead formation, flowering, withering and total growing period stages. When the same stage was detected in not less than 75 percent of the same species in a research plot at the particular time period we considered it as the beginning of particular phenology stage.

Our research focused on four plots, consisting of: couch grass – Adams' wormwood – Kryllov's feather grass community (plot 1) and forb – grass community (plot 3) where Kryllov's feather grass dominates; small grass – caragana – bindweed – Klement's feather grass community (plot 2) and small grass – needle grass – bindweed - Klement's feather grass community (plot 4) where Klement's feather grass dominates (Figure 1). Statistical analysis of multiple factor regression (Multiple GLM) was performed using "R" to identify the effect of air temperature and precipitation on the spring regrowth, budding, flowering, withering and total growing period of each species.

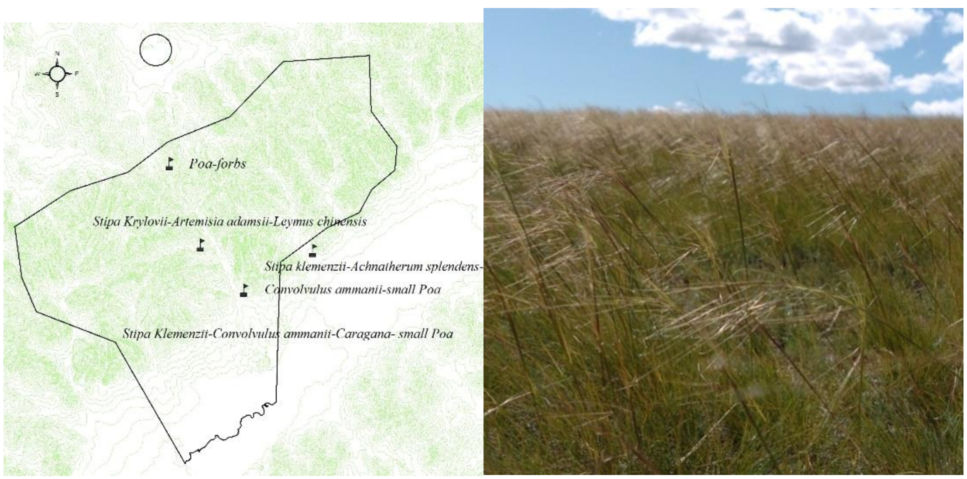

Figure 1. Research area and view of Kryllov's feather grass.

RESULTS AND COMMENTS

The assessment of the relation between the beginning of spring regrowth day, beginning of budding, beginning of flowering, total plant growth period at each plot and total monthly precipitation and temperature indicators showed that beginning of spring regrowing period of Kryllov's feather grass at the first plot (Figure 2) is dependent on May and June precipitation ($P<0.02685$). Beginning of budding ($P<0.0207$) and beginning of flowering ($P<0.01$) was dependent on July and August air temperature. Total plant growth period had positive correlation with precipitation ($r=0.78$). When entered into multi-factor linear regression pattern is showed greater dependence on average September air temperature ($P<0.04$). According to Mann-Kendall test extention of plant growing period has been detected only in Kryllov's feather grass from the first plot ($P<0.0282$). However at the third plot, regrowing period depended on May and June precipitation ($P<0.01$) and beginning of budding period of Kryllov's feather grass depended on June precipitation

(P<0.02). Except from the first plot, no changes were detected in flowering and total growing period. The reason for this may be the location of those two plots in different environmental context. The third plot situates in meadow-like steppe, while the first plot situates in the mountain steppe.

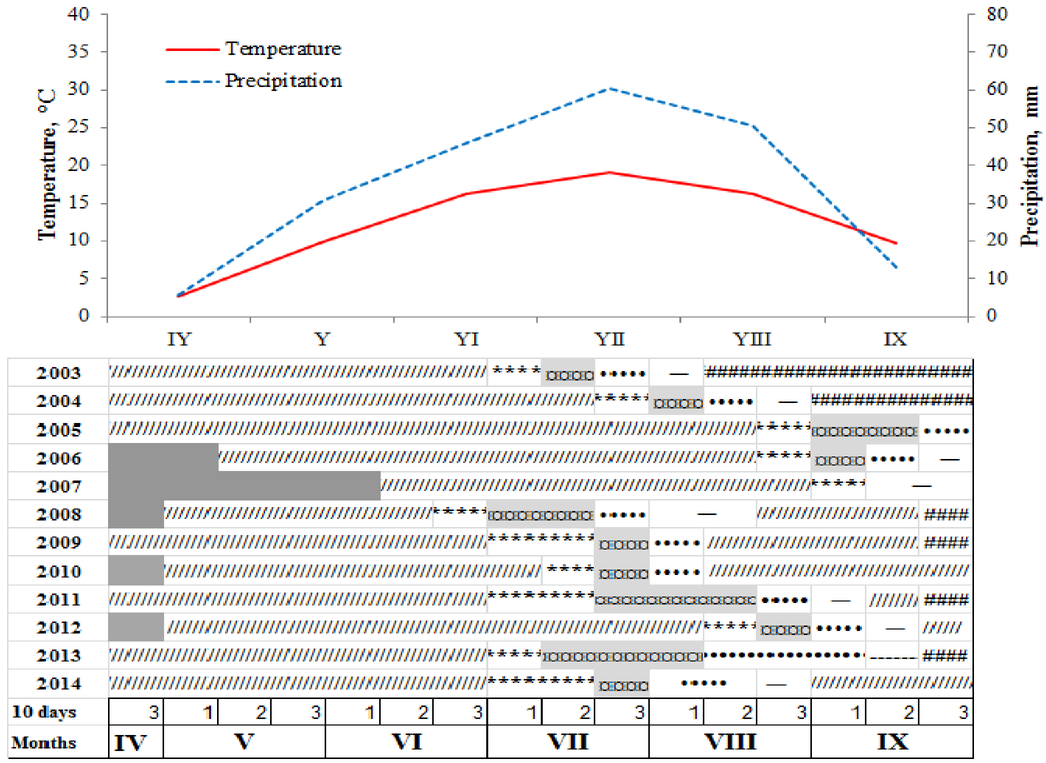

Figure 2. Climate diagram of Hustai National Park (1999-2014) and phenology of *Stipa krylovii* at the 1st plot (2003-2014).

Plot: eriod without vegetation, /////////- growing, ****- seadhead formation, ¤¤¤- flowering, •••••- seed formation, ------- seed dispersal, ###- withering

In the second mountain steppe plot, beginning of growing period of Klement's feather grass depended on May and June precipitation (P<0.02), while seedhead formation (P<0.007) and beginning of flowering (P<0.04) period depended on July and August temperature. If the level of statistical significance is set at 90%, then the beginning of flowering was dependent on average summer air temperature (P<0.0821) and total summer precipitation (P<0.0693). But total plant growth period changes related to September air temperature. According to our choice pattern, total growing period was dependent on September precipitation (P<0.04) and total summer precipitation (P<0.01). This last result is consistent with research that has shown that plant withering or autumn growing period showed more variance than the beginning of the growing period in spring (Sparks and Menzel, 2002; Cleland et al., 2007). The fourth plot located in the pure steppe was quite specific compared to other plots. This plot is exposed to intensive livestock grazing as it is situated outside of protected area. Since the research has been conducted here since 2007 due to insufficient data array there may be many statistically inconclusive indicators.

CONCLUSIONS

Temporal changes of plant phenology stages are becoming more evident in the recent years, and were revealed in this work carried out at HNP. Our study showed the influence of precipitation and temperature changes over the total plant growing period for the past 10 years. The preliminary conclusion is that the changes detected in the feather grass species' phenology in the mountain steppe is more influenced by the autumn growing period rather than beginning of growth in spring.

ACKNOWLEDGEMENTS

We express deep gratitude to HNP administration for giving us the opportunity to conduct this research and to NUM Research Support Center and Asian Research Center (ARC, NUM) for funding some parts of this study.

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2 Climate Change and Hydrology

Spatial Changes in Climate across Mongolia

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ABSTRACT

Previous research using meteorological station data suggests that temperatures and precipitation have been changing more across the semi-arid and arid country of Mongolia than in many other locations across the globe. We used gridded monthly data to determine the annual and seasonal rate of change in total precipitation (P), maximum temperature (Tmax), and minimum temperature (Tmin), as computed from the non-parametric Thiel-Sen slope estimator method. The significance of those changes were computed from the Mann-Kendall test. The University of East Anglia Climatic Research Unit (CRU) dataset was used for the 50-year time period from 1963 through 2012 at a 0.5 degree (~55 km) resolution. For the first 30 years, 30 to 35 meteorological stations from across Mongolia were used to create the spatially distributed "*High Resolution Gridded Data of Month-by-Month Variation in Climate*" CRU product; 20 to 30 stations were used for the last 20 years due to a decrease in the number of operational stations. Results are presented as maps of 1) mean total annual P, and mean annual Tmax and Tmin, and ii) annual trends over the length of record (1963-2012) with significance overlain, for the three variables. Rates of change at annual and seasonal time scales varied spatially with more consistent increases in temperature; significant precipitation trends were observed over smaller areas than significant temperature trends.

Keywords: Mongolia, climate change, Mann-Kendall, Thiel-Sen, gridded climate variables, trend analyses

INTRODUCTION

The climate of Mongolia is characterized as semi-arid with cold winters, warm summers and strongly seasonal precipitation patterns. Over the last few decades, a myriad of sources of change have affected traditional nomadic pastoralist lifestyles. These include, but are not limited to, major socio-economic and political changes and an increasingly warming and potentially drying landscape with changes in the frequency and severity of extreme climatic events, such as winter disasters or *dzud* (Batima *et al*., 2005; Fernandez-Gimenez *et al*., 2015). Simultaneously, changes are occurring such as the promotion of more intensive agricultural land uses with trends toward less nomadic practices, and increasing urban, industrial, and mining development (Ojima and Chuluun, 2008; Yamamura *et al*., 2013). Herders have observed changes to their environment and many of these observations correlate well with available climatic data (Marin, 2010; Fassnacht *et al*., 2011; Venable *et al*., 2012; Lkhagvadorj *et al*., 2013).

Climate research in Mongolia as reported in the international literature is limited, but there is a general consensus regarding the occurrence of increasing trends in mean, warm, and cool season temperatures but a relative lack of countrywide patterns in precipitation change (e.g. Batima et al., 2005; Dagvadorj et al., 2010; Jamiyansharav, 2010). Longer-term climate research using climate proxies suggests that the most recent decade may be one of warming and drought unlike that seen over the last millennia (Pederson *et al*., 2014). Given the uncertainties inherent in station-based data due to sparse station availability and the amount of missing data, we chose to examine Mongolian climate trends using spatially and temporally coherent gridded datasets. Our work extends existing research by investigating climate variability seasonally and annually across the country at spatial resolutions beyond the station level.

METHODS

Monthly maximum and minimum temperature (Tmax and Tmin) and precipitation (P) grids from the Climatic Research Unit (CRU) Timeseries 3.21 were acquired from the British Atmospheric Data Centre (Harris *et al*., 2013). The 0.5 longitude by 0.5 latitude grids are interpolated from anomalies of station data (1961-1990 means) and then combined with existing climatologies to give absolute monthly grid values. The data were provided to CRU primarily by the World Meteorological Organization via the Mongolian Institute for Meteorology, Hydrology and the Environment. While the number of contributing stations varies depending on the presence or absence of recorded data, generally 30 to 35 stations contributed from 1963 up to 1990 with a slight decrease in stations (20-30) recording to 2012.

The gridded files of monthly P, Tmax, and Tmin were compiled annually and seasonally (winter is December through February, spring is March through May, summer is June through August, and fall is September through November) for the length of record (1963-2012). The Thiel-Sen estimator for slope and the Mann-Kendall test for significance of trend (Gilbert, 1987) were calculated for the aggregate (total for P, and mean for Tmax and Tmin) time series at each grid cell using R statistical software (R Core Team, 2014).

RESULTS

Climate Patterns

Mean annual total P, Tmax and Tmin are shown in Figure 1 for the 50-year length of record. Precipitation gradients are noticeable from north to south and in mountainous versus valley regions of the country (Fig 1a). Similar patterns are noticeable for Tmax and Tmin (Fig 1b and c), with cooler temperatures on average in the mountainous and more northerly portions of the country.

Annual Trends

On an annual basis, significantly decreasing precipitation trends occur in the eastern and central parts of the country (ranging from about -8 to -21 mm/decade), with slight decreases in parts of the far south-central Gobi region (from -7 and -9 mm/decade) and the northwestern part of the country near Zavkhan *aimag* (province), (between -12 and -14 mm/decade) (Fig 2a). Changes in annual mean maximum temperature through time were found to be significant across most of the country (ranging from 0.2 to 0.6 deg C/decade) (Fig 2b). Trends in annual mean minimum temperature were significant across the entire country (ranging from 0.2 to 0.7 deg C/decade) with the greatest rates of change occurring in the north central part of the nation near Lake Khovsgol (0.7 deg C/decade), across parts of the western Altai Mountains and Great Lakes region (up to 0.6 deg C/decade), and in the far eastern steppe (from 0.5 to 0.6 deg C/decade). Increasing mean minimum temperature trends were also greater in the central Gobi region (up to 0.5 deg C/decade) (Fig 2c).

Seasonal Trends

Seasonal trends (not shown) are more spatially diverse than the annual trends. Changes in precipitation are generally not significant across a majority of the country particularly in the winter and spring months. In summer however, significant decreases in precipitation are seen from the central northwest across the central forest steppe to the eastern steppe, similar in magnitude and location to and of somewhat greater extent than those patterns illustrated in the annual trend (Fig 2a). Decreasing trends in fall precipitation are centered in a region extending east from near the eastern edge of Khovsgol *aimag* across the central forest steppe and steppe to the area west of Ulaanbaatar (from -2 to -7 mm/decade).

Trends in mean maximum winter temperatures are not significant over a majority of Mongolia. Fall mean maximum temperature changes over the period of record are also generally non-significant with the exception of the northwestern part of the country (up to 0.6 deg C/decade), the south central Gobi region (up to 0.3 deg C/decade) and areas south of the Khangai Mountains (from 0.3 to 0.4 deg C/decade). Increases in mean maximum fall temperatures are also seen north and west of Ulaanbaatar (up to 0.4 deg C/decade). Significant increases in spring and summer mean maximum temperatures are observed across most areas of the country (up to 0.4 deg C/decade in the summer), except for in the central Gobi (not significant in springtime) and parts of the eastern steppe.

Minimum mean temperature has been warming the most and has the largest extent of significant change throughout the seasons. While minimum winter and fall temperatures have increased significantly mainly over the western, central-southern and eastern portions of the country (overall ranges from 0.3 to 0.8 deg C/ decade in winter, and 0.2 to 0.7 deg C/decade increase in fall), minimum spring and summer temperatures have increased significantly across the entire nation. Only one small area of the far western Khangai Mountain region has not seen a significant warming of minimum spring temperatures over the last 50 years. Similar rates of change are seen in both spring and summer seasons (from 0.3 to 0.7 deg C/decade spring, 0.2 to 0.5 deg C/decade summer).

DISCUSSION AND CONCLUSIONS

The results of previous climate trend analyses by other authors often parallel the gridded results presented here. There are however, key differences. For example, when studying mean seasonal temperatures, Batima *et al*., (2005) concluded that primarily winter temperatures were increasing with increases also in spring and fall. They did not find clear increasing or decreasing trends in summer, though they found evidence of longer durations of periods with hot days. They did not find significant changes in seasonal precipitation, though they did acknowledge strong spatial variability in the precipitation results. Our analyses of these gridded datasets reveal clear temperature increases in summer, particularly for minimum temperatures and significant changes (decreasing) in precipitation in the summer and fall for nearly a quarter to a third of the country, depending on the season.

Other analyses of climate are more difficult to compare to our results due to the use of climate indices rather than explicit values of P, Tmax, and Tmin. In the *Mongolia Second National Communication* document (Dagvadorj, 2010), results are presented as an increase in the frequency of extreme high temperatures and a drop in the occurrence of extreme low temperatures. Increases in winter precipitation are also mentioned with decreases in summer precipitation across the country. These results are somewhat correlative to the increasing mean maximum and minimum temperatures, as well as the significant decreases in summer precipitation shown herein.

Inherent in the use of climatic datasets are uncertainties introduced due to data collection, processing, and in the case of gridded datasets, the interpolation of climate data. Jamiyasharav (2010) documented biases that may be present in the Mongolian climate records due to station siting, movements of station locations, and changes to instrumentation. Whether the differences between existing studies and our results are artifacts of the original station data, the interpolation processes used in gridding the climate variables, or differences in trend analyses methodology, or all of these, it is clear that the historical climate record exhibits significant change over a 50-year period from 1963 through 2012.

Spatial trend analyses at annual and seasonal time steps using gridded datasets (e.g. Hendricks and Fassnacht, *in prep*) provide a strong visual tool for examining significant climate change across Mongolia. These results suggest that significant warming trends and some drying trends are present in areas of the country that support much of the population. Mitigating adverse impacts from these changes will be particularly challenging under increasing agricultural and water-resource intensive mining development in these regions.

AKNOWLEDGEMENTS

The National Science Foundation Dynamics of Coupled Natural and Human Systems Program partially funded this work (Award BCS-1011801, PI Maria Fernanadez-Gimenez). Comments from two anonymous reviewers were greatly appreciated.

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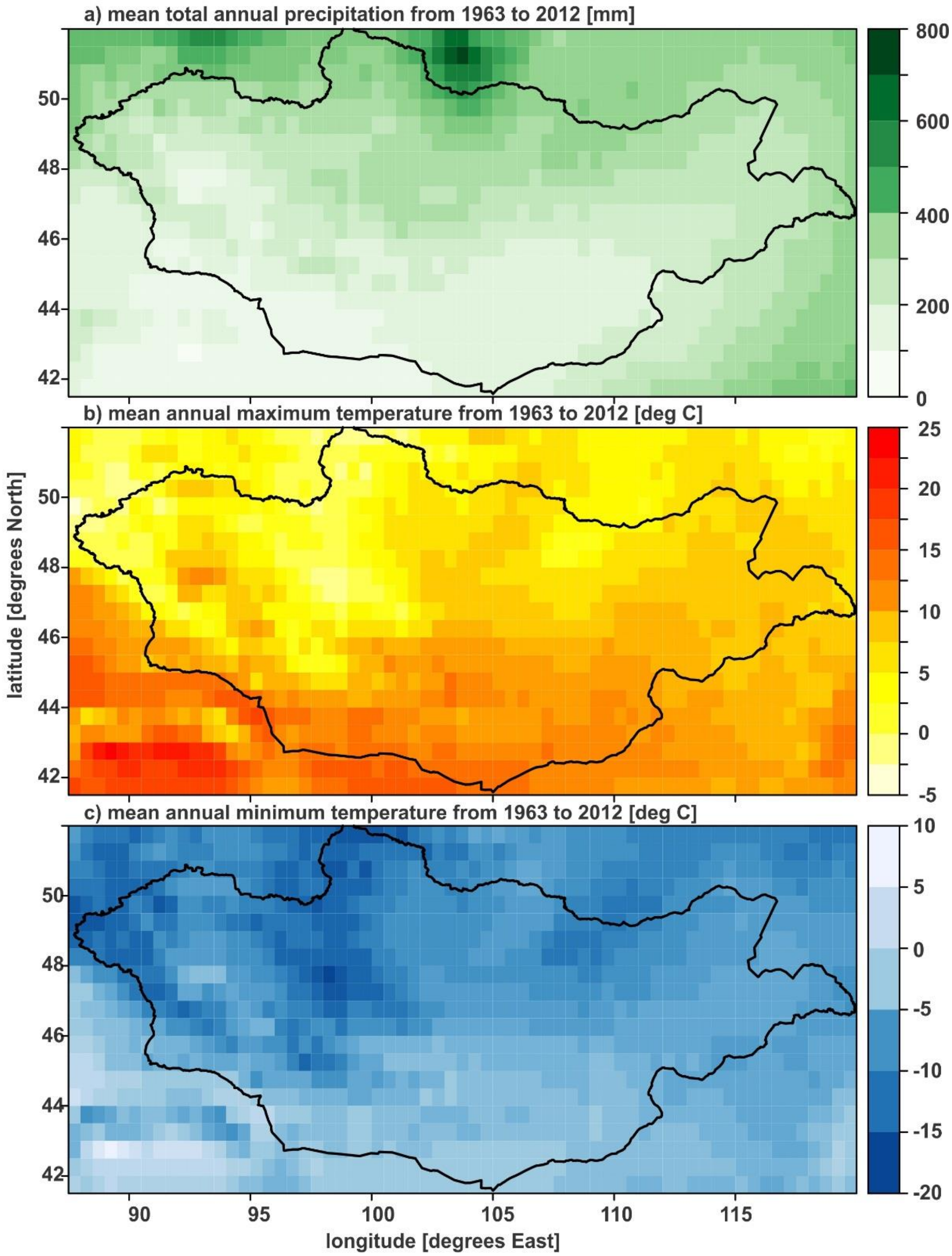

Figure 1. Mongolia mean annual (1963-2012) a) total precipitation in millimeters, b) maximum temperature in degrees Celsius, c) minimum temperature in degrees Celsius.

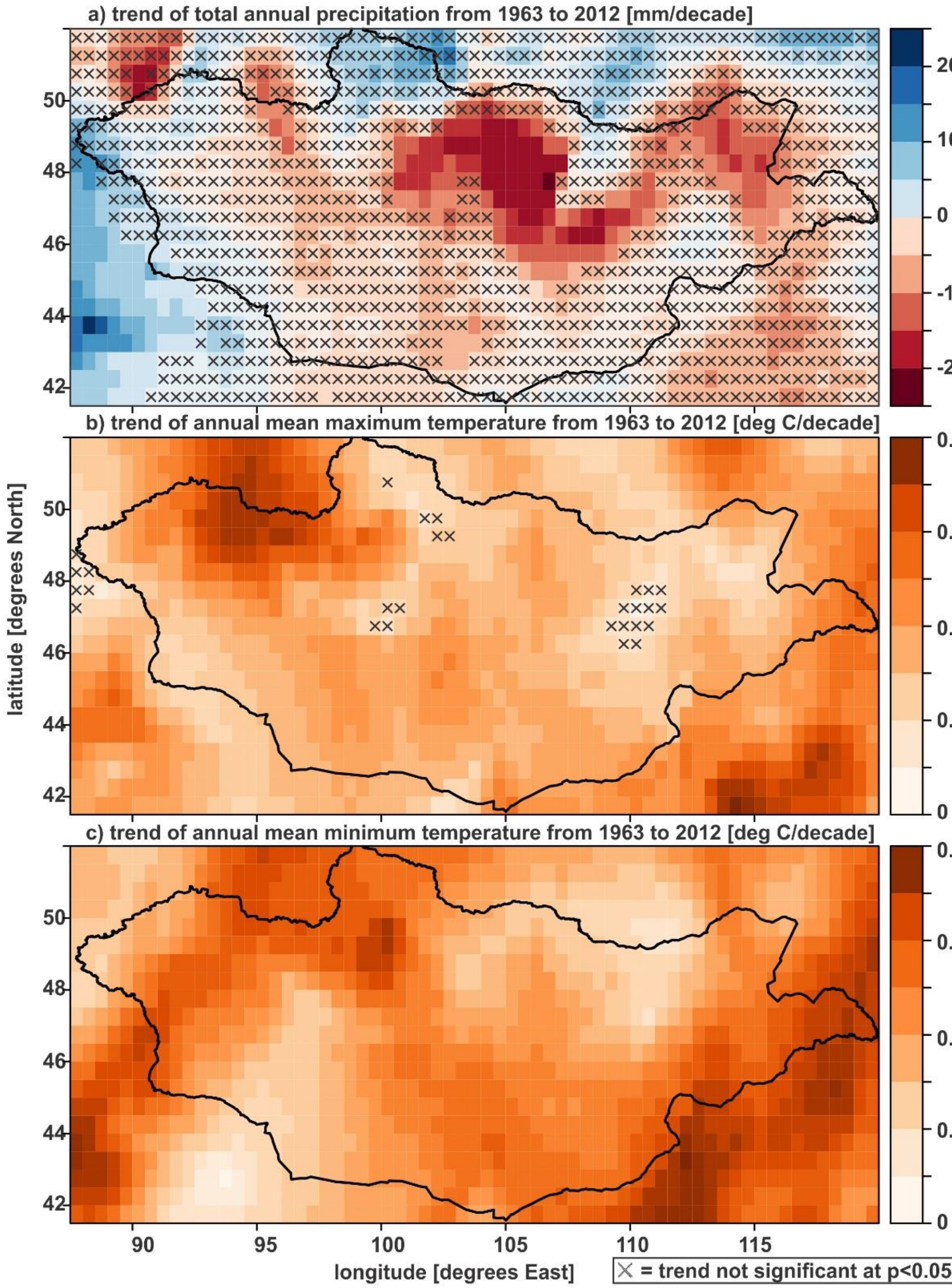

Figure 2. Trends per decade in the annual mean a) total precipitation trend in millimeters, b) maximum temperature in degrees Celsius, and c) minimum temperature in degrees Celsius. Note that the X's in the figure denote areas where the trend was not significant at the p<0.05 level.

How Unusual Was the 21st Century Drought in Mongolia? Placing Recent Extremes in an 1100-Year Context

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ABSTRACT

Understanding the connections between climate, ecosystems, and society during historical and modern climate transitions requires annual resolution records with high fidelity climate signals. In the 21st century, Mongolia experienced a rapid transition away from pastoralism as many families lost their herds during a drought and severe winter conditions (*dzuds*). Though the drivers of this transition were likely multi-factorial, many blamed market forces and overgrazing by herders. Because Mongolia's climate is highly variable, it is difficult to place recent climatic extremes and associated social change in context without long records of climatic variability. Here we ask: how extreme was the 21st century drought in the last 1100 years? We developed a 1100 year long tree-ring reconstruction of warm-season drought, derived from live and dead Siberian pine (*Pinus sibirica*) trees growing on a Holocene lava flow in north central Mongolia. Trees growing on the lava today are stunted and widely spaced, occurring on microsites with little to no soil development. These trees are water-stressed and their radial growth is correlated with both soil water availability (scPDSI) and grassland productivity (Normalized Difference Vegetation Index (NDVI)). Our reconstruction, calibrated and validated on instrumental June-August scPDSI (1959-2009) account for >57% of the variability in the regional scPDSI when >70% of the annual rainfall occurs. Our tree-ring data combined with meteorological data suggests that the early 21st century drought was the hottest and one of the most severe droughts in the last 1100 years. These results are consistent with model projections of warming in Inner Asia where rising temperatures will contribute to increased water stress, independent of changes in rainfall. Future warming may overwhelm increases in precipitation leading to similar high temperature droughts, with potentially severe environmental and social consequences for modern Mongolia. Long records of past climate variability can help us understand the relative importance of climate versus land management in catalyzing social change and help prepare societies for the full range of future climatic extremes.

Keywords: drought, tree rings, ecology, past environments.

INTRODUCTION

Semi-arid continental locations like Mongolia are characterized by highly variable moisture regimes even in the absence of human-caused climate change making it difficult to distinguish the long-term consequences of anthropogenic warming from inter-annual variation in moisture. Projections of future drying in Mongolia hinge on expected changes in rainfall – projections that are less certain than those of future temperature. Understanding the connections between climate variability, ecosystems, and society during historical and modern climatic transitions requires annual resolution records with high fidelity climate signals. When combined with climate forecasts, these long records can help us place recent extremes in climate in the context of the last two millennia and help us estimate the range of possible conditions likely to occur in future decades.

During the late 20th and early 21st centuries, Mongolia experienced a major drought, several *dzuds* (harsh winters) and rapid social and economic change (Sternberg, 2010). Following the independence movement of the 1990s, opening markets lead to large increases in total livestock production and a trend towards larger proportions of herds in resource-demanding goats (Liu et al., 2013). A severe drought as well as several *dzuds*, combined to kill off ~30% of the national herd in 1999-2002 and 20% of all livestock in 2010, forcing large numbers of herders and their families to relocate to cities such as Ulaanbaatar (Sternberg, 2010). Informal housing on the outskirts of the capital city and its associated environmental and social consequences continue to challenge Mongolia's ability to adapt to changing conditions.

Though a suite of social, economic, and climatic phenomena are likely responsible for the rapid changes observed in Mongolia's herding economy, the instrumental climate record is insufficient to place recent climatic extremes in context. The purpose of this study is to use an 1100 year record of past moisture conditions and climate model simulations to place the 21st century drought in context. Here we ask: how extreme was the 21st century drought in the last 1100 years?

STUDY SITE

We collected Siberian pine (*Pinus sibirica*) increment cores and cross sections from a Holocene lava flow (Khorgo) in north central Mongolia in 2010, 2012, and 2014. Samples were collected from living and dead trees on thin or absent soils surrounded by dark basalt. Trees growing on the lava flow today are widely spaced, stunted, and appear severely moisture-limited. We measured total ring width to +/- 0.001 mm and crossdated samples using standard procedures. Our chronology extends from 900 CE to 2011 CE and maintains a minimum sample depth of 25 series between 228 and 2009 CE (Table 1). This new chronology includes two more years of the recent drought (2010 and 2011) as well as additional samples collected in 2014 to our existing chronology (Pederson et al., 2014).

METHODS

Tree Ring Data

Tree rings contain growth-related trends, unrelated to climate that can be reduced using detrending techniques. To maintain as much low frequency information as possible, we used conservative techniques in the program ARSTAN to detrend and standardize the raw ring width series (Cook, 1985). We used either a negative exponential curve or straight line with slope ≤0 (typically samples containing or close to pith), straight line with slope ≤0 (typically non-strip bark samples without early growth), or straight line with slope > 0 (typically strip-bark samples). Three samples with unusual growth trends were standardized using the Friedman SuperSmoother (alpha = 9), a flexible piecewise, smoothing technique (Friedman and Silverman, 1989). Median series length was 512 (range 300 – 1193 years) (Table 1).

Climate Data

Mongolia's climate stations are sparse and at times incomplete, particularly since 1980. We instead chose to use the gridded self-calibrating Palmer Drought Severity Index (scPDSI) derived from CRU 3.20 precipitation and potential evapotranspiration fields (van der Schrier et al., 2013).

Tree Ring Reconstruction of scPDSI

The average correlation between tree-ring series (rbar) included in the chronology is 0.65, indicating that tree growth is responding to a common environmental signal. The average expressed population signal (EPS), a metric that quantifies how well a chronology based on a finite number of trees represents a hypothetical perfect or 'true' chronology, is >0.90 (possible range 0-1.0) beginning in 900 CE, indicating adequate sample size during the period of analysis (900 to 2011 CE).

Calibration/Validation

We reconstructed average June to August scPDSI for north central Mongolia using a linear regression model relating June to August scPDSI from a grid box (46-49N, 99-109E) to the mean of our detrended ring width chronologies over the 1959 to 2012 period (Fig. 1b). Gridded climate data for Mongolia prior to 1959 are based on few stations and exhibit unstable variance. We then validated our model and estimated prediction error using a split-period cross-validation approach by partitioning our time series into two 27-year periods (1959-1986; 1987-2012). We then compared the recent drought (1996 to 2012) in Mongolia to time spans of the same length sampled from our reconstructed scPDSI record.

Model Simulations

We used the long unforced control run of the GFDL CM2.1 climate model (Wittenberg, 2009) to contextualize the severity of the 21st century drought within the scope of natural climate variability in Central Asia. We extracted model simulated monthly precipitation and temperature from the half degree gridcells corresponding to central Mongolia, and calculated the Palmer Drought Severity Index (PDSI). These were compared to the empirical estimates of PDSI generated from the tree ring reconstruction from Khorgo (Pederson et al., 2014) and summer temperatures from the Asia2k reconstruction (Cook et al., 2012).

We compared past and recent droughts with those predicted using climate models. Our chronology has a strong, significant, and stable correlation ($r=0.76$, $p<0.01$, 1959-2011) with June through August scPDSI (van der Schrier 2013). This reconstruction permits a direct comparison to the future scPDSI projections developed by Cook et al. (2014) using 36 simulations from the historical and RCP8.5 experiments from CMIP5. We extracted the model simulated June to August scPDSI corresponding to our reconstructed region, as well as evaluating the relative contributions to total scPDSI from changes in precipitation and potential evapotranspiration.

RESULTS

Reconstructed scPDSI

Our reconstruction accounts for 56.5% of the variance in the observational scPDSI from 1959-2012 and faithfully represents the range of decadal changes from the late 20th century through the early decades of the 21st century (Figure 1). Split calibration and verification statistics indicate that the reconstruction is reliable over the full calibration period and that the model yields significant skill over a null model (Pearson $r > 0.70$ for all calibration and verification periods). Reduction of error (RE) and coefficient of efficiency (CE) statistics exceed 0.60 and 0.45, respectively for both calibration and verification periods indicating a robust model.

The tree-ring record of growing season moisture (June to August) suggests that the 21st century drought actually began in 1996 and continued until at least 2011 (Figure 1b), interrupted by only two non-adjacent years that were slightly above the mean (1999 and 2008). Similarly, the instrumental record of June to August scPDSI suggests the drought began in 1996, with only one year, 1998, recording a positive scPDSI value between 1996-2013. Cumulative reconstructed scPDSI during this period (1996-2012) was -27.4. Randomly selecting 10,000 16-year periods from the reconstruction of scPDSI suggests that the recent drought exceeds the 95% confidence limits and nearly exceeds the 99.9% confidence limits of the distribution of these draws (Figure 1c).

Model Simulations

Comparison of decadal-scale drought simulated by the long control run of the GFDL CM2.1 shows that the 21st century droughts fall outside the range of the simulated drought severity and associations with temperature. The 21st century drought falls just outside the simulated decadal drought severity distribution, but is associated with elevated decadal average temperatures not observed in the unforced control run.

Comparison of our scPDSI reconstruction to future simulated drought and pluvial (wet) trends suggests a highly uncertain future. Model predictions through the end of the 21st century encompass a range of possible future moisture conditions that include both pluvial and drought conditions outside the range of the last millennium. There is no model consensus on future moisture trends in north central Mongolia. Analysis of the influence of the simulated precipitation and potential evaporation terms over the 21st century reveals that this uncertainty arises from the balance between the tendency toward wetter conditions associated with increased precipitation and greater evaporative demand associated with rising temperatures. The diverse range of possible future moisture trajectories reflects the relative influence in each model of these two opposing trends.

DISCUSSION

Multiple failures in the steppe ecosystem of Mongolia during the early 21st century have been attributed to a variety of factors including: livestock privatization, reduced government support for herders, and changes in traditional livestock herding techniques including decreased mobility, a focus on commercial production, and increase in proportion of goats (Liu et al., 2013; Sternberg, 2008). However, these changes in policy and culture occurred during a period of unprecedented drought relative to the last 1100 years, exceeding the 99.9% confidence intervals of 10,000 replicated reconstruction segments of the same length as the recent drought. Elevated temperatures during the drought further suggest the anthropogenic warming contributed to the severity of this event (Pederson et al., 2014). The ecological, social and economic challenges experienced by herders over the last two decades must be placed within the context of this severe and possibility unprecedented drought. Modeled projections of drought for central Mongolia suggest a highly uncertain future with increasing variability in moisture likely to result in both pluvials (wet periods) and droughts that exceed those of the last 1000 years (Figure 2).

IMPLICATIONS

Results from this study provide a long context for recent environmental conditions in Mongolia. Though policy changes and an emphasis on commercial livestock production undoubtedly had negative impacts on rangeland quality during the late 20th and early 21st centuries, these impacts coincided with a drought of great magnitude given the context of the last 1100 years. This drought presented Mongolia with a set of environmental conditions that would challenge most livestock management approaches. Modeled drought conditions for Mongolia over the next 100 years indicate a wide range of extremes including droughts of similar or larger magnitude to the 21st century drought as well as wet conditions that meet or exceed those of the recent past. Our results indicate that a key challenge for Mongolia in coming decades will be to adjust policy in the face of widely varying forecasts of drought and moisture. Policy makers can use the recent drought as an example of future extremes, but should also consider the social, economic, and environmental implications of increased frequency and severity of drought and pluvial (wet) conditions beyond those experienced in recent decades.

ACKNOWLEDGEMENTS

We are grateful for the support of field and laboratory technicians: John Burkhart, Shawn Cockrell, Alex Dye, Kristin DeGraauw, Joseph James, Dario Martin-Benito, Javier Martin-Fernandez, Byarbaatar Soronzonbold, and Balginnyam Ulziibyar. This research was made possible through grants from National Geographic 9114-12, National Science Foundation CNH 1210360 and DEB-0816700, WVU Faculty Senate, and The Climate Center of Lamont-Doherty Earth Observatory.

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Table 1. Summary statistics of the Khorgo (KLP) tree ring chronology from north central Mongolia including number of series, median, minimum, and maximum segment length, and total number of rings in each chronology. R-bar is the average correlation between series.

Site Id	First Year	Last Year	# Series	Median Segm.	Min Segm.	Max Segm.	r-bar (std)	EPS>0.9
KLP	900	2011	127	492	302	1192	0.713 (0.04)	900 - 2011

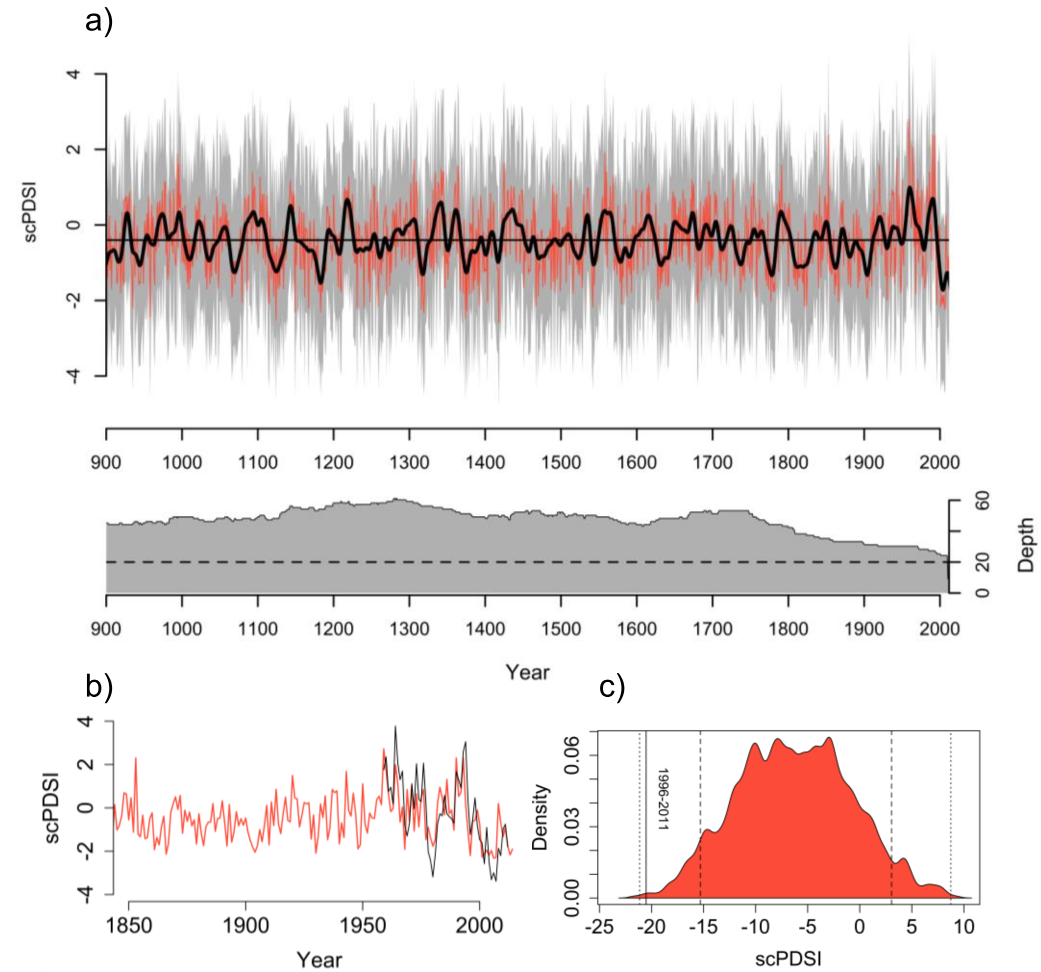

Figure 1. (a) Reconstructed scPDSI from Khorgo from 900 to 2011 CE (red line) with a 15 year spline (black line), 2RMSE of the reconstruction (grey) and sample depth (filled gray area). (b) Inset of reconstructed scPDSI (red line) and instrumental scPDSI (van der Schrier et al. 2013) (black line) from a grid box (46-49° N, 99-109° W) 1850-2012 CE. (c) Kernel density function of cumulative scPDSI derived from 10,000 random samples of 16 year segments from reconstruction (red) with the 1996-2011 drought (black line) and 95% (dashed) 99.9% (dotted) confidence limits.

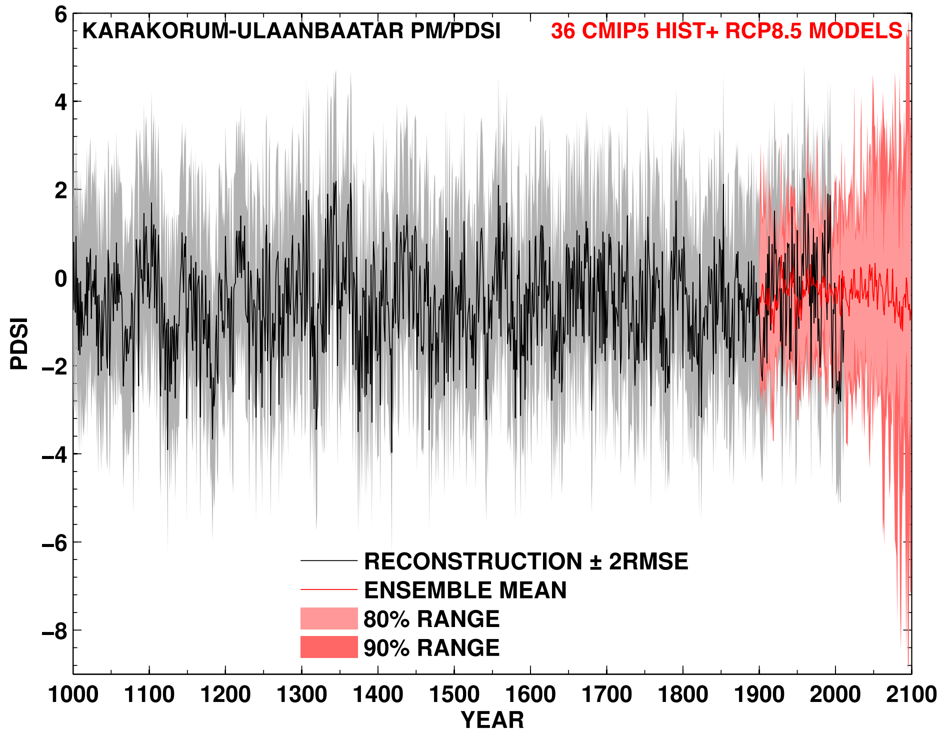

Figure 2. Pederson et al. (2014) tree ring reconstruction of scPDSI for central Mongolia (black) and modeled (red) Palmer Drought Severity Index (PDSI) using CMIP5 Historical and RCP8.5 future climate models.

Earlywood, Latewood, and Adjusted Latewood Correlations to Precipitation: A Test Case from the Khangai Mountains, Mongolia

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ABSTRACT

The Khangai Mountains of central Mongolia provide important ecosystem services to the surrounding region as the headwaters for a number of river systems and critical pasture for the animal herds of nomadic pastoralists. The mountains also provide a long-term record of regional moisture variability preserved within the tree-rings of Siberian larch (*Larix sibirica*) forests. Ring width measurements are commonly used to statistically reconstruct the hydroclimatology of a region based on the correlation of ring widths to precipitation and/or streamflow. Tree cores were collected, cross-dated, and the ring widths were measured from a site near Jargalant *bagh* in northern Bayankhongor *aimag*. Seasonal precipitation totals for the period from 1962 to 2012 were compiled from several meteorological stations surrounding the site. These historical precipitation values were compared to indices of total (TW), earlywood (EW), and latewood (LW) ring widths generated from a series of 16 cores. Nearly 70% of the annual precipitation in the Khangai region falls during the summer season (June, July, August), resulting in stronger correlations of ring widths (TW, EW and LW) to the previous year's summer precipitation than to the current year's spring or previous year's fall precipitation. The dependence of LW widths on antecedent EW ring widths masks any correlation to spring and fall precipitation. This dependence was removed using linear regression, resulting in the discovery of a negative relationship between the adjusted latewood (LW_a) ring widths and precipitation in both spring of the current year and fall of the previous year. This indicates that LW_a captures a different climate signal not detectable when working with the original LW, EW or TW measurements. Correlations of EW with (previous year's) summer precipitation were similar in value to correlations of TW with (previous year's) summer precipitation, suggesting that additional measurements of ring width may not be needed for use in reconstructing long-term summer precipitation variability. However, LW_a and the associated measurements required for its calculation may be potentially useful for reconstructing spring and fall precipitation patterns in summer precipitation-dominated hydroclimate systems.

Keywords: Mongolia, tree-rings, larch, precipitation, earlywood, adjusted latewood, paleoclimate

INTRODUCTION

The Khangai Mountain region covers nearly 120,000 square kilometers of forest steppe, steppe, and desert steppe ecozones across three *aimags* in central Mongolia. The mountains are the headwaters for a number of important river systems and provide critical pasture for the animal herds of nomadic pastoralists on a seasonal basis (Fernandez-Gimenez, 2000). Precipitation of the region is dominated by synoptic scale disturbances in the summer months of June, July, and August during which nearly 70% of annual precipitation falls (Sato et al., 2007). Spring and fall precipitation patterns are also important for the greening of vegetation needed for grazing and for sustaining natural water supplies for domestic and agricultural uses (Yu et al., 2003; Fassnacht et al., 2011).

While temperatures in the region have been warming significantly over the period of record, patterns of precipitation change are less clear (Batima et al., 2005; Dagvadorj, 2010; Jamiyansharav, 2010; Fassnacht et al., 2011; Venable *et al.*, 2012). Observational climate records for the region are fairly short, extending from the mid-1960's to the present. Here, we use tree-rings of Siberian larch (*Larix sibirica*) to provide a longer-term record of moisture variability in the Khangai region.

Of particular interest is discerning differences in seasonal precipitation patterns of the region to better understand changes through time to the local hydroclimatology. Traditional dendroclimatologic analysis correlates measurements of total ring width to climate variables such as temperature and precipitation (i.e. Fritts, 1976). Past precipitation reconstructions in Mongolia have used total ring widths due to the relatively strong relations of summer precipitation (previous and current year's) to total ring width (e.g. Jacoby *et al.*, 1999; Pederson *et al*., 2001).

More recent research suggests that the widths of the earlywood and latewood components of tree-rings have differing, and often better correlations with seasonal precipitation than total ring widths, especially in regions with bi-annual and monsoonal precipitation patterns (Meko and Baisan, 2001). This has proved particularly useful in the American Southwest when trying to reconstruct warm-season precipitation patterns from total ring widths that correlate more highly with cool-season precipitation patterns (Stahle et al., 2009, Griffin et al., 2011). In Mongolia, only a few published studies have used earlywood and latewood to examine seasonal temperature and/or precipitation patterns (De Grandpré et al., 2011; Dulamsuren et al., 2011; Khishigjargal et al., 2014). The goal of this study is to explore the correlation of total, earlywood, and latewood ring widths from tree cores recently collected in Mongolia with seasonal precipitation data from the Khangai region for potential use in hydroclimatic reconstructions.

METHODS

Study Area and Tree Cores

Tree cores were collected from 25 Siberian larch (*Larix sibirica*) trees at a dry mountain site (46.7 degrees north latitude, 100.9 degrees east longitude) near Jargalant *bagh* in Erdentsogt *soum* of Bayankhongor *aimag* in the Khangai Mountain region of Mongolia during June of 2012 (Figure 1). Older trees typically exhibited heart-rot, and there was recent evidence of some cutting in the stand and fire scarring of a few stumps and trees at the higher elevations. Of the original 53 cores collected for analysis, 16 cores from younger trees (between about 50 and 100 years of age) were selected for analysis since latewood tends to stabilize and decrease in size as a tree ages. Older trees often possess latewood with greatly reduced signal strength and are more difficult to measure accurately (Griffin et al., 2011).

The subset of cores were prepared and cross-dated using standard dendrochronological methods (e.g. Stokes and Smiley, 1996). The dplR package in R was used to statistically verify the accuracy of hand cross-dating and to iteratively detrend the ring width measurements using a spline function with a frequency response of 50% at a wavelength of 2/3 the length of the series intended to isolate climate as the dominant signal in the standardized ring widths (Cook, 1985, Bunn, 2008; Bunn, 2010; R Core Team, 2014). Robust chronologies for earlywood, latewood and total ring widths were built for the site by merging the series using a robust mean function with an Expressed Population Signal (EPS) of at least 0.85 for the total ring width chronology (e.g. Wigley et al., 1984, Briffa and Jones, 1990; Griffin et al., 2011) (Table 1). Adjusted latewood indices were calculated at the site level in a manner similar to previous studies to remove the dependence of latewood widths on antecedent earlywood widths (e.g. Griffin et al., 2011; Meko and Baisan, 2011; Stahle et al., 2009).

Precipitation Data

A majority of the precipitation in the Khangai region of Mongolia occurs in what locals describe as quasi-monsoonal rainfall during the months of April through September, defined here as the wet season. The dry season extends from October through March, and for the current tree-ring year it includes most of the period of dormancy for larch (previous year's October through the current year's March). Seasonal precipitation was defined as spring from March through May, summer as June through August, fall as September through November, and winter as December through February. Peak rainfall amounts generally occur during July and August and averaged 69.2% of annual rainfall during the period of record.

Precipitation totals for the tree-ring site were produced using basic inverse distance weighting from three long-term monitoring stations (Bayankhongor, Galuut, and Tsetserleg), with missing data filled by values from the Global Precipitation Climatology Center (GPCC) monthly grids (Schneider *et al.*, 2014) (Figure 1).

RESULTS

Correlations of current and previous years' total annual, wet/dry season (six-month aggregates), and seasonal precipitation (three-month aggregates) with total, earlywood, latewood and adjusted latewood ring widths from the current year were performed. Only significant results are (at the p<0.05 level) presented here (Table 1). The strongest correlations are positive for total and earlywood ring widths with previous year's total, summer, and wet season precipitation. Latewood correlates positively with previous year's summer precipitation and negatively with the dry season of the current year (previous October to current March). Unlike latewood, adjusted latewood has no significant correlation with the previous year's summer precipitation. Instead it negatively correlates with fall precipitation (September-November) and spring precipitation (March-May), both of the previous year. Latewood and adjusted latewood both have negative correlations of similar magnitude with the current years dry season precipitation.

DISCUSSION AND CONCLUSIONS

There is little difference between the total and earlywood ring width results in terms of improved correlation magnitude with wet season and summer precipitation, suggesting it may not be worth the extra measurement effort to use earlywood in reconstructions as compared to total ring width. Significant correlations with previous year's July and August precipitation were noted for total, earlywood, and latewood (but not for adjusted latewood) ring widths from larch in a region northeast of our study area (De Grandpré et al., 2011). Khishigjargal et al. (2014), also found positive correlations of total ring width with June (included in our summer category) and previous year's late season precipitation (included in our category of wet) in the same region. They found a negative correlation between December precipitation (included in our dry category) and ring width. A study by Dulamsuren et al. (2011), in the western Khenty Mountains had a similar result. Our analysis results did not support any significant correlations with winter precipitation and ring width per se, though the dry season defined here would include December/winter precipitation.

The difference between the correlation of latewood and adjusted latewood to previous year's wet season and summer precipitation illustrates the relation between earlywood and latewood and the need to remove that dependence in the Jargalant cores. There is no correlation between total previous year's precipitation with latewood or adjusted latewood probably because of the dominance of the summer wet season signal and its strong relation to earlywood and total ring width formation. No correlation may also be a result of the influence of temperature on latewood development, though summer moisture stress may influence the thickness of latewood formation (De Grandpré et al., 2011).

Affirming previous results in Mongolia (e.g. De Grandpré et al., 2011), correlations of previous year's summer precipitation with total and earlywood widths are the strongest found, with correlation coefficients of r=0.46 and r=0.47 respectively (Table 1). Additional measures of ring-with (i.e. EW, LW and LW_a) show increased and/or significant magnitudes of correlation for previous year's fall (r=-0.35 with LW_a), previous year's wet season (r=0.37 with EW), and previous year's total annual precipitation (r=0.36 with EW) over total width measures, strengthening the case for use of these additional measures in reconstruction of seasonal precipitation patterns. These results suggest a clear partitioning of growth between early and latewood and the seasonality of rainfall in Mongolia. They confirm the ability of adjusted latewood widths of larch to capture early and late season precipitation signals in the Khangai.

These findings could be used for examining changes in the patterns of seasonal rainfall over several decades prior to the instrumented meteorological record depending on the length of measurable earlywood/latewood record. Correlations could also be made between remotely sensed, and other measurements of seasonal moisture patterns, such as timing of vegetative green-up and brown-down to corroborate and perhaps extend observations of these conditions into the past. At minimum, a determination of state of seasonal precipitation could be made, i.e. dry vs. wet spring or fall. Such a metric may provide insight into the severity and patterns of historical *dzud* (winter disaster and livestock death) through qualitative comparison to state (wet/dry) of seasonal patterns.

ACKNOWLEDGEMENTS

The authors would like to thank Tumenjargal Sukh for providing the precipitation data from the Mongolian Institute of Meteorology, Hydrology and the Environment (IMHE) used in this analysis, and the tree-core collection team of Dr. Steven Fassnacht, Odgarav Jigjsuren, and Sukhbataar Jaminkhuyag (team also included the second author, Venable). Biogeography lab facilities for core processing were provided by Dr. Jason Sibold of the Department of Anthropology at Colorado State University. We would also like to thank Dr. Peter Brown of Rocky Mountain Tree-Ring Research for his insight and advice regarding the core dating and analysis process. The collection of the tree-ring data was supported by the American Center for Mongolian Studies (ACMS) US-Mongolia Field Research Fellowship Program, and the National Science Foundation Dynamics of Coupled Natural and Human Systems Program (Award BCS-1011801 PI Dr. Maria Fernandez-Gimenez). The comments of two anonymous reviewers were greatly appreciated.

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Table 1. Significant correlations between tree-ring type (indices) and seasonal precipitation, where (c) and (p) indicate current and previous year's precipitation, and chronology statistics for each tree-ring type. Note: EPS quantifies how well a chronology (based on a finite number of trees) represents a hypothetically perfect chronology. RBAR is a measure of the average correlation between cores from one tree (RBAR within), between cores from different trees (RBAR between), and the effective signal from the chronology (RBAR effective).

		Total width	Earlywood width	Latewood width	Adjusted latewood
Seasonal Correlations	Spring (c)	--	--	--	-0.29
	Summer (p)	0.46	0.47	0.29	--
	Fall (p)	--	--	--	-0.35
	Wet (p)	0.36	0.37	--	--
	Dry (c)	--	--	-0.32	-0.34
	Total (p)	0.34	0.36	--	--
Chronology Statistics	EPS	0.86	0.85	0.81	--
	RBAR within	0.71	0.68	0.51	--
	RBAR between	0.42	0.40	0.32	--
	RBAR effective	0.50	0.48	0.42	--

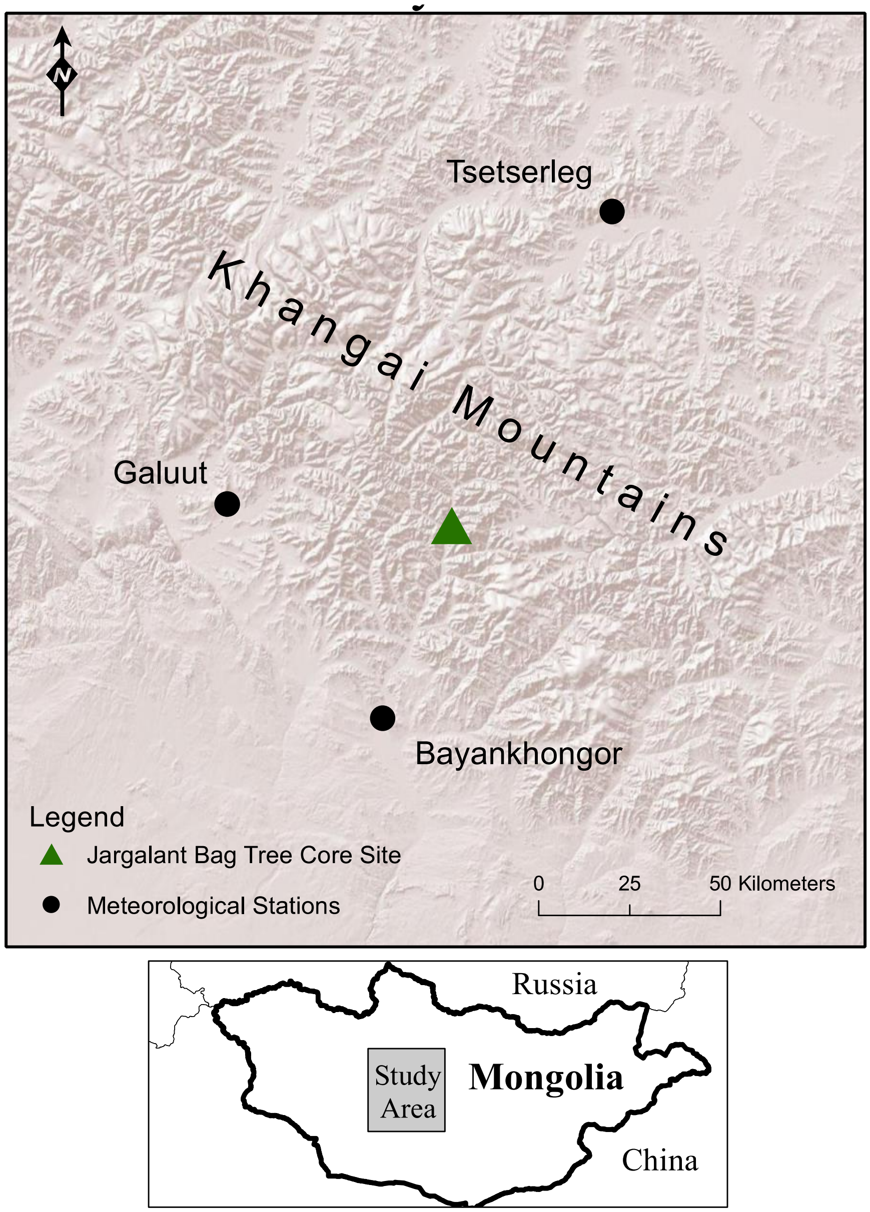

Figure 1. Tree-ring sampling site (triangle) and meteorological station locations (circles) in the Khangai Mountain region, Mongolia.

Characterizing Environmental Low Flows in Terms of Magnitude, Duration and Frequency

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ABSTRACT

Increased water demand has led to the need for development of water resources in Mongolia. With the Mongolian government implementation of integrated water resources management approach, assessing environmental flow requirements of major rivers becomes a primary issue. Using Indicators of Hydrological Alteration tools, physical habitat survey at Orkhon-Orkhon gauge site and statistical analysis of annual maximum flows, environmental low flow scenarios have been developed that attempt to reflect more “natural” characteristics of magnitude, frequency and duration. Specifically, minimum seasonal low flows of greater than the 75th percentile flow duration with bankfull flow releases during wet periods that have a duration of 12 to 24 days.

Keywords: environmental flow, bankfull flow

INTRODUCTION

Mongolia has been experiencing extensive growth in urban, agricultural and mineral resource development. This growth has increased the demand and need for development of water resources. Feasibility studies have been conducted or are being conducted on reservoir locations to provide water for these increasing demands (Baldsndorj et al., 2012). Several of these locations are in the Selenge River Basin which represents over 60 percent of the drainage area to Lake Baikal (UNOPS 2013). Environmental low flows in the form of annual constant minimums have been proposed by Baldsndorj et al. (2012). Poff and Zimmerman (2010) provided an extensive review of ecological responses to altered flow regimes. Poff et al. (2010) has recommended that environmental flows reflect “natural” variability (magnitude, frequency and duration) and that specified environmental flows be recognized as initial values and have the flexibility to be changed as observations are made in the future, i.e., adaptive management. In this study we have collected physical habitat data, conducted geomorphological characterization and statistical analysis of daily flow data at the Orkhon-Orkhon gauge site on the Orkhon River at Bulgan. Using this information we have developed environmental low flow scenarios that attempt to reflect more “natural” characteristics of magnitude, frequency and duration.

METHODS

Daily flow data for the Orkhon River Orkhon-Orkhon gauge site (Orkhon *soum*, Bulgan *aimag*) were used for this analysis. The flow data have a 33 year period of record from 1978 to 2010. This characterization uses the Indicators of Hydrologic Alteration (The Nature Conservancy, 2009) to characterize flow duration percentiles and seasonal characteristics of those flow percentiles based on monthly flow duration analysis (Searcy 1959). Field identification of bankfull flow was done following methods described in Wadeable Stream Assessment: Site Evaluation Guidelines (US Environmental Protection Agency, 2004). Bankfull flow was estimated by calibration of channel hydraulics to field discharge measurements and then calculating the discharge that would fill the channel to the bankfull elevation identified in the field. Hydraulic analysis was carried out using HECRAS (Brunner, 2010). The daily long-term flow record was then used to determine the frequency (percent of years) bankfull flow is exceeded and when it is exceeded, the duration (number of days) it is exceeded. Log Pearson III Frequency analysis (US Department of Interior, 1982) of annual maximum peak flow data was done to characterize the annual frequency of low level floods. The objective behind bankfull flow is to provide a magnitude and frequency of flood events that provides for river flushing and riparian enrichment.

RESULTS

Flow Duration

Flow duration analysis was done on daily flows for each month over the period of record. Figure 1 shows the monthly flow duration for exceedance durations of 10, 25, 50, 75 and 90 percent. These represent the percent of time (days) the associated flow value is exceeded for that month. From Figure 1 we can see that the percent duration flows vary with season. Visually we identify three seasons, low flow (November – March), medium flow (April – June and October) and peak flow (July – September) periods. Thus individual monthly flow duration percentiles could be averaged to represent seasonal flow duration percentiles. This would enable seasonal management versus monthly management. For a flow duration of 75 percent the seasonal flow durations would be 4.8 cms (low), 30.1 cms (medium) and 53.3 cms (high).

Bankfull Flow and Frequency Analysis

Various definitions of bankfull flow exist in the literature (Rosgen, 1996). Generally bankfull flow relates to the 1.5 to 2 year annual peak flows. Figure 2 presents a plot of the annual peak flows along with the estimated bank full flow, 1.5 yr and 2 yr frequency peak flows and flow at top of bank. Based on these initial estimates bankfull is less than the 1.5 and 2 year frequency flows which are all less than the top of bank flow. Table 1 gives the number of years over the period of record each flow value is exceeded and when the peak flow exceeds the specified value the number of days the flow exceeds the specified flow. This represents the duration of the “low level flooding period”. Thus from this analysis we can identify the magnitude, frequency and duration of low level flood flows. For example the 1.5 yr frequency flow was exceeded 20 out of 33 years (61 %) and when it was exceeded the average duration was 47 days.

DISCUSSION

Monthly flow duration analysis of daily flow clearly shows the seasonal variability of flows over the range of flow duration percentages. Representation of minimum daily environmental flows on a seasonal basis can represent minimum daily flows and annual seasonal variability. The selection of which specific percent duration to use is a bit more subjective. Percent durations tend to be lower (i.e. 90 %) for arid to semi-arid regions and higher for wetter climate regions (70 to 80 %). Our initial recommendation is on the order of 75 to 80 % with an understanding that the specified minimum percent duration can be adjusted through adaptive management practices.

In addition to establishing a minimum daily seasonal flow, the magnitude frequency and duration of flood flows should be established to provide for river flushing and riparian enrichment (Rosgen, 1996). Based on the frequency and duration of flows exceeding bankfull for the Orkhon River at Bulgan (Orkhon-Orkhon gauge), flood flows that exceed bankfull should occur on average about every 1.5 to 2 years and should have a duration of 33 to 47 days. The storage to provide for the flood flows can be incorporated into the storage requirements of a proposed reservoir. Once a certain minimum storage level is reached an operational release can be triggered to release low level flood flows.

CONCLUSION

We have recommended a two level approach to establishing minimum environmental flows that includes a minimum seasonal daily flow and the magnitude frequency and duration of a low level flood flow that would provide for river flushing and riparian enrichment. The minimum seasonal flows are represented by the seasonal 75th percentile flow duration. The magnitude and duration of low level floods can be well represented by the 1.5 year frequency flow. Our results provide environmental flow characterization that can be used in an adaptive management approach for the development and operation of proposed reservoirs.

ACKNOWLEDGEMENT

The authors would like to thank the Mongolian National Science Foundation for financial support and Ministry of Environment, Green Development and Tourism for close cooperation to conduct this research. We would also like to thank the students that worked very hard in the field; without their efforts the analysis would not be possible.

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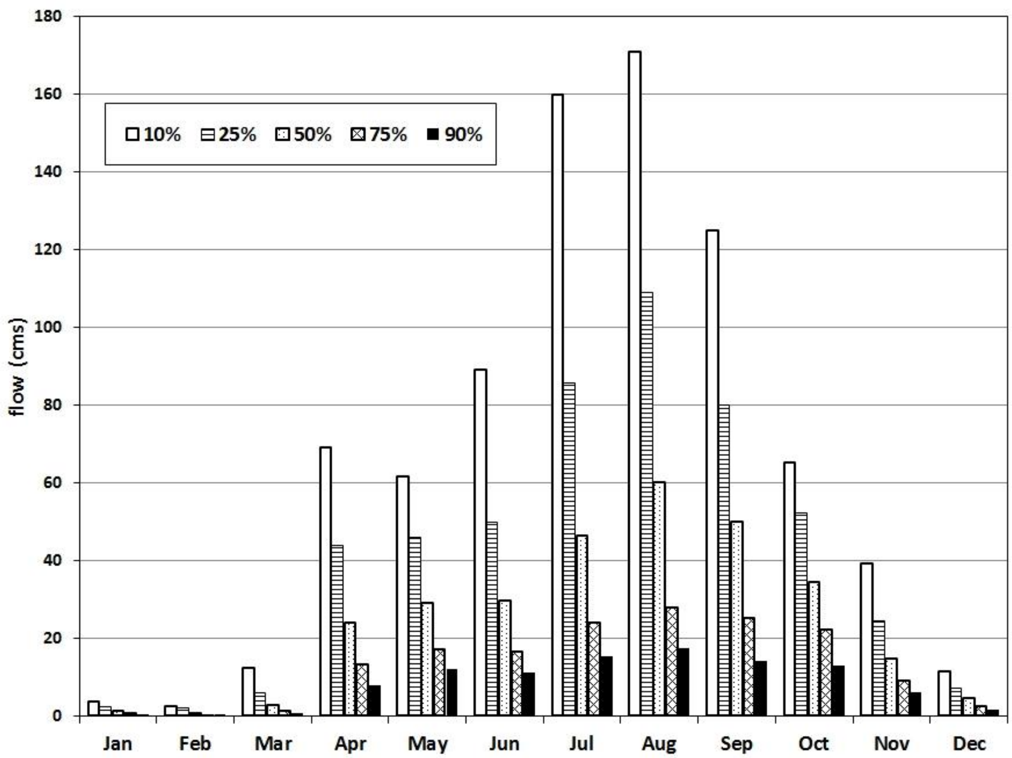

Figure 1. Monthly flow duration percentiles of daily flows for the Orkhon River at Bulgan for the period 1978 to 2010.

Table 1. Annual frequency and duration of selected low-level floods (bankfull, 1.5 and 2 year frequencies) for the Orkhon River at Bulgan (Orkhon-Orkhon).

Flow Characteristic	Flow (cms)	# of Years Exceeded	% of Years Exceeded	Statistics of Number of Days exceeded			
				mean	median	maximum	minimum
bankfull flow	30	33	100	131	148	260	3
top of bank flow	177	14	42	19	4.5	129	1
1.5 year return period flow	95	20	61	47	32.5	157	4
2 year return period flow	140	19	58	24	12	143	2

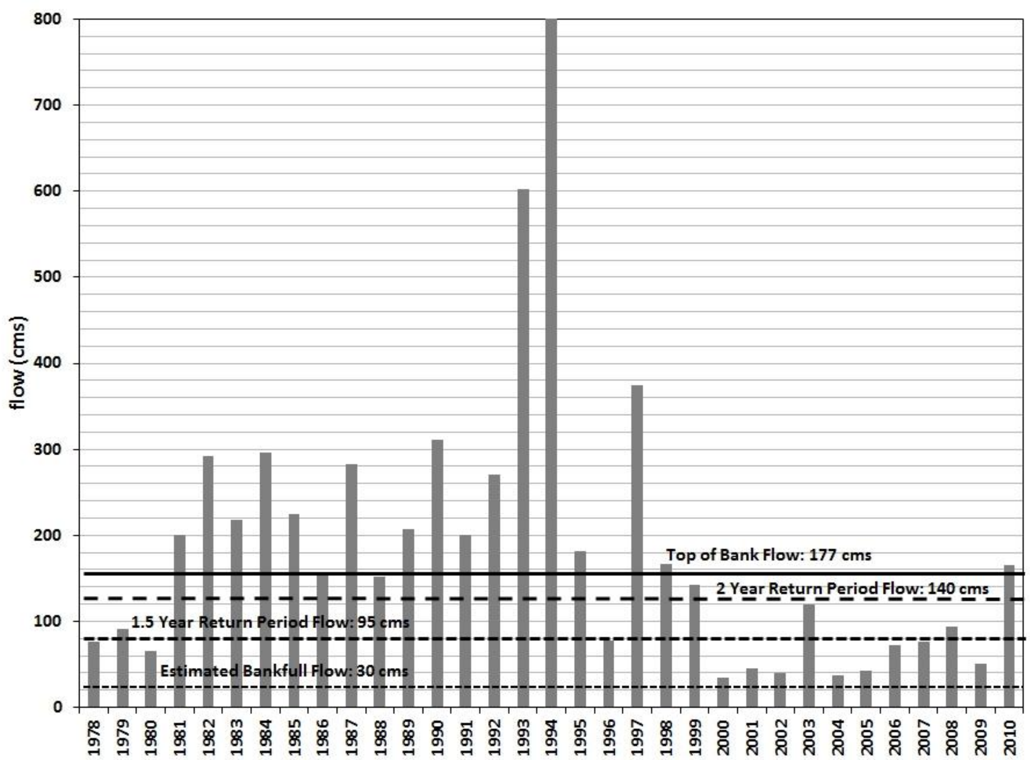

Figure 2. Annual peak flows, bankfull flow, 1.5 and 2 year return period flows with number of years exceeded and exceedance duration in days for the Orkhon River at Bulgan (Orkhon-Orkhon gauge).

A Journey Down the Tuin: the Hydraulics of an Internal Draining River from the Khangai Mountains to the Gobi Desert

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ABSTRACT

River systems flowing through semi-arid and arid regions provide critical ecosystem services for inhabitants of these areas. In remote and/or difficult to access areas away from population centers, few direct measurements exist to characterize the nature of streamflow in these systems. The Tuin River flows from the rugged high mountain and forest steppe landscape of the Khangai Mountains in central Mongolia to its terminus at Orog Lake in the desert steppe and sand dunes of the northern Gobi Desert. Field measurements taken in June 2012 at numerous locations from river headwaters to mouth were used to characterize streamflow in the main river channel and associated floodplain. From these measurements, channel hydraulic characteristics were estimated and hydrologic properties were assessed using a digital elevation model and other spatial data. These properties include contributing area, slope, hydraulic radius, and channel roughness. During the low flow conditions of the survey, streamflow was decreasing from upstream to downstream. At a point between the Bayankhongor and Bogd gaging stations, streamflow ceased at the surface and reappeared approximately 10 kilometres downstream, exemplifying losing flow conditions and subsurface flow components. The results of this analysis could be scalable to other internally draining river systems, especially for hydrologic modelling.

Keywords: streamflow, hydrology, digital elevation model

INTRODUCTION

Mongolia is an arid to semi-arid country receiving between 30 and 500 mm precipitation annually (Venable et al., 2015). Rivers are often lifelines of the Mongolian rangelands, as they are a watering point for livestock and the nomadic pastoralist of the area. For the purposes of understanding water resources in parts of Mongolia, field data were collected to provide channel hydraulic information for hydrological modeling. This paper outlines the hydrologic and hydraulic data collected for the Tuin River in Central Mongolia (Figure 1a). As this river is an internal drainage, it is classified as a “losing” river in terms of flow.

METHODS

Fieldwork

Field measurements were made in June 2012 by a team of U.S. and Mongolian researchers. Starting at the headwaters of the Tuin River in the high mountain ecozone of the Khangai, streamflow and hydraulics cross-sectional measurements were conducted along the length of the river to its terminus at Orog Lake in the desert steppe (Figure 1, Table 1).

Seventeen measurements of streamflow were conducted using standard hydrologic methodologies (Carter and Davidian, 1989). Sites were chosen carefully to minimize effects of vegetation and obstructions, braided channels, and meanders in the channel on velocity measurements (USGS, 1980). Field methods included affixing a meter tape to both banks of the channel and a using depth rod to take measurements across the channel width to calculate cross-sectional area. A standard Price-type rotating cup pygmy current-velocity meter was attached to the wading (depth) rod with velocity measurements made at each depth location. Since depths were always less than 1 metre, the average velocity was measured at 60% of the depth, as determined on the wading rod. The flow measurements and area calculations together yield the average discharge at the site in cubic meters per second.

Additionally, eight hydraulic measurements of the main channel and adjoining floodplain were made to estimate channel roughness and to facilitate determination of bank full discharge and hydraulic radius for future modelling (Chow, 1959). Field notes were made of vegetation characteristics and channel/floodplain sediments to further assist with roughness estimates. In the headwaters regions where channel conditions were more compact due to topographic relief, entire cross-sections could be measured. In more distal portions of the river, measurements could only be made near the main channel as the floodplain stretched several kilometers away from the channel.

Geospatial

The locations of each field site were recorded using GPS. These locations were entered into a geographic information system (GIS) for further analysis of area contributing to each measurement point. Estimates of main channel stream length and gradient (slope) were made using a digital elevation model of the region at a 30-meter resolution (NASA, 2012). The area contributing to each measurement point was delineated using the ArcGIS Hydro Tool (Maidment, 2002; Djokic, 2008; ESRI, 2009). The software tool includes methods for terrain preprocessing, generating watersheds (catchment delineation), and generating stream networks.

Point locations from the field sites were used for delineation as well as stream gage locations provided by the Mongolian Institute of Meteorology, Hydrology, and the Environment. Minor adjustments to reflect additional location information or due to the use of the software tool were needed to generate the basin contributing area estimates. For example, the Bayankhongor gage location used in the basin analysis was relocated 1.3 km from the given GPS location.

Hydrologic and Hydraulic Analysis

Standard hydrological assessment included a comparison of streamflow and gradient along the Tuin River (e.g., Chow, 1959). By combining the GIS-based analysis with the field measurements, we estimated the unitless channel roughness (n) from Manning’s equation:

$V = 1/n\ R^{2/3}\ S^{1/2}$ [Eq. 1],

where V is the average channel velocity in m/s computed from the streamflow per unit area, R is the hydraulic radius in m computed as the area per unit wetted perimeter, and S is the slope (Chow, 1959). From our data, V was computed from streamflow (Q) and area (A), R from A and depth, and S from the GIS analysis.

Table 1. Contributing drainage area, main channel segment length, and gradient for each field sampling site derived using the Arc Hydro Tool. The Manning's *n* roughness coefficient was computed using Equation 1. (Note: * Site Q03 includes the junction with the major tributary branch to the east, segment length is of the main westernmost channel.)

Tuin Site Name	drainage area [km^2]	segment length [km]	gradient [m/m]	streamflow [m^3/s]	Manning's n [unitless]
above Erdenetsogt	920	27	0.011	N/A	N/A
at Bayankhongor	2436	84	0.007	N/A	N/A
Q01	2621	89	0.008	1.79	0.053
Q02	2777	105	0.007	0.386	0.051
Q03	5596	133*	0.006	0.907	0.063
Q04	5721	136	0.006	1.14	0.075
Q05	5973	142	0.006	1.07	0.100
Q06	6489	172	0.005	1.14	0.117
Q07	6498	175	0.005	0.860	0.064
Q08	6662	194	0.005	0.427	0.070
Q09	6675	196	0.005	0.337	0.076
Q10	6682	198	0.005	0.084	N/A
Q11	6683	199	0.005	0.054	N/A
Q12	6684	200	0.005	0.019	N/A
above Jinst	6693	201	0.005	N/A	N/A
at Bogd	7524	240	0.005	0.191	N/A
above Orog Lake	7540	249	0.005	0.012	N/A
terminus at Orog L.	7561	258	0.005	N/A	N/A

RESULTS AND COMMENTS

When the measured streamflow was standardized by area, it decreased with area, as is expected of a losing stream system. However, all measurements except one were downstream of Bayankhongor and most of the drainage areas were larger (>5000 km^2), so the variation of drainage area with streamflow is difficult to interpret. It should be noted that discharge ended above Jinst as it all became subsurface flow, similar to what is observed in other closed basins (e.g., Valdez, undated). This loss of streamflow reduces the amount of surface water, but increases groundwater reserves. This groundwater-surface water interaction needs to be considered in conjunction with climate change for future water resources management. Streamflow subsequently reappeared above the Bogd gauge as groundwater discharge.

The estimated slopes derived from GIS are all shallow, with most gradients being about 0.5% with the maximum upstream gradient being 1.1% (Table 1). It was expected that further downstream gradients would decrease (Fassnacht, 2000). For the segments examined herein, the change in elevation was at a rate of -3.74 m/km with an almost perfect linear fit.

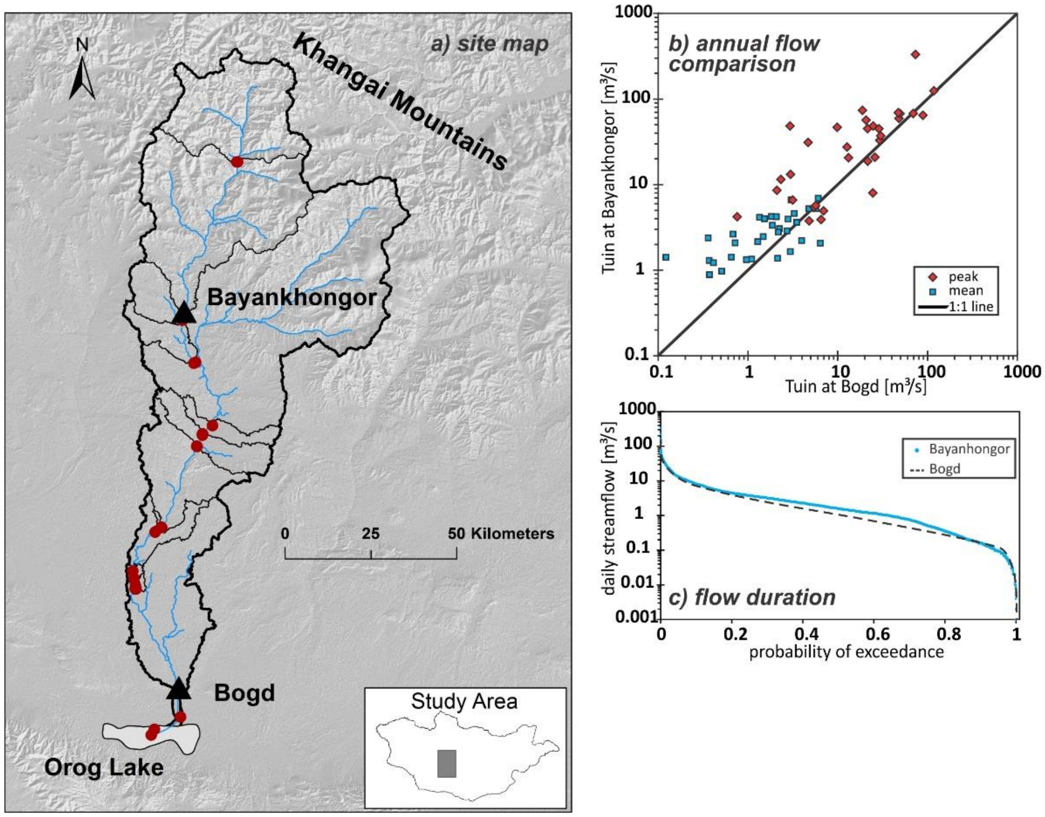

Figure 1. a) The Tuin River basin in central Mongolia, with the long-term streamflow gauging stations at Bayankhongor and Bogd and the measurement locations, b) comparison of annual mean and peak streamflow for the Tuin River at the Bayankhongor versus the Bogd gauging stations, and c) flow duration curves for the Tuin River at the Bayankhongor and Bogd.

Streamflow along the Tuin River at Bayankhonger tends to be greater than at Bogd (Figures 1b and 1c). This is especially true for lower flows (shown as mean streamflow in Figure 1b and the flow duration curves in Figure 1c) that recharge groundwater, as seen during our 2012 survey. We saw the Tuin River end and reappear (as groundwater discharge) above Jinst (Table 1). Peak flows (shown as the annual maximum daily streamflow in Figure 1b) were generally greater upstream than downstream; however, these are not always generated from the same rainfall event due to the spatial heterogeneity of precipitation events in this region.

The Manning's roughness coefficient was computed from the slope and field streamflow measurements (Table 1). The channels became rougher as they become wider (Table 1). However, the range of computed *n* is too large to be considered realistic (0.051 to 0.117), likely since the actual change in slope is much more local than the slope computed from GIS. The channel cross-sections selected for flow measurement were considered representative as standard protocols were followed for site selection (Carter and Davidian, 1989).

In future work, it is recommended that cross-section data for the entire channel beyond bank full to across the flood plain should be used to further evaluate channel hydraulics, as the data captured here represents low flow conditions in the main channel of each area sampled. At each cross-section this includes computing *R* as a function of depth, and using photographs of each site to estimate *n* and then computing bank full and flood stage streamflow. High flows in these river systems cover much larger areas, which would likely change the estimates of channel roughness and slope needed for detailed modeling efforts.

ACKNOWLEDGEMENTS

Funding for this project was provided by the National Science Foundation Dynamics of Coupled Natural and Human Systems (CNH) Program (award BCS-1011801 entitled *Does Community-Based Rangeland Ecosystem Management Increase Coupled Systems' Resilience to Climate Change in Mongolia?*, PI Maria Fernandez-Gimenez). We thank the two anonymous reviewers for providing insightful comments to improve this paper.

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3 Institutional Innovations in Mongolian Rangelands

What Matters Most in Institutional Design for Community-Based Rangeland Management in Mongolia?

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ABSTRACT

This study tested the effect of institutional design principles on social outcomes of evolving pastoral institutions in post-socialist Mongolia. Using data from 77 community-based rangeland management (CBRM) groups and 392 member households, we examined the effect of donor facilitation on institutional design. We found that donor facilitation approach significantly influenced group attributes and their external environment, but not institutional arrangements. The study confirmed that small group size, homogeneous interests, and heterogeneity of well-being are important group characteristics that predict higher levels of information diversity, leadership, and income diversity. Institutional arrangements such as the presence of sanctions, group-devised rules, frequent meetings, and recording documents increased cooperation, rules, and information diversity. Similarly, access to training and local government support provided a favorable external environment for increasing social outcomes. Furthermore, group characteristics such as dependence on livestock, homogeneity of interests, and leader legitimacy were critical for increasing social capital, livelihoods, sustainable rangeland practices, and proactive behavior of members. More frequent meetings of leaders were the most influential for these outcomes. Local government support and available donor support were associated with increased trust and norms of reciprocity, sustainable rangeland management practices, proactiveness, and livestock holdings. Lastly, group attributes and external environment influenced social outcomes of pastoral CBRMs in Mongolia more than institutional arrangements.

Keywords: commons institutions, Mongolia, institutional design, social outcomes

INTRODUCTION

Rural poverty and resource degradation have been the two major problems facing post-socialist Mongolia. The mixed results of CBRM, which was promoted to address these problems, prompted us to investigate factors influencing CBRM success. In 2007, 14 external donor programs facilitated over 2000 herder groups in Mongolia. This study sampled groups supported by four agencies: United Nations Development Programme (UNDP), New Zealand Nature Institute (NZNI), Swiss Development Agency (SDC) and Wildlife Conservation Society (WCS). Donors named their groups differently. Groups under UNDP projects were herder groups, SDC's groups were Pasture User Groups or PUGs, and groups assisted by NZNI named themselves *nukhurluls*. The study adopted these naming conventions. NZNI and WCS applied the same facilitation strategies (WCS, 2010) thus are grouped together. The four donors had similar participatory approaches to working with herders (Leisher et al., 2012). They also engaged relevant local and national stakeholders. However, their approach to CBRM membership differed. *Nukhurluls* and herder groups had voluntary membership, where some households chose not to participate in CBRM although they shared resources in the same locality. Hence, this approach had limitations for improving rangeland condition as some resource users were not part of the rules for restraining access to resources. For this reason, SDC adopted a territory-based approach, where CBRM membership was mandatory for all households sharing the same resources (Usukh et al., 2010). The different membership approach, program focus and, possibly, other variations in facilitation may have shaped institutional designs of CBRMs. This motivated us to test the effect of group types or donor facilitation approaches on CBRM group institutional design. We addressed the following two research questions: (1) does group type or donor facilitation approach influence the institutional design of CBRMs? and (2) which institutional design elements most influence social outcomes for Mongolian pastoral groups?

STUDY SITE

We sampled 77 CBRM groups and 392 member households in four ecological zones including desert steppe, steppe, eastern steppe and mountain forest steppe zones. However, the effect of ecological zones was tested in a different study. Hence, this study excluded this variable. Our sample included 36 herder groups, 33 PUGs, and eight *nukhurluls*.

METHODS

Survey

Our data included household interviews and organization profile questionnaires. Household interviews measured household demographics, livelihoods, rangeland management practices, norms, behaviors, and social networks. The organization profile represented an initial synthesis of qualitative interview and focus group data about group characteristics, organizational management, social capital, and leadership.

Variables

In Mongolia's context of externally-driven CBRM, group type or donor facilitation approach was the primary influence on the formal organization of herders and CBRM institutional designs. Therefore, the group type was our independent categorical variable including herder groups, PUGs, and *nukhurluls*. We had three sets of institutional design variables (Agrawal, 2002): group attributes, institutional arrangements, and external environment (Table 1). Institutional design variables were dependent for ANOVA test (Table 1) but functioned as independent in multiple regressions (Table 2 and 3) influencing social outcomes.

Intermediate and ultimate social outcomes commonly measured for the performance of community-based resource institutions (Agrawal, 2002; Fernandez-Gimenez et al., 2014; Leisher et al., 2012) were dependent variables. Six intermediate outcome variables included information diversity, leadership, knowledge exchange, the presence of rules, income diversity and cooperation. Six ultimate social outcomes included essential household assets, cognitive social capital (trust and norms of reciprocity), structural social capital (the presence social ties), rangeland practices (traditional and innovative types) and proactive behavior (members' engagement in rangeland issues).

Analysis

We used ANOVA to answer the first question about more effective facilitation type. For multiple comparisons, we used the Games-Howell procedure, the most robust for tests with unequal samples and variances like ours, to control family-wise error rates. We used multiple regressions to answer the second question. We tested the effect of institutional designs first, on intermediate outcomes, then, ultimate social outcomes.

RESULTS

Comparison of institutional designs by group types

Four group attributes varied significantly among the group types (Table 1): group size, group experience, and group diversity (members' well-being and homogeneity of interests). Institutional arrangements did not differ by group types except document records. The group types significantly differed in external environment variables including access to training, ongoing donor support, and market integration. Herder groups had significantly greater access to training and market integration than PUGs. PUGs were larger and had more donor support than herder groups.

Effect of institutional designs on intermediate social outcomes

Group attributes had significant positive effects on all intermediate outcomes while three variables had a negative influence (Table 2). Among them, group size, heterogeneity of well-being and homogeneity of interests significantly influenced three intermediate outcomes each. However, institutional arrangement variables had a limited effect: influenced rules, cooperation and information diversity. The presence of sanctions had a consistent positive effect on these outcomes. The external environment significantly influenced four intermediate outcomes including rules, information diversity, cooperation and leadership. Access to training had a strong positive effect on these outcomes.

Effect of institutional designs on ultimate social outcomes

Group attributes significantly affected all ultimate social outcomes except structural social capital (Table 3). Among them, three were most influential: dependence on livestock, homogeneity of interests, and leader legitimacy. Institutional arrangements had a significant effect on two ultimate social outcomes only: structural social capital and innovative rangeland practices. Leader meetings was the most influential variable increasing the levels of five outcomes. External environment significantly influenced four ultimate social outcomes including both types of social capital, innovative practices, and proactiveness. Local government support had a strong positive effect on these outcomes.

DISCUSSION

As we explained earlier, different group types imply different donor facilitation approaches. Regarding our first research question, we found that group attributes and their external environments were associated with donor approach. However, donor approach did not influence institutional arrangements. A prevailing dichotomy was shown between herder groups and PUGs in institutional designs. Herder group had more of the attributes theorized to promote successful outcomes in commons institutions, such as smaller group size, longer experience working together, heterogeneity of well-being, and homogenous interests of the members. Herder groups also had greater access to training and markets. In contrast, PUGs had only two positive features to group outcomes: maintaining good documentation and available external assistance.

Our study supported that small group size, homogeneous interests, and heterogeneity of well-being can predict higher levels of intermediate social outcomes. Aligning with theory, institutional arrangements such as the presence of sanctions, group-devised rules, frequent leader meetings, and recording documents increased cooperation, agreed rules, and information diversity. Access to training and local government support provided a favorable external environment for these three intermediate outcomes as well as leadership.

For ultimate social outcomes, group characteristics such as dependence on livestock, homogeneity of interests and leader's legitimacy were critical for increased social capital, livelihood and rangeland practices and proactive behavior of members. From institutional arrangement variables, leader meeting frequency was the most influential for ultimate social outcomes. Among external environment variables, local government support and ongoing donor support increased trust and norms of reciprocity, rangeland management practices, proactiveness, and herd size.

Our second research question was about institutional designs that have a positive influence on achieving greater social outcomes. We found that group attributes and external environment were more influential determinants of social outcomes than institutional arrangements. Along with these theoretically supported outcomes, we found results that contradict theoretical expectations. These included the negative effect of group size, experience and heterogeneity of well-being on knowledge exchange. Also meeting attendance and cooperation with outside agents negatively influenced the presence of rules. The quality of rules, meeting frequency, and transparency reduced the level of innovative practices while heterogeneity of well-being, dependence on livestock, and ongoing donor support were negative for social capital. We suspect that most of these negative influences may be associated with group size.

IMPLICATIONS

The design principle sets for group characteristics and external environment were shown to be applicable for predicting social outcomes of Mongolian pastoral institutions. Methodologically, two design variables including market integration and heterogeneity of endowments, needed to be contextually specific to Mongolia. Practically, the results provided a potential solution to the current disputes over the appropriate size of CBRM groups in Mongolia. The study demonstrated that for the majority of social outcomes, traditional small groups were more effective, while for cooperation and setting rules, large groups sizes were appropriate. Hence, CBRM facilitation should start from small groups eventually leading to a nested structure of CBRM.

ACKNOWLEDGEMENTS

This research was sponsored by the National Science Foundation award No. BCS-1011801, "*Does community-based rangeland management increase coupled systems' resilience to climate change in Mongolia*?"

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Table 1. Results of Comparisons of Institutional Design Variables by Group Types: Herder Groups (n=36), Pasture User Groups (PUGs, n=36) and Nukhurluls (n=8)

	Institutional design variables	Sample		Herder groups[a]		PUGs[b]		Nukhurluls[c]		*F*	η^{2e}
		mean	range	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Group attributes	Group size	89	8-482	44	32	156	100	55	47	21.32***	.38
	Group experience	5	0-14	5	3	3	2	9	4	16.07***	.30
	Leaders' legitimacy[d]	3.3	2-4	3.41	.61	3.17	.69	3.36	.63	1.26	.03
	Heterogeneity of well-being	.47	0-.73	.40	.26	.58	.10	.39	.23	6.44***	.16
	Homogeneity of interests	1.62	.5-2.0	1.75	.29	1.49	.40	1.56	.28	5.20***	.12
	Poverty level	.11	0-.94	.11	.11	.13	.16	.09	.07	.23	.01
	Dependence on livestock	.65	.18-.91	.61	.18	.70	.11	.64	.10	2.61	.07
Institutional arrangements	Ease of rules	2.57	1-3	2.68	.48	2.50	.64	2.29	.76	1.64	.05
	Awareness of rules	3.31	1-5	3.50	1.14	3.03	1.12	3.57	1.13	1.54	.04
	Group-devised rules	1.61	1-3	1.72	.81	1.44	.76	2.00	.89	1.77	.05
	Quality of rules	2.96	0-4	3.06	1.11	2.84	1.44	3.00	.63	.26	.01
	Presence of sanction	.50	0-1	.54	.51	.50	.51	.29	.49	.76	.02
	Leaders' meeting	3.18	1-8	2.80	2.03	3.76	1.92	2.71	2.14	2.05	.06
	Members' meeting	3.41	1-7	3.03	1.81	3.93	1.70	3.14	2.04	2.19	.06
	Meeting attendance	2.38	1-3	2.50	.66	2.21	.63	2.43	.79	1.51	.04
	Transparency	4.33	1-5	4.24	.74	4.42	1.12	4.43	.54	.37	.01
	Documents records	8	0-15	6	4	9	4	9	3	7.60***	.18
External.environment	Access to training	1.99	0-3	2.39	.87	1.55	1.15	2.00	1.31	5.61***	.13
	Local government support	1.31	.2-2.6	1.36	.59	1.27	.53	1.28	.44	.24	.01
	External cooperation	1.38	0-3.	1.39	.73	1.38	.71	1.38	.92	0	0
	Ongoing donor support	.72	0-2	.44	.76	1.07	.79	.50	.84	5.34***	.14
	Market integration	107	20-230	82	28	137	56	93	69	11.79***	.24

[a] Groups supported by the United Nations Development Programme, [b] Pasture User Groups supported by the Swiss Development Agency, [c] Groups supported by the New Zealand Nature Institute and Wildlife Conservation Society, [d] Variable was coded as follows: 1 = Not accepted at all, 2 = Little acceptance, 3 = Majority acceptance, 4 = Openly accepted. [e] Eta squared is the proportion of variation in *Y* that is associated with membership of the different groups defined by *X* (Lakens, 2013). An effect size can be small (η^2=.01), medium (η^2=.06) and large (η^2=.14) (Cohen, 1988).
*, ** and *** significant at 0.10, 0.05 and 0.01 respectively

Table 2. Results of Multiple Regressions of Institutional Design Variables on Intermediate Social Outcomes

Dependent variables Independent variables	Rules	Cooperation	Information diversity	Knowledge exchange	Income diversity	Leadership
Group attributes						
Group size	.38***	.21*	-.01	-.04	-.33**	.04
Group experience	.14	.18	-.13	-.45***	.24*	-.22*
Leaders' legitimacy	-.07	.23**	.11	.23**	.14	.14
Heterogeneity of well-being	.04	.25*	-.18	-.42***	.22	-.13
Homogeneity of interests	.23*	.29**	.35***	-.01	-.12	.36***
Poverty level	.25*	-.07	.17	-.02	.07	.01
Dependence on livestock	0	.15	.09	.09	-.15	.13
R^2, and F	.22/2.26**	.30/3.40***	.21/2.20**	.29/3.39***	.24/2.59**	.23/2.48**
Institutional arrangements						
Ease of rules	-.07	.13	.23	.01	-.29**	.05
Awareness of rules	.08	.03	-.21	.05	-.07	-.11
Group-devised rules	-.14	-.10	.18	.19	.39**	.26*
Quality of rules	.13	-.13	-.14	-.02	-.03	-.07
Presence of sanction	.30**	.45***	.32*	-.20	.07	.03
Leaders' meeting	.20	.32*	.38*	.21	.07	.34
Members' meeting	-.15	-.16	-.40**	-.08	-.19	-.13
Meeting attendance	-.33**	.02	.08	.06	.15	-.04
Transparency	-.16	-.30*	.16	.06	-.04	.10
Documents records	.39***	.35**	.03	-.02	.06	-.03
R^2, and F	.54/5.03***	.43/3.25***	.31/1.89*	.11/.52	.25/1.43	.17/.86
External environment						
Access to training	.46***	.42***	.25*	-.09	-.05	.05
Local government support	.18	.12	.18	.31**	.01	.37***
External cooperation	-.29**	-.15	.05	.12	-.09	0
Ongoing donor support	.37***	.16	.14	-.04	.06	-.08
Donor approach	.07	-.12	-.23	.08	-.32*	.05
Market integration	-.01	.11	.05	.08	.16	.19
R^2, and F	.36/5.59***	.23/2.98**	.21/2.63**	.16/1.85	.07/.77	.20/2.45**

*, ** and *** significant at 0.10, 0.05 and 0.01 respectively

Table 3. Results of Multiple Regressions of Institutional Design Variables on Ultimate Social Outcomes

Dependent variables / Independent variables	Assets	Cash income	Herd size	Social capital cognitive	Social capital structural	Rangeland practices traditional	Rangeland practices innovative	Proactive behavior
Group attributes								
Group size	-.33**	.01	-.16	.12	.15	-.14	-.23*	-.10
Group experience	.15	.22	-.26**	-.05	.02	-.10	.18	-.08
Leaders' legitimacy	.15	.11	.22*	.19*	.04	.36***	.20	.32**
Heterogeneity of well-being	.04	-.06	0	-.21*	-.10	-.18	-.02	-.01
Homogeneity of interests	-.06	-.09	-.24*	.37***	.31**	-.07	.08	.24*
Poverty level	.06	-.18	-.19	-.24**	-.17	.07	.01	.05
Dependence on livestock	.33**	.25*	.33***	-.36***	.07	.26*	.28**	.21
R^2, and F	.19/1.91*	.22/2.32**	.31/3.73***	.40/5.44***	.17/1.63	.22/2.27**	.21/2.17**	.23/2.48**
Institutional arrangements								
Ease of rules	.29*	.10	-.05	-.0	.06	.07	.40***	-.01
Awareness of rules	-.09	-.11	-.18	.09	.06	-.03	-.22	.06
Group-devised rules	.01	-.05	-.13	.09	.35**	.12	.23	.04
Quality of rules	-.37*	.01	-.05	.08	-.15	-.31	-.44**	-.09
Presence of sanction	.23	-.08	-.11	-.17	.08	.19	.44**	.16
Leaders' meeting	.47**	-.14	-.08	.01	.42**	.41*	.40**	.39*
Members' meeting	-.28	.21	.21	-.02	-.15	-.24	-.37**	-.43**
Meeting attendance	-.01	-.20	-.08	.30*	-.21	.01	.10	.15
Transparency	-.08	.27	.06	.26	-.02	.01	-.33**	-.07
Documents records	-.20	-.15	-.04	.04	-.01	-.03	-.13	.12
R^2, and F	.16/.83	.18/.94	.17/.88	.22/1.22	.30/1.79*	.14/.69	.36/2.38**	.20/1.10
External environment								
Access to training	-.15	-.04	-.12	-.18	.26*	-.14	.05	.12
Local government support	.02	-0.3	-.17	.41***	.21	.28**	.14	.36***
External cooperation	-.05	.21	.09	.01	-.04	.13	-.20*	-.03
Ongoing donor support	.15	-.04	.29**	-.13	-.23*	.14	.25*	-.05
Donor approach	-.34**	-.20	-.10	-.14	.20	-.24	-.49***	-.20
Market integration	-.18	0.22	0.04	.12	-.21	-.02	-.10	.24*
R^2, and F	.14/1.65	.09/1.01	.13/1.44	.27/3.60*	.18/2.05*	.15/1.77	.29/4.06***	.25/3.22***

*, ** and *** significant at 0.10, 0.05 and 0.01 respectively.

What Explains Positive Social Outcomes of Community-Based Rangeland Management in Mongolia?

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ABSTRACT

Community-based rangeland management (CBRM) has been proposed as a promising option to reduce rural poverty and resource degradation in Mongolia. However, results have been mixed. Studies about the factors influencing CBRM success have been limited. We explored the mechanisms underlying social outcomes of Mongolian CBRM. The study revealed that access to diverse information, leadership, knowledge exchange and rules facilitated the effect of formal organization on pastoralists' traditional and innovative rangeland practices, proactive behavior, and social networking. Importantly, information diversity had a triggering effect on the other three facilitating variables. This chain of four mediators collectively increased the effect of the formal organization on the above social outcomes. We also found that ecological zone had a moderating effect on the relationship between formal organization and members' proactive behavior and social networking.

Keywords: community-based management, pastoralism, Mongolia, social outcomes

INTRODUCTION

Several studies of Mongolian CBRM have revealed improved livelihoods, better resource condition and increased adaptive capacity (Usukh et al., 2010; Fernández-Giménez et al., 2012; Leisher et al., 2012). In contrast, others showed CBRM to be ineffective and potentially exclusionary (Upton, 2008; Murphy, 2011; Addison et al., 2013). Research on the relationships between factors that may explain mixed outcomes of CBRM has been limited, however. To address this gap, we examined how and why CBRM increases social outcomes and if the group's ecological zone influences this relationship. We advanced three hypotheses:

(1) The effect of formal organization on social outcomes is mediated by intermediate variables including access to diverse information sources, leadership, knowledge exchange, and the presence of rules.

(2) These four mediators are causally interrelated.

(3) The ecological zone moderates the mediated effect of formal organization on social outcomes.

In this study, pastoral groups sharing resources in the same area and organized into groups under external donor support are defined as formal CBRM groups. They had agreed-upon rules to manage rangeland resources, in contrast to informal non-CBRM groups practicing customary norms for resource use.

STUDY SITE

We sampled 142 pastoral groups and 706 member households in four ecological zones including desert steppe, steppe, eastern steppe and mountain and forest steppe. Adjacent *soums* (counties) (N=36) were paired with (N=77) and without (N=65) CBRM groups in 10 *aimags* (provinces) of Mongolia.

METHODS

Survey

We collected data using household interviews and organization profile questionnaires. Household interviews measured household demographics, livelihoods, rangeland management practices, norms, behaviors, and social networks. The organization profiles represented an initial synthesis of the field data about each group's characteristics, organizational management, social capital, and leadership.

Variables

The independent variables were organization status and ecological zone. The organization status was coded as either "no formal organization or non-CBRM" or "formal organization or CBRM." Ecological zone included four categories mentioned earlier.

Ultimate social outcomes were our dependent variables. Six ultimate social outcomes measured essential household assets, cognitive social capital (trust and norms of reciprocity), structural social capital (social ties for mutual assistance), rangeland practices, and proactive behavior. Traditional practices were a sum of 16 customary practices such as seasonal moves and setting aside reserve pastures. Innovative practices included 19 different activities recently introduced by donors. Proactive behavior measured members' reports of constructive actions to solve rangeland issues. Intermediate outcome variables were dependent on organization status and ecological zone but functioned as independent for ultimate social outcomes. Intermediate outcomes included information diversity, perceptions about local leadership, reported knowledge exchange within and outside of the group, and the presence of rules for rangeland management.

Analysis

We used a regression-based conditional process analysis (Hayes, 2013) to test a moderated mediation effect of organization status on ultimate social outcomes. This is a causal model where a mediator links a cause and an effect, and explains "why" and "how" this causal process occurs (Wu and Zumbo, 2008). A moderator modifies this causal effect and clarifies "when" or "for whom" independent variable most strongly causes dependent variable (ibid). We used a serial-multiple mediator model of the path analysis using bias-corrected bootstrap confidence intervals (5,000 bootstrap samples) introduced by Hayes (2013). His PROCESS software provided estimates for the total effects (c), direct effects (c'), and total indirect effects (c-c') as well as specific indirect effects (the total indirect effect is a sum of these specific effects). For the moderation test, we used a model that treated four mediators as parallel controlling combined indirect effects on social outcomes. To define causal relationships between the four intermediate variables, we conducted multiple regressions controlling organization status and ecological zone.

RESULTS

We found a significant interdependence of four mediators except the relationship between leadership and the presence of rules. Information diversity significantly affected the other three mediators at $p<.05$: $\beta=.38$ on leadership, .39 on rules and .29 on knowledge exchange. Leadership had a significant effect on information diversity and knowledge exchange (both $\beta=.35$, $p<.01$). Knowledge exchange had a significant positive effect on information diversity and leadership ($\beta=.25$ and .34, $p<.01$ respectively) and a negative effect on rules ($\beta=-.19$, $p<.05$). Rules significantly influenced information diversity ($\beta=.31$, $p<.01$) but had a significant negative effect on knowledge exchange ($\beta=.-17$, $p<.05$). We placed the mediators in a causal sequence based on the strength and magnitude of the association as well as on the basis of reported order by donors.

A total effect of organization status on ultimate social outcomes is a sum of its direct effect on outcomes and the indirect effects through mediators. We found a significant total indirect effect of organization status on four ultimate social outcomes: traditional (*c-c'* =.72) and innovative (.76) rangeland practices, proactive behavior (.44), and structural social capital (.37) at 95% bias-corrected confidence intervals (CI). Accordingly, the total effect was significant (*c*=1.05, 1.21, .74 and .31 for traditional and innovative practices, proactive behavior, and structural social capital respectively at $p<.01$). We note that only proactive behavior had a partial mediation or a significant direct effect of organization status (c'=.30 at $p<.05$) while the other three outcomes were fully mediated (i.e. no significant direct effect) by the serial-mediators.

We also examined which mediators were more influential for transferring the effect of formal organization onto social outcomes. These indirect effects were channeled through information diversity path alone onto traditional practices (*B*=.52), innovative practices (.62), proactive behavior (.20) and assets (.45). Information diversity and leadership together transferred the organization effect onto traditional practices (*B*=.16), proactiveness and structural social capital (.11 each) and cognitive social capital (.05) with 95% of bias-corrected CI. Other paths had small indirect effects. Figure 1 shows these two influential paths. A contrast test indicated a significantly greater specific indirect effect on traditional practices through information diversity compared to the path through information diversity and leadership.

Ecological zone significantly moderated two ultimate social outcomes with the significant mediation effect at $p<.05$ (Figure 2). Desert steppe ecological zone had a significant positive moderation of the indirect organization effect on proactive behavior through agreed rules (*B*=1.19). However, the steppe zone had a significant negative moderation of the same path (*B*=-.60). Eastern steppe also had a significant negative moderation on structural social capital through leadership (*B*=-1.82).

DISCUSSION

The results partially supported our hypothesis about the mediation effect of intermediate variables. The effect was found on four of six ultimate social outcomes including traditional and innovative rangeland practices, proactive behavior, and structural social capital. The most influential mediators that explain the effect of organization status on the four ultimate social outcomes were information diversity and information diversity together with leadership. The second hypothesis was supported with significant relationships among the four mediators. The results revealed a sequential order of these factors, where better access to information triggered an increase in subsequent variables including leadership, knowledge exchange and the presence of rules. However, rules were negatively associated with leadership and knowledge exchange. Lastly, the significant moderation of ecological zone partially supported our third hypothesis affecting only two social outcomes. The desert ecological zone has a positive moderation effect on the effect path to proactive behavior through agreed rules. The same path was negatively moderated by the steppe zone. We also found that the path to structural social capital through leadership was less effective for eastern steppe CBRMs.

The results were consistent with our prior findings that formal organization had a stronger effect on proactive behaviors and rangeland management practices than on other social outcomes. We note that rules had a negative effect on several outcomes although the effect was not significant. Many studies highlight the importance of resource users' participation in designing rules for their successful enforcement. Further study is necessary to examine the reasons behind the negative influence of rules on social outcomes found in this study.

The fact that the mediation of information diversity alone was powerful in increasing traditional and innovative practices is worth noting. It may imply that adequate education and training is the key for herders to revive proven traditional practices and introduce new adaptive methods for rangeland management.

IMPLICATIONS

The study has theoretical, practical and methodological implications. The results partially confirm that the formal organization of resource users increases their social outcomes. These outcomes are theorized to be essential to long-enduring successful commons institutions (Ostrom, 1990; Agrawal, 2002). In the Mongolian context, such outcomes included herders' traditional rangeland management practices, recently introduced management innovations, and herders' pro-activeness in bringing rangeland-related issues to local authorities for solutions. The study contributes to commons theory by examining underlying mechanisms through which formal organizations affect social outcomes. It showed that formal organization of herders could achieve social outcomes given their access to information, increased leadership, knowledge exchange and resource rules.

Commons theory also predicts better outcomes of commons institutions in resource-rich areas such as steppe and eastern steppe with relatively stable and predictable production. In contrast, successful collective action and resulting outcomes are anticipated to be more challenging in areas with unpredictable patchy production such as the desert steppe (Schlager et al., 1994). Our findings showed differences among ecological zones, potentially associated with their resource characteristics. However, contrary to predictions, we observed more proactive behavior and social networking among desert steppe CBRM members. Further, these results were in line with our prior findings of higher levels of reciprocal norms and mutual assistance in the desert steppe groups (Ulambayar, 2015). Overall, our findings suggest that the mixed conclusions about CBRM reported by past studies may be explained in part by failure to consider mediating and moderating factors and the sequential order of intermediate variables during the CBRM implementation.

We propose that social outcomes such as CBRM members' proactive behavior about rangeland matters and their rangeland management practices are building blocks for successful collaboration among resource users. These household-level outcomes are important first accomplishments of the emerging commons institutions that help to overcome inherent social dilemmas for resource use. For the goal of large-scale resource management, these achievements should gradually expand to interactions and cooperation beyond household groupings. Hence, in the pastoral context, the pace of progress seems important. The study groups had an average of five years' experience of collective action and in this timeframe were able to increase outcomes primarily in rangeland practices and behaviors. It may require more time and experience to revitalize trust and strengthen reciprocal relationships among resource users.

Two major policy implications emerge from this study. First, policy for CBRM development should prioritize information and training to herders. Educating herders and local leaders first is a necessary step for CBRM facilitation. Second, policy should aim to provide organized groups with mediating factors including information access, knowledge exchange, leadership and rules for resource use to support proactive behaviors and management practices thought to benefit resource conditions. Methodologically, the conditional process analysis provided a powerful tool to test underlying mechanisms for achieving CBRM social outcomes. Finally, our study highlights the need for further research to elucidate why rules have a negative effect on social outcomes, how rules were negotiated, and the specific content of resource use rules.

ACKNOWLEDGEMENTS

This research was sponsored by the National Science Foundation award No. BCS-1011801, *"Does community-based rangeland management increase coupled systems' resilience to climate change in Mongolia*?"

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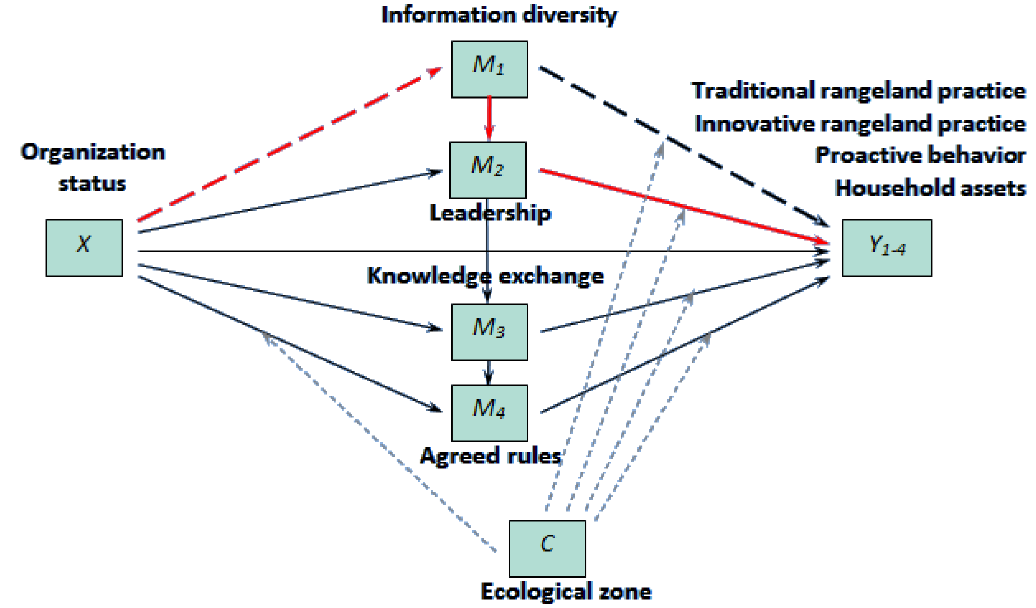

Figure 1. Schematic of the mediated effect of organization status on four ultimate social outcomes through serial-mediators: bold lines represent a variable's effect on other variables and arrows show the direction of the effect. Ecological zone moderates the combined effect of mediators (M_{1-4}) and organization status (X) on ultimate social outcomes (Y_{1-4}) shown by pecked grey lines. Information diversity alone (bold pecked lines) was the most influential path, and the second influential was the path through information diversity and leadership (red line)

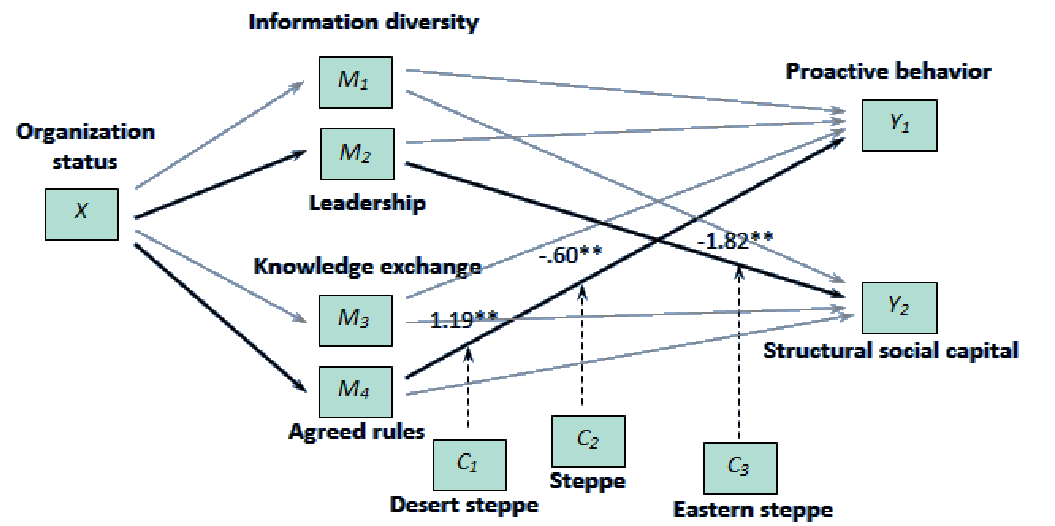

Figure 2. Significant conditional indirect effect of the organization status on two ultimate social outcomes through four mediators is shown by bold lines. Desert steppe had a significantly positive moderation (pecked line) of the indirect effect of the organization status on proactive behavior of members through rules. Eastern steppe and steppe zones had a negative conditional indirect effect (pecked line) on proactive behavior and structural social capital through leadership and rules respectively. Unstandardized coefficients are shown at p<.05 shown by two asterisk.

Do formal, community-based institutions improve rangeland vegetation and soils in Mongolia more than informal, traditional institutions?

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ABSTRACT

Since the 1990's, herding communities across Mongolia have established over 2000 community-based rangeland management (CBRM) organizations to improve livestock grazing management and reverse perceived declines in rangeland (grassland) productivity. Here, we compare the vegetation and soils of rangelands managed by these formal community-based herder groups (CBRM) with those managed by informal traditional neighborhoods (non-CBRM) in four ecological zones across Mongolia. A companion study shows CBRM used both traditional and innovative rangeland management practices more often than traditional neighborhoods. We hypothesized that this should then result in better rangeland vegetation and soils in CBRM-managed than non-CBRM managed rangeland. We sampled vegetation and soils in winter pastures around 143 livestock camps or water points in *soum*s (counties) with and without CBRM management. We explicitly controlled for grazing intensity by sampling plots along grazing gradients at 100, 500 and 1000 m from these impact points. At each 50 x 50 m plot (n=428) we sampled standing biomass, plant cover, basal gap, species richness, forage quality, and soil and site characteristics. We also compared paired time series of MODIS NDVI data in counties with and without CBRM organizations from 2000-2014 to quantify changes in length of the growing season, and current and previous season greenness (a proxy for biomass accumulation). We then analyzed all data using general linear models and χ^2 tests.

CBRM had surprisingly few and subtle impacts on vegetation and soils in Mongolia's rangelands, whether measured in the field or by remote sensing, compared with areas managed by more traditional neighborhood groups. Some CBRM pastures supported

more litter biomass, plant connectivity and less soil erosion, and a lower abundance of grazing tolerant or annual plant species than non-CBRM pastures in some ecological zones. CBRM management appears to modestly improve vegetation condition in the steppe than other ecological zones. At the *soum* level, we could see no differences in the length of the growing season, current season greenness or current and previous season greenness of the vegetation over the 15 years from 2000-2014. We did find, however, that herding families that participate in CBRM groups hold more livestock, sometimes twice as many, in 3 of the 4 ecological zones. This suggests that CBRM management may be having more impact on pastures than our data show, since these pastures can support more livestock without losing rangeland vegetation abundance and soil retention capacity.

Keywords: Community-based rangeland management, NDVI, biomass, forage quality

INTRODUCTION

Since the 1990's, herding communities across Mongolia have established over 2000 community-based rangeland management (CBRM) organizations to improve livestock grazing management and reverse perceived declines in rangeland productivity (Mau and Chantsallkham, 2006; Fernandez-Gimenez et al., 2014). Here, our objectives were to compare the vegetation and soils of rangelands managed by formal community-based herder groups (CBRM) with those without such formal management (non-CBRM) across Mongolia. Our other work (Ulambayar, 2015) suggests that CBRM groups used both traditional and innovative rangeland management practices more often than traditional neighborhoods. We hypothesized that this should then result in more vegetation abundance and soil retention capacity in CBRM-managed than non-CBRM managed rangeland.

STUDY SITES

Our goal was to sample vegetation and soils across Mongolia and compare CBRM effects in four ecological zones: mountain and forest steppe (MFS), eastern steppe (ES), steppe (S), and desert steppe (DS). We sampled vegetation and soils at 143 winter camps or water points in 36 paired *soum*s (or counties), 18 *soum*s with formal CBRM organizations and 18 with informal, traditional neighborhoods across these 4 ecological zones.

METHODS

Our design explicitly controlled for grazing intensity and production potential by sampling plots along grazing gradients at 100, 500 and 1000 m from livestock winter camps or water points and by placing these grazing gradients on similar landforms and soils (or ecological sites). At each 50 x 50 m plot (n=428) we sampled standing biomass, plant cover, basal gap, species richness, plant gap sizes, plant palatability, forage quality, connectivity of plant patches, evidence of surficial soil movement and site characteristics in 2011 and 2012. We also compared paired time series of MODIS NDVI data (vegetative greenness) at a 250 m spatial resolution (MOD13A1) in *soums* with and without CBRM organizations from 2000-2014 to quantify changes in vegetation greenness and seasonality. We used TIMESAT software (Eklundh and Jonsson, 2009) to calculate green-up and brown-down dates (and thus growing season length), current season NDVI, and current and previous season NDVI. We then analyzed all data using model type III ANOVA in SAS 9.3 software using both log and arcsine transformations to correct for non-normality of data. We use conservative p-value interpretation ('significant' = $p<0.01$, ‘near significant’ (NRS*)= $p \geq 0.01$ and <0.05 and not significant (NS) = $p \geq 0.05$) in our results, because of our large number of dependent variables.

RESULTS AND COMMENTS

Overall, both grazing and ecological site, measured at the scale of each winter camp, had more impact on vegetation and soils than did community-based management. This is expected since we purposely measured along a strong grazing gradient and soils often have strong effects on vegetation productivity.

CBRM had surprisingly few and subtle impacts on vegetation and soils of Mongolia’s rangelands, whether measured in the field or by remote sensing, compared with areas managed by more traditional neighborhood groups (Table 1; Chantsallkham, 2015). There were no fully significant ($p<0.01$) differences in total standing biomass, total cover and functional group biomass, species richness, forage quality, growing season length, or current (or previous) season greenness comparing between CBRM vs non-CBRM-managed pastures. Generally, CBRM pastures were had slightly more litter biomass (ES only), more plant connectivity (MFS, S, Figure 1) and less soil erosion (MFS) in some ecological zones, and lower abundance of a grazing tolerant grass (MFS), a grazing tolerant sedge (ES) and an annual grass species (DS). We included plant connectivity since it is probably directly related to soil erosion and showed some of our most significant effects. In the desert steppe, our results are contradictory, where CBRM pastures had smaller open gaps between perennial plants, but less connected plant patches and more soil erosion (Table 1). If we include near significant effects, the largest impacts occurred in the steppe, where pastures managed by CBRM groups supported more shrub, litter and standing dead vegetation biomass and litter cover than pastures managed by traditional neighborhoods.

There were few significant interactions among our three main effects of CBRM, grazing and ecological site (grazing effects are covered in another paper at this conference). In general, CBRM pastures sometimes had stronger and declining grazing gradients than non-CBRM pastures. And, some plant species responded differently to the two management types on clayey compared to rocky soils.

At the *soum* level, CBRM *soums* were not different from non-CBRM based on remote sensing data. Hence, there was no difference in the length of the growing season, current season vegetative greenness or current plus previous season greenness.

DISCUSSION AND IMPLICATIONS

This is the first study, to our knowledge, to assess the effectiveness of CBRM across all of Mongolia’s major ecological zones. Our results suggest that traditional neighborhood groups are almost as able to maintain the vegetation and soils of Mongolian rangelands as formal community-based rangeland groups, ranging from the southern desert steppe (Gobi) to the northern forest steppe. Our field and remote sensing results consistently show few differences in the two management types. For the desert steppe, our results support another Gobi field study (Addison et al., 2013), which showed little impact of CBRM groups, but they contradict a Gobi remote sensing study, which showed 11% greater full season NDVI in pastures managed by CBRM groups (Leisher et al., 2012).

We temper these conclusions with two caveats. First, in 3 of our 4 zones (MFS, ES, and S), we recorded livestock herd sizes at each of our sampled winter camps in a companion study (Ulambayar, 2015). There were more livestock (all species, measured as sheep forage units) at CBRM than non-CBRM winter camps in the MFS (54% more), eastern steppe (13% more) and steppe (135% more); but there were 30% fewer livestock in the desert steppe at CBRM camps (Chantsallkham, 2015). Thus, it is remarkable that CBRM pastures near the camps in all zones but the desert steppe had similar vegetation and soils to winter camps with smaller livestock herds managed by families in traditional neighborhoods. We cannot be sure that CBRM families always hold larger livestock herds than non-CBRM families over the long term at these winter camps, but they did in 2011 and 2012 when our team conducted livestock surveys.

While the families hold larger livestock herds at CBRM winter camps, their families were also larger, meaning that per capita livestock holdings were not different comparing the two management types (Ulambayar, 2015). This tells us that CBRM families are not wealthier than non-CBRM families (Ulambayar, 2015).

Second, our data suggest some subtle improvements in pastures under CBRM compared with non-CBRM management, particularly through different litter amounts, indicator species abundances, plant patch connectivity and surficial soil erosion. This may suggest that CBRM groups need to improve their management to significantly affect rangeland vegetation abundance and soil retention capacity and that the effects of CBRM management may take a long time to affect Mongolian rangelands.

ACKNOWLEDGEMENTS

We thank the many herder families who welcomed us into their *gers* and out onto their pastures during this research. We also thank our kind co-researchers in the Mongolia and the US, who contributed many hours in the field and thoughtful comments about this research.

This material is based upon work supported by the National Science Foundation under CNH Program Grant No. award BCS-1011 *Does Community-based Rangeland Ecosystem Management Increase the Resilience of Coupled Systems to Climate Change in Mongolia?* Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Table 1. Significance and direction of ANOVA tests comparing vegetation (ANOVA) and soils (χ^2) characteristics in winter pastures in CBRM and non-CBRM *soums* in each ecological zone. NS = p≥ 0.05; NRS* = p≥ 0.01 and <0.05 (near significant). Non = winter pastures with informal, traditional management but no formal CBRM management.

Variable	Mountain and forest steppe	Eastern steppe	Steppe	Desert steppe
Total green biomass	NS	NS	NS	NS
Grass biomass	NS	NS	NS	NS
Forb biomass	NS	NS	NS	NS
Sedge biomass	NS	NS	NS	NS
Shrub biomass	NS	NS	**NRS***	NS
Litter biomass	NS	**CBRM>Non**	**NRS***	NS
Standing dead biomass	NS	NS	**NRS***	NS
Total foliar cover	NS	NS	NS	NS
Grass cover	NS	NS	NS	NS
Forb cover	NS	NS	NS	NS
Sedge cover	NS	NS	NS	NS
Shrub cover	NS	NS	NS	NS
Litter cover	NS	NS	**NRS***	NS
Standing dead cover	NS	NS	NS	NS
Perennial grass cover	NS	NS	NS	NS
Annual grass cover	NS	NS	NS	**Non>CBRM**
Dominant species cover	***Cleistogenes squarrosa,*** **Non>CBRM**	***NRS*, Carex duriuscula,*** **Non>CBRM**	***Kochia prostrata,*** **CBRM>Non**	***Eragrostis minor,*** **Non>CBRM**
Gap size	NS	NS	NS	***NRS*, Non>CBRM***
Species richness	NS	NS	NS	NS
Crude protein	NS	NS	NS	NS
Acid detergent fiber	NS	NS	NS	NS
Plant patch connectivity	**CBRM>Non**	NS	**NRS*, CBRM>Non**	**Non>CBRM**
Soil erosion	**Non>CBRM**	NS	NS	**CBRM>Non**
Total current season NDVI (*soum* level)	NS	NS	NS	NS
Total season-to-season NDVI (*soum* level)	NS	NS	NS	NS
Length of growing season (*soum* level)	NS	NS	NS	NS

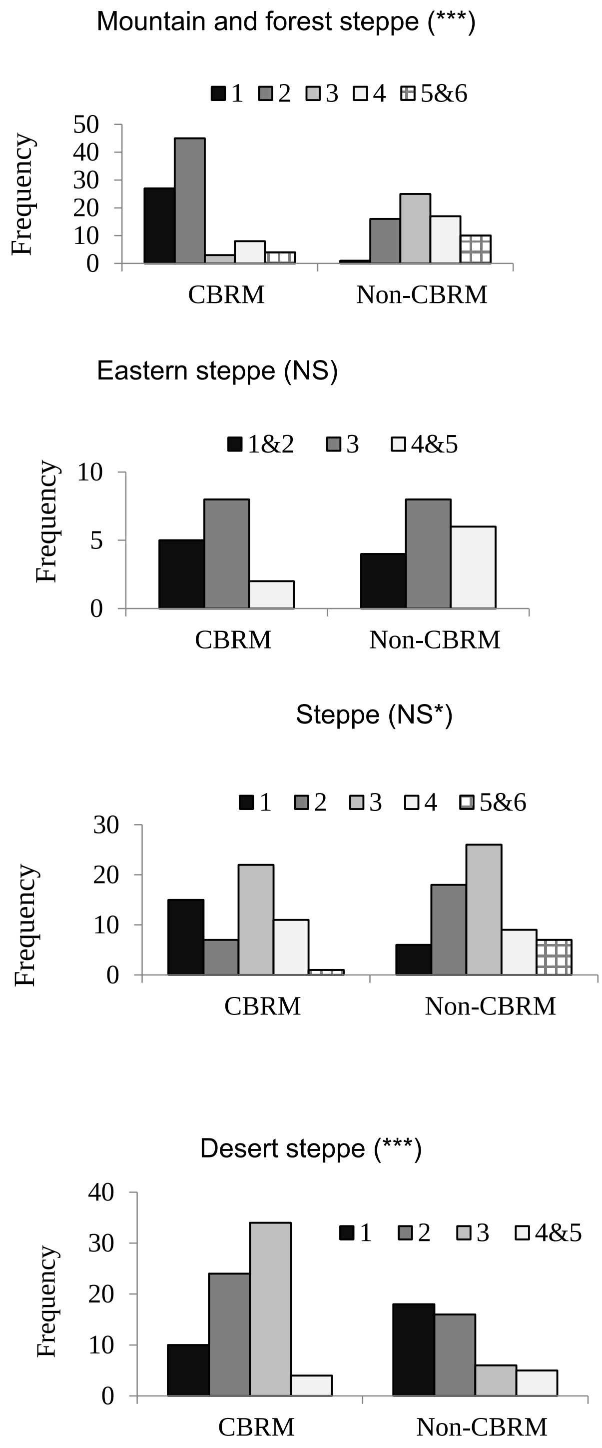

Figure 1. Frequency distribution of the connectivity of plant patches at a plot scale in the mountain and forest steppe, eastern steppe, steppe and desert steppe. Low values are highly connected patches, while high values indicate low connectivity. Zone results are significantly different with NS* = p<.05, ** = p<.01, and *** = p<.001, based on a χ^2 test. NS=Not significant.

Time Series Analysis of Satellite Greenness Indices for Assessing Vegetation Response to Community Based Rangeland Management

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ABSTRACT

After the transition of Mongolia's agriculture sector to a market economy in the early 1990's, community-based rangeland management (CBRM) organizations have been established across Mongolia to cooperatively manage rangeland resources. We hypothesized that rangeland ecoregions under CBRM would have greater biomass than ecoregions managed using traditional herder practices. We used time series analysis of AVHRR (8-km resolution, 1982 to 2012) and MODIS Normalized Difference Vegetation Index (NDVI) (250-m, 2000 to 2013) to calculate integrated NDVI (iNDVI) as a proxy for vegetation biomass. To address whether CBRM response is scale related, we created buffers of increasing distance around livestock winter shelter locations in *soums* where CBRM programs had been initiated and *soums* without formal programs. Spatial averages of iNDVI were calculated within buffer boundaries for each location, stratified by ecological zone. A repeated measures mixed model with yearly rainfall as a covariate was used to test for differences in iNDVI for CBRM status over time for buffer distances of 1, 2, 5, 10, and 30 for MODIS, and 10 and 30 km for AVHRR. In general, results were similar across buffer distances indicating that average vegetation response was similar for distances greater than 1 km around sampling sites. For MODIS NDVI, sites in the Desert Steppe and Eastern Steppe did not have significantly higher productivity in CBRM managed *soums* over time, regardless of buffer size. Mountain and Forest Steppe (MFS) locations had higher iNDVI in non-CBRM sites throughout the time series for both NDVI data sets, although these differences were not statistically significant. CBRM sites in the Steppe zone had higher iNDVI throughout the time series for both MODIS and AVHRR.

Given that these differences occur throughout the AVHRR time series, they do not appear to be the result of CBRM activities. Our findings indicate that differences in vegetation response as a result of CBRM activities were not detected during the time series using productivity proxies from satellite imagery. In addition, the MODIS time series may be too short for detecting CBRM differences since it does not include data prior to when most CBRM programs were implemented.

Keywords: NDVI, community based rangeland management, Mongolia, AVHRR, MODIS

INTRODUCTION

Following the transition of Mongolia's agriculture sector to a market economy in the early 1990's, concerns about land degradation, in addition to large scale losses of livestock during a series of droughts and winter disasters (*dzuds*) in 1999-2002 led to the establishment of community-based rangeland management (CBRM) organizations across Mongolia. These organizations were formed to cooperatively manage rangeland resources (Fernández-Giménez et al., 2015). A major activity of these organizations is to locally manage their livestock herds to reduce overgrazing and improve pasture conditions. Many of these CBRM organizations have been in place since the late 1990's and provide an opportunity to study their effectiveness in managing rangeland resources.

Remote sensing-based vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), have been found to be suitable proxies for vegetation biomass or net primary productivity (Tucker et al., 1983; Tucker et al., 1985). The high spatial and temporal frequency of remote sensing imagery such as NDVI provides opportunities for examining trends in vegetation response, and evaluating these in relation to climate and management For example, NDVI products have been used to examine effects of land management and changing climate on rangeland degradation (Evans and Geerken, 2004; Wessels et al., 2007).

For this study, we sought to determine if differences in vegetation response resulting from CBRM pasture management activities could be detected using time series of NDVI. We hypothesized that improved livestock management on rangelands under CBRM would lead to increased vegetation biomass compared to lands managed using less formal, traditional herder neighborhoods, and that the increased vegetation response could be detected using NDVI as a proxy for vegetation biomass. A secondary objective was to examine whether vegetation response to CBRM activities is scale related in that individual herder activities for CBRM may be detected at the scale of their winter pasture boundaries, but not at increasing distances away from their winter pastures where they potentially have less control over the grazing management.

STUDY SITE

A total of 18 paired *soums* (an administrative unit similar to districts), with one of the pair having formal CBRM organizations active within its boundaries and the other having informal, traditional neighborhoods, were identified in four major ecological zones in Mongolia. The four ecological zones included: mountain and forest steppe (MFS), eastern steppe (ES), steppe (S), and desert steppe (DS). Within each *soum*, 4-5 winter shelters (used by herders for overwintering and protecting their animals) were identified for field sampling (see companion study, Reid et al. [2015]). These points served as the locations for the time series remote sensing analysis.

METHODS

We conducted time series analyses using NDVI from the MODIS-Terra platform (MOD13Q1-L3 product, 250-m resolution, 16 day maximum composite images from 2000 to 2013) (Huete et al., 2002) and AVHRR-NDVI3g (~8 km resolution, bimonthly, 16 day maximum value composite images from 1982 to 2012) (Pinzon and Tucker, 2014). We evaluated both NDVI products because of differences in the resolution and time series length between the two products. The AVHRR-NDVI3g product is coarser resolution, but has a longer time series (30 years) that includes a period before the majority of CBRM programs were initiated in Mongolia. The MODIS NDVI data have a finer resolution than AVHRR, but the time series is relatively short (14 years). In addition, the time series from 2000 to 2013 for MODIS occurs after many of the CBRM programs in Mongolia had already been implemented.

MODIS-NDVI tiles for the study area were acquired from the Land Processes Distributed Active Archive Center (LP DAAC; https://lpdaac.usgs.gov/). The tiles were mosaicked and reprojected to an Albers Equal Area projection using the MODIS Reprojection Tool (Dwyer and Schmidt, 2006) and were screened for pixels with negative NDVI (i.e. pixels with clouds, snow, ice, and water). AVHRR-NDVI3g data were acquired from the NASA Earth Exchange NDVI3g archive (https://nex.nasa.gov/nex/projects/1349/)and were reprojected to a common projection (Albers Equal Area) and clipped to the study area boundary.

For both NDVI data sets, a least squares, double logistic function in TIMESAT software (Jönsson and Eklundh, 2004; Eklundh and Jonsson, 2009) was used to fit seasonal curves to pixels in the NDVI time series, on a pixel-by-pixel basis. From the fitted curves, we extracted the time integrated NDVI (iNDVI) for each year to serve as a proxy for the yearly response of the vegetation biomass.

To address whether CBRM response could be scale related, we created buffers of increasing distance around the winter shelter locations in each *soum*. Buffer radii examined were 1, 2, 5, 10, and 30 km from the point locations for MODIS NDVI, and 10 and 30 km radii for AVHRR. Spatial averages of iNDVI were calculated within buffer boundaries for each location and year, stratified by ecological zone. A repeated measures mixed model, with CBRM status as a main factor, year as a repeated measure, and yearly rainfall as a covariate, was used to test for differences in iNDVI that could be related to CBRM status over time for each of the buffer distances.

For the precipitation covariate, we used the global Climate Prediction Center Unified Precipitation Data (Chen et al., 2008), which is an interpolation of daily precipitation measured from weather stations. The data have a pixel resolution of approximately 55 km and the daily data archive is available for 1979 to 2014. The precipitation raster's pixels were resampled to 1 km resolution and summed for each day of the year to determine annual rainfall in each pixel. Spatial averages of the annual precipitation were calculated within buffer boundaries for each location and year, stratified by ecological zone.

RESULTS

In both the MODIS-NDVI and AVHRR-NDVI analysis, rainfall was highly significant ($p<0.0001$) for the DS, MFS, and Steppe sites, providing an indication of the importance in controlling for precipitation differences across the study sites in the statistical model. The rainfall covariate for ES sites was significant ($p<0.05$) for the MODIS-NDVI analysis, but was not significant for the AVHRR-NDVI. Also, in general, the statistical analysis results for the buffer radii around the sample sites were similar; indicating that patterns in average iNDVI did not differ greatly with increasing scale from the sample locations in the ecological zones. Therefore, the results presented below will focus on the analysis using the 10-km buffer to allow comparisons between the MODIS and AVHRR datasets at similar scales.

For sites in the DS, there was no significant difference in vegetation response over time for the management types in both the MODIS-NDVI and AVHRR-NDVI time series after controlling for the effects of rainfall difference across sites (Figure 1a, Figure 2a). In both time series, there was a slight tendency for the non-CBRM sites to have higher iNDVI than CBRM sites (Figure 1a, Figure 2a).

For the ES sites, CBRM status was not significantly different for any year in the MODIS NDVI time series (Figure 1b). For the AVHRR-NDVI, sites with CBRM management had significantly higher iNDVI in 2010 and 2011 after controlling for rainfall differences across sites (Figure 2b). For the MODIS NDVI time series, there was a slight tendency for non-CBRM sites to have higher vegetation response (Figure 1b). However, the opposite was seen for the AVHRR-NDVI (Figure 2b). For years where the two time series overlap, the iNDVI time trends are similar, but the vegetation response, as indicated from the iNDVI, is much higher in the AVHRR than MODIS NDVI.

The MODIS-NDVI in the MFS locations had a significant CBRM status by time interaction ($p < 0.0001$); however there were no significant differences in CBRM status throughout the time series, indicating that differences in iNDVI between years was the dominant factor in the interaction (Figure 1c). This was also confirmed by the highly significant main effect for year ($p<0.0001$). The results were similar for the AVHRR time series, with no significant differences in CBRM status over time (Figure 2c).

CBRM sites in the S zone had significantly higher iNDVI in 2002 and 2010 than non-CBRM sites, and there was a trend for higher iNDVI at CBRM sites throughout the MODIS-NDVI time series (Figure 1d). For AVHRR, the iNDVI at CBRM sites was significantly higher than non-CBRM sites for 16 of the 30 years in the time series (Figure 2d). However, these differences existed throughout the time series (Figure 2d), indicating that these differences were likely not the result of CBRM management practices.

DISCUSSION

In general, we found few differences in vegetation response (as measured with iNDVI) for sites under the two different management approaches. Where differences did exist throughout the time series (e.g., in the MFS and S zones), these differences occurred throughout the time series and prior to when CBRM activities were implemented. These results somewhat contradict those in a previous study in the Gobi region of Mongolia (desert steppe areas) that found significantly higher iNDVI (6%) at sites under CBRM than in control areas 6 years after the initiation of the community based management (Leisher et al., 2012). These differences may be related to the use of the rainfall covariate to control for rainfall differences across sites, in addition to the longer time series that was available in our study.

For our study, a possible reason for not being able to detect significant differences in vegetation response resulting from CBRM management may be related to *soum* (and surrounding *soum*) livestock numbers and livestock forage use. In a companion study (see Gao et al., 2015), we examined forage use across all *soums* in Mongolia for the period from 2000 to 2014 and found high grazing pressure by livestock in about 32% of the country. Using data from the Gao et al. (2015) study, we compared the livestock forage use in the paired *soums* in each of the ecological zones. Although average forage use was slightly lower in the CBRM soums, the forage use was generally similar between the two management types (Table 1); therefore, the biomass response seen in this study may reflect the similar grazing by livestock within these *soums*. Another factor may be forage use by livestock moved from adjacent *soums*. Addison et al. (2013), in an examination of CBRM groups in the Gobi region of Mongolia, found that the boundaries of pastures under CBRM were not enforced and movements by herders and their livestock from adjacent areas were not controlled. In our case, uncontrolled use of forage in CBRM areas may have negated any biomass savings that would of occurred through reduced animal numbers or pasture deferment implemented by the CBRM group.

IMPLICATIONS

Natural differences in site response, and the uncertainty associated with the effectiveness of the CBRM activities, make detection of vegetation response resulting from CBRM activities difficult using coarse spatial, and temporally limited resolution, productivity proxies from satellite imagery. Field assessments conducted at these sites in 2011 and 2012 indicated that the effect of management types varied among ecological zones and were limited to slightly higher litter biomass and plant connectivity, less soil erosion, and lower abundance of annual plant species on CBRM pastures (Reid *et al.*, 2015). Given these slight differences, it is unlikely that these field-acquired, vegetative indicators would be easily detected by the coarse resolution MODIS or AVHRR imagery. Wessels (2007) points out the need for long-term field monitoring programs to complement remote sensing studies and improve detection of important indicators such as species change and erosion that are not easy to detect with coarse resolution, long-term remote sensing datasets. Long-term monitoring programs are needed to aid in improving detection of management from remote sensing. Additionally, monitoring of pasture utilization would also be important for documenting whether CBRM activities such as pasture deferment or stocking rate reductions are having their intended effects.

Despite its finer spatial resolution compared to the AVHRR time series, the MODIS time series does not provide baseline information prior to CBRM establishment. Examining vegetation response with a long time series such as with the AVHRR-NDVI dataset is important for ensuring that differences in vegetation response under different management programs can be attributed to management, and not be the result of inherent differences between the sites being evaluated. In this study, if the MODIS-NDVI had been the only product used, it could have led to a false interpretation of the CBRM management effects in the S and MFS ecological zones. Although the resolution of the AVHRR imagery is lower, the long time series provides an opportunity to examine long-term trends to evaluate whether the areas chosen are different and could prove useful in a-priori selection of sites and *soums* for CBRM evaluation.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation under CNH Program Grant No. BCS-1011 Does Community-based Rangeland Ecosystem Management Increase the Resilience of Coupled Systems to Climate Change in Mongolia? Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Table 1. Average estimated forage use (+/- standard error [SE]) by livestock across years for *soums* with community based rangeland management (CBRM) versus those using traditional management (non-CBRM) during the period from 2000 to 2014 by ecological zone. See Gao *et al.* (2015) for methods on calculation of forage use.

Ecological Zone	CBRM	+/- SE	Non-CBRM	+/- SE
Desert Steppe	41.7	0.9	46.1	0.7
Eastern Steppe	38.5	1.0	31.6	0.6
Mountain and Forest Steppe	70.5	1.1	72.7	1.6
Steppe	61.3	1.4	69.6	2.6

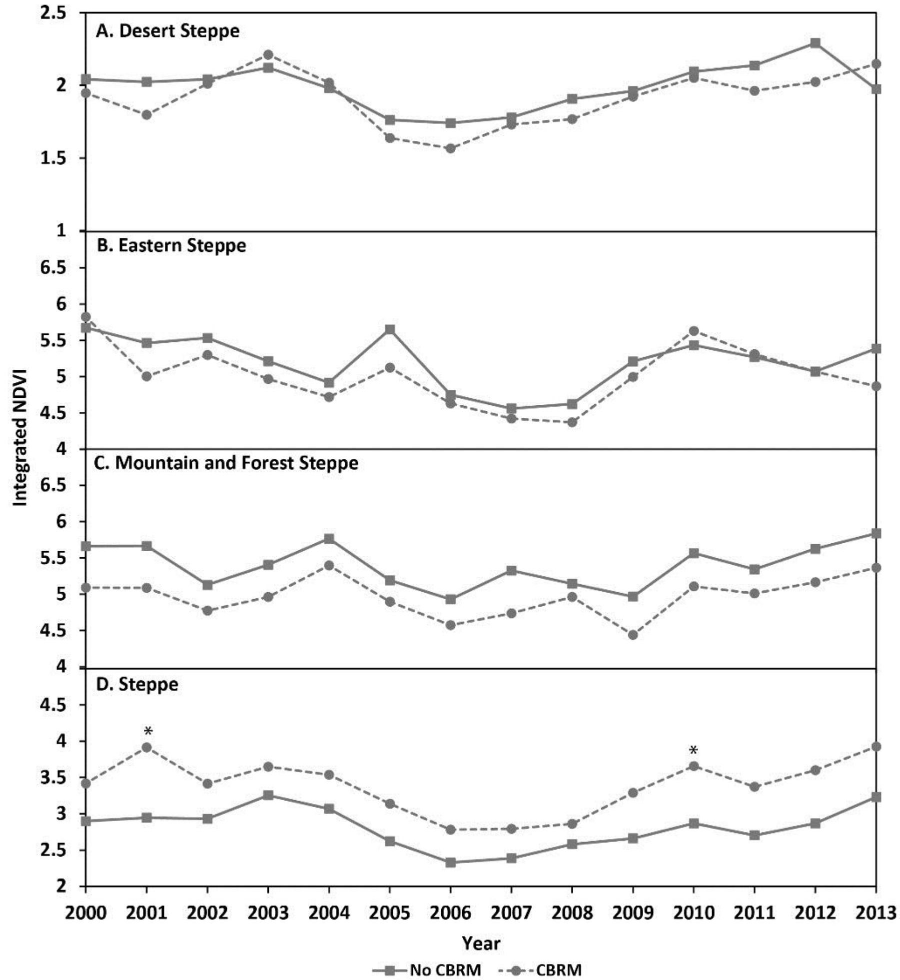

Figure 1. Least square means for time integrated Normalized Difference Vegetation Index (iNDVI) from the MODIS sensor by year, management treatment (Community Based Rangeland Management [CBRM] vs. traditional management [No CBRM]) and ecological zone. Means reflect adjustment for the covariate in the mixed model analysis to control for the effects of rainfall difference across sites within each ecological zone. Means with a "*" indicate a significant difference (p<0.05) between CBRM and No-CBRM means for that year.

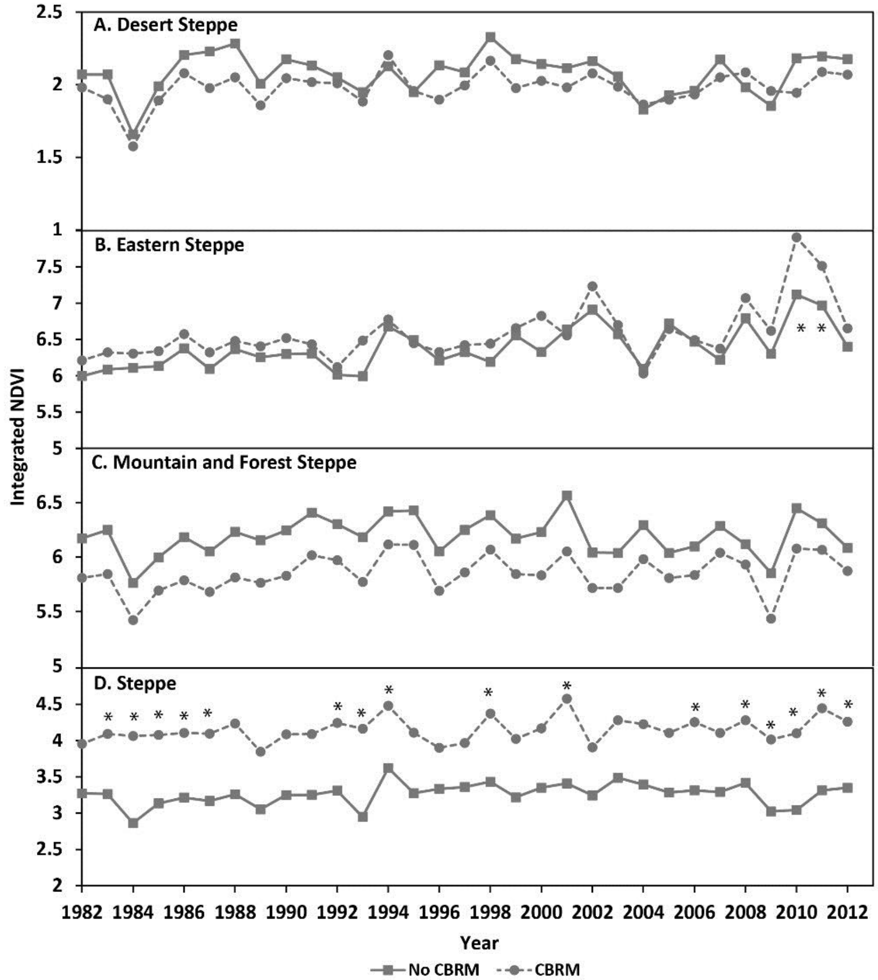

Figure 2. Least square means for time integrated Normalized Difference Vegetation Index (iNDVI) from the AHVRR sensor by year, management treatment (Community Based Rangeland Management [CBRM] vs. traditional management [No CBRM]) and ecological zone. Means reflect adjustment for the covariate in the mixed model analysis to control for the effects of rainfall difference across sites within each ecological zone. Means with a "*" indicate a significant difference (p<0.05) between CBRM and No-CBRM means for that year.

Management of *dzud* risk in Mongolia: Mutual aid and institutional interventions

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ABSTRACT

Heavy livestock losses from severe winter conditions (*dzud*) in Mongolia in recent years have prompted a variety of interventions by government and development agencies, aiming to reduce herders' vulnerability to severe weather and other climate factors. Unfortunately, many of these interventions have not systematically diminished risk to herders. In this paper we identify several strategies deployed by herders for managing *dzud* risks and impacts through informal mutual aid networks. We contrast these strategies to interventions taken by international donor agencies operating in Mongolia, which have largely focused on the household as an independent socio-economic unit. We conclude that risk mitigation can be improved through recognition of informal mutual aid networks, and through support to mutual aid institutions.

Keywords: Pastoralism, Mongolia, *dzud*, mutual aid

INTRODUCTION

Heavy livestock losses from severe winter conditions (*dzud*) in Mongolia in recent years have prompted a variety of interventions by government and development agencies, aiming to reduce herders' vulnerability to severe weather and other climate factors. Unfortunately, many of these interventions have not significantly diminished risk to herders. International assistance provided to *dzud*-affected herders in 2010 was poorly coordinated and late, reflecting last-minute interventions rather than a systematic preparedness strategy (Viguier et al,. 2010). In practice, we found that herders rely heavily on informal mutual aid networks to manage *dzud* risks and impacts. In this paper we contrast herders' informal mutual aid strategies to the household-focused approach widely employed by aid agencies operating in Mongolia.

Most existing research on *dzud* vulnerability focuses on governance and institutional coordination to a greater extent than informal mutual assistance (Fernandez-Gimenez et al, 2014; Upton, 2012; Sternberg, 2010). While adaptive benefits have been associated with community-based groups organized on mutual aid principles (Fernandez-Gimenez et al., 2014; Baival and Fernandez-Gimenez, 2012; Upton, 2012), the absence or weakness of such formal institutions should not be taken as indication that mutual aid among herders is necessarily poor. Indeed, in many successful adaptive practices we identified mutualistic relations involving non-herders, which are not easily accommodated by formal herder groupings. Previous findings that household or community-level risk management may be hindered by external factors such as cross-boundary movement suggest the need for strengthened governance or community institutions (Fernandez-Gimenez et al., 2012), but also reveal the limitations of measures that rely on households or communities as bounded units. Whereas *dzud* vulnerability and impacts have generally been defined in terms of household-level livestock loss, a household's absolute losses may be less meaningful as an indicator of resilience than the family's ability to rely on its extended social networks to overcome crisis. Given that herder relatives living nearby may be equally affected by *dzud*, and thus unable to provide substantial assistance (Siurua and Swift, 2002), we emphasize the importance of mutual aid operating through multi-sited networks that involve both herders and non-herders.

METHODS

We developed a typology of herders' risk-mitigation strategies based primarily on data from our participant observation field research conducted in three *soums* in Selenge and Dornogovi *aimags*. This research was performed by Eric Thrift over twelve months in 2011–2012, with follow-up interviews in 2013 and 2014. Approximately 30 herder households and family groups were selected through cluster sampling methods, with the resulting sample reflecting significant variation according to factors of mobility, distance from the *soum* or *aimag* centre, herd size and composition, and income sources. Collaborating herders participated in audiovisual field recordings documenting their everyday and seasonal activities, during or following which they were invited to discuss the economic significance and social organization of the documented activities. Observed or reported tactics for adapting to social-ecological change and uncertainty were then grouped by type, and analyzed to determine the extent to which these tactics were facilitated by mutual aid involving other herders or non-herders.

We contrasted herders' informal adaptive tactics to the more formal risk-mitigation mechanisms promoted in government policy and implemented through several international development projects. As a primary contributor to the UNDP study of humanitarian response to the 2010 *dzud* (Viguier et al,. 2010), Byambabaatar Ichinkhorloo conducted field surveys in *dzud*-affected areas, holding focus groups and individual interviews with herders and local officials to identify their responses to *dzud* and the effectiveness of institutional measures. Byambabaatar additionally communicated with representatives of government and international development agencies who played a role in the *dzud* response, to document the nature and extent of each organization's actions. In revisiting this earlier study, we held anonymous discussions with former development practitioner colleagues regarding the shortcomings of institutional responses and the herder dissatisfaction captured in interviews from 2010, identifying areas of compatibility or conflict with the observed informal tactics practiced by herders.

RESULTS

For the purposes of our study, we considered a "*dzud*" to involve conditions brought about by a sequence of summertime drought, preventing livestock from gaining significant body weight from grazing, followed by extreme cold and/or deep snowfall in winter. Although no *dzud* event occurred during the participant observation component of our field research (2011–2012), we observed herders' strategies taken in response to the 2010 *dzud* in Selenge, as well as mitigation strategies taken by herders in Dornogovi due to dry conditions in the summer of 2012, considered a potential precursor to *dzud* in the following winter.

The key risk-mitigation strategies we documented included (1) high mobility (frequent or distant *otor* moves) during times of crisis; (2) maximizing herd sizes in good years so as to build a buffer against loss during *dzud*, with acceptance of periodic loss of livestock as a "natural" feedback mechanism; (3) pursuit of diversified subsistence strategies, including non-pastoral sources of income; (4) reliance on reciprocity obligations in obtaining material assistance from relatives or others at times of crisis; and (5) targeted winter preparation in years when a harsh winter was expected. The adaptive responses we outline are consistent with those documented by other authors (e.g., Middleton et al. 2015). Whereas individual households with above-average wealth and herd sizes were better positioned to engage on their own in vulnerability-reducing practices such as *otor* (Murphy, 2011), we found that for a majority of herders, at least some strategies were implemented with assistance from people beyond the immediate household (Table 1). Central to the success of these mechanisms was a fluidity of the pastoral system. Households or individual herders were able to shift from town to country and back, with more or fewer people stationed with livestock depending on current needs and herd sizes. Additionally, herders relied on collaborative relations with non-herders in obtaining supplementary income, which could offset economic losses due to *dzud*.

These informal strategies stand in contrast to the institutional interventions discussed by development planners following the 2009–2010 *dzud*. In summer 2010 we conducted a review of *dzud* impacts and the coordination of disaster response among national institutions and international donor organizations, commissioned as part of the "Strengthening Early Recovery Planning" component of the UNDP Early Recovery Programme (Viguier et al., 2010). Although the draft version of this report identified significant operational failings in international donor agencies' response to the *dzud*, the final version focused on inadequate winter preparation among herders and local government. We ultimately concluded that while policies were in place for effective management of *dzud* impacts, the severe lack of institutional coordination and leadership impeded the effectiveness of both preparedness and emergency response interventions (see also Fernandez-Gimenez et al., 2012; Sternberg, 2010).

Unsurprisingly given this lack of institutional support, herders have largely relied on informal mutual aid mechanisms to address *dzud* risk. Some of the strategies listed above were acknowledged by development planners – ACF (2010), for example, acknowledges the existence of "solidarity mechanisms" whereby herders who had lost many animals in the *dzud* would stay with relatives who had been less severely affected. By and large, however, the donor community has underrepresented or ignored the role of mutual aid networks extending beyond the household. In effect, international organizations have framed the issue of *dzud* as one of "emergency preparedness", focusing on household-level subsistence rather than resilience at the scale of social networks. Humanitarian interventions in 2010 were thus represented as assistance for *households* who had become destitute as a result of the *dzud*. In the language of one ADB press release, for example, affected households were described as having "exhausted their wood and cooking fuel", having lost their "main source of livelihood", and being "unable to access medical care and other social support services" (ADB, 2010).

This household focus is also apparent in the FAO emergency response, which involved providing emergency supplies of livestock fodder, milk powder, and veterinary packages to 2614 households in seven *aimags* in the spring of 2010. Recipients were warned in an accompanying pamphlet "not to try and share [the supplies] with relatives and friends" (Brown, 2010, 21, 41). Although this advice was clearly grounded in a calculated assumption that the supplies would only be adequate to support a limited number of weak animals over the remainder of the winter, it can also be seen as undermining mutual aid amongst herder households, by limiting the selection of "salvageable" livestock to the animals belonging to the targeted household itself.

Table 1. Examples of observed mutual aid involving herders, by risk mitigation strategy

No.	Strategy	Examples of assistance from outside the household
1	Otor moves	• Non-herder relatives make a truck or small yurt (*otryn ger*) available for a move • Neighbours or relatives help watch children and small livestock during a long-distance move • Several households move together to the same distant *otor* area; those who move first help newcomers get established
2	Fluctuating herd size: Maximizing growth in good years	• People who do not own livestock are hired to manage livestock for herders with many animals, but look for work in town after a *dzud* • Herders who have lost animals in a *dzud* place their remaining livestock in care of parents or relatives, and move to town until the herd has been built up again
3	Diversified subsistence strategy including non-pastoral income	• Herders join non-pastoral relatives in small-scale, seasonal natural resource extraction (strawberries, Agriophyllum squarrosum, timber, gold) • Herder households provide services to tourists (camel rides, overnight stays) through a travel company • One or more members of a herder household is employed as a public servant in the *soum* centre or as a worker in the nearby mine • The herder household obtains supplementary income from guarding a natural resource or property (mobile telephone antenna, *bagh* centre buildings, etc.)
4	Reliance on material assistance from relatives	• Households that have lost animals during a *dzud* obtain money from urban relatives, or livestock from other herders who were less seriously affected
5	Targeted winter preparation	• Men from different households in Selenge collaborate in making hay, unloading it in turns at each family's winter camp • Herders who own tractors produce extra quantities of hay, which they sell or redistribute to cattle owners who live in town

The World Bank initiated Indexed Livestock Insurance Program similarly aims to shifts responsibility for maintaining emergency reserves from the state to the household, bypassing kin networks altogether. Although many herders have seen the value of household-level livestock insurance, they remain a minority: only 10 percent of herders subscribed to the indexed livestock insurance policy in 2014, a drop from 15 percent in 2013 (Annor-Frempong, 2014). Many of the herders with whom we worked appeared to be uneasy with the individualistic logic of household-based insurance, which would allow less-affected herders to benefit more than others – and indeed at the expense of less fortunate herders in the same area.

DISCUSSION

The most significant finding of this study is that whereas development agencies defined risk at the household level, none of the herders involved in our research consistently managed their livestock or other resources as independent households, but instead did so through larger networks of relatives. Although day-to-day herding operations were frequently carried out at the household level, a majority of families shared livestock or used livestock to support non-pastoral kin; many also participated in non-pastoral subsistence activities. By managing resources at a scale broader than the household, herders maintained informal mutual aid networks that could be drawn upon at times of need. Whereas from the perspective of the individual household the loss of livestock was often a major shock, such a shock could be absorbed by a broader family network, where that network was sufficiently resilient. We observed that resilience to shock in these networks pragmatically correlated to the presence of sufficiently diverse social and economic relations, extending into distant sites and into urban areas.

IMPLICATIONS

Our research indicates that efforts to develop more effective management of *dzud*-related risk in Mongolia will need to address the allocation of resources and informal aid through suprahousehold networks, which often – and ideally, from a risk mitigation perspective – extend into non-pastoral spheres.

We suggest two follow-up areas. First, it will be desirable to develop a method for assessing herders' economic vulnerability that looks beyond the household, to aid in guiding more targeted interventions. Second, we identify the need for institutional interventions that strengthen mutual aid amongst herders and non-herders above the level of the household. Herder groups, herder cooperatives, and pasture user groups have been established by a variety of projects in order to promote collective action amongst herders who share common rangeland resources, but from a risk mitigation perspective it is necessary to maintain *diverse* mutual aid groups or networks that include non-herders and non-livestock capital. Our research indicates that informal mutual aid mechanisms already exist in the form of kin networks, but these networks cannot necessarily be expected to help herders with limited social capital. The primary recommendation from our research, therefore, is that further work is needed toward establishing and strengthening mutual aid institutions that link herders and non-herders. These institutions could take the form of cooperatives, but – unlike the herder cooperatives currently being established in Mongolia – would require a broader role than simply marketing commodities. The specific roles of mutual aid institutions in assisting the most vulnerable, small-scale herders is a topic necessitating future research attention.

ACKNOWLEDGEMENTS

Eric Thrift's field research was funded through a Doctoral Research Award from the International Development Research Centre (IDRC) and a Joseph-Armand Bombardier Canada Graduate Fellowship from the Social Sciences and Humanities Research Council of Canada. Byambabaatar Ichinkhorloo's contribution was based on work performed while employed by the Mongolia Country Office of the United Nations Development Programme (UNDP) in a position funded by the Swiss Agency for Development and Cooperation (SDC). We acknowledge the support of UNDP staff members who agreed to be interviewed anonymously for this project. All views expressed in this paper are those of the authors, and do not necessarily reflect the position of the funding organizations.

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Resilience, Values and Ecosystem Services: Innovations in Rangeland Governance

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ABSTRACT

Mongolia's socio-ecological rangeland systems face a number of critical, contemporary challenges. Climatic change, persistent poverty and growing land use conflicts, especially around mining, pose complex problems both for herders and policy-makers. Furthermore, there is renewed emphasis on meeting Convention on Biological Diversity (CBD) and Aichi targets, following the publication of Mongolia's 5th National CBD report in March 2014, and the development of a new National Biodiversity Strategic Action Plan. (E)valuation of the contributions of rangeland ecosystem services (ES) to biodiversity and livelihoods/wellbeing are highlighted as priorities for future planning therein. ES thinking, valuation and commodification are becoming increasingly influential in other contemporary policy initiatives, not least through the development of the national REDD+ roadmap, Business and Biodiversity offset programmes and Government commitments to the 'Green Economy'. Nonetheless critical questions remain about the ES paradigm itself, values/ valuation of ES and how these may be enacted and supported through policy. Here we report on a three year Darwin-Initiative funded project, which aimed to 'generate policy and practice relevant knowledge of values of ecosystem services (ES) in Mongolia, and test the efficacy of Payment for Ecosystem Services (PES) schemes, in order to enhance biodiversity and livelihoods'. Aims were realised through i) participatory mapping and analysis of ES, including cultural ES, with 300 herder households across four case study sites, and the development of innovative methods for non-economic valuation; ii) co-development and implementation of a novel rangeland payment for ES (PES) scheme at the four sites, through the Plan Vivo standard; iii) analysis of the impacts ES and of the PES scheme on biodiversity and livelihoods. Methods used included deliberative valuation approaches, mapping, ranking and choice modelling to examine group and individual values and trade-offs between ES across ecologically contrasting areas. We also applied the SOLVES (Social Values of ES) GIS model to highlight spatial, place-specific dimensions of ES values, as part of a series of wider biodiversity, livelihoods and ES assessments. Results highlight spatial and temporal diversities in ES values, importance of cultural ES for wellbeing, and the potential of carefully designed PES schemes to contribute to more resilient socio-ecological rangeland systems in the future.

Keywords: values, ecosystem services, livelihoods, biodiversity, governance

INTRODUCTION

In contemporary Mongolia, ecosystem services (ES) thinking is becoming increasingly influential in contemporary policy initiatives and in framing decision-making around rural futures, despite growing critiques of the commodification of nature, arguably inherent in the ES paradigm (Robertson, 2012; Upton, 2014). These issues are brought into particularly sharp relief in Mongolia by the recent, rapid proliferation of mining activities, which look set to transform economic growth and trajectories. Furthermore, there is renewed emphasis on meeting Convention on Biological Diversity (CBD) and Aichi targets, following the publication of Mongolia's 5th National CBD report in March 2014, and the development of a new National Biodiversity Strategic Action Plan. (E)valuation of the contributions of rangeland ecosystem services (ES) to biodiversity and livelihoods/wellbeing are highlighted as priorities for future planning therein. Nonetheless critical conceptual and practical questions remain concerning not only the ES paradigm per se, but its local meanings, and contested ES values and valuation practices. The concept of 'ES' is by no means universal or universally accepted, with the continued recognition of different cultural understandings of human/ nature relationships vital for future policy making and for environmental justice. Nonetheless, a global form of ES thinking continues to extend its influence, not least in Mongolia. Vital issues at this juncture are therefore to explore local meanings and values around 'ES' in this respect, something which we begin to do herein. Of particular relevance to pastoral resource governance are questions of how local, culturally specific values and concepts of ES may be elicited, enacted and supported through policy, not least in relation to holistic (e)valuation encompassing not only provisioning but cultural ES and values (Plieninger et al., 2013).

Critiques of the ES paradigm notwithstanding, recent work in the social and environmental sciences has begun to explore the possibilities and impacts of economic mechanisms, notably Payment for Ecosystem Services (PES) schemes, in resource governance and sustainable resource use. However, with a few notable exceptions (e.g. Dougill et al., 2012; Reed et al., 2015), pastoral/ rangeland systems have not featured prominently in this literature to date. These absences reflect the particular challenges presented by inherent characteristics of rangeland socio-ecological systems, for example: low rates of carbon sequestration in rangeland soils compared to above ground biomass (trees and shrubs) in forested systems; complex and variable socio-ecological boundaries linked to widespread lack of clear individual tenure rights; and climatic variability prompting temporally and spatially variable adaptive responses (Dougill et al., 2012). Nonetheless, and given the wider Mongolian environmental and policy contexts outlined above, critical analyses and exploration of (P)ES and the promises and pitfalls of ES-based approaches in rangelands are timely and offer important insights for future policy directions.

This paper reports on a Darwin-Initiative funded project (2012-2015), which aimed to 'generate policy and practice relevant knowledge of values of ecosystem services (ES) in Mongolia, and test the efficacy of Payment for Ecosystem Services (PES) schemes, in order to enhance biodiversity and livelihoods'. Specifically, and with the emphasis on eliciting local meanings and values of 'ES' as a primary concern, we ask a) how herders at four different case study sites across Mongolia understand, use and value ES, with particular attention to the role of cultural ES therein; b) how pilot PES schemes may be developed and implemented at these sites, given challenges inherent in rangeland systems and to reflect local ES values; c) what are the policy lessons in relation to sustainable livelihoods and biodiversity into the future?

STUDY SITES

Research was conducted at four sites across Mongolia, as shown in Figure 1, from 2012-2015. In total, 12 herder groups participated in the work, 3 from each of the main study areas, selected to represent contrasting ecological zones (Ikh Tamir *soum*, Arkhangai *aimag* in the forest steppe; Undurshireet soum, Tuv *aimag* in the steppe; Bogd *soum* Bayanhongor *aimag* in the steppe/ desert steppe; Ulziit *soum*, Dundgov *aimag* in the desert steppe). With the exception of the Bogd *soum* groups, all were Mongolian Society for Range Management (MSRM)/ Swiss Development Agency (SDC) Pasture User Groups (PUGs)/*heseg*. They therefore represent a particular form of the herders' groups/ organizations, which have proliferated in rural Mongolia in recent years, typically under donor influence. Recent studies of these groups have highlighted intra-group diversity, relationships with non-group members, sustainability and the extent to which they represent traditional, endogenous forms, as issues meriting further, critical consideration (e.g. Upton, 2008). Nonetheless, they continue to constitute important local institutions, variously involved with pasture use and livelihoods, in particular areas. The groups identified in Figure 1 above are a subset of the 12 groups who participated in this study, and are those involved in the pilot PES scheme through the Plan Vivo standard.

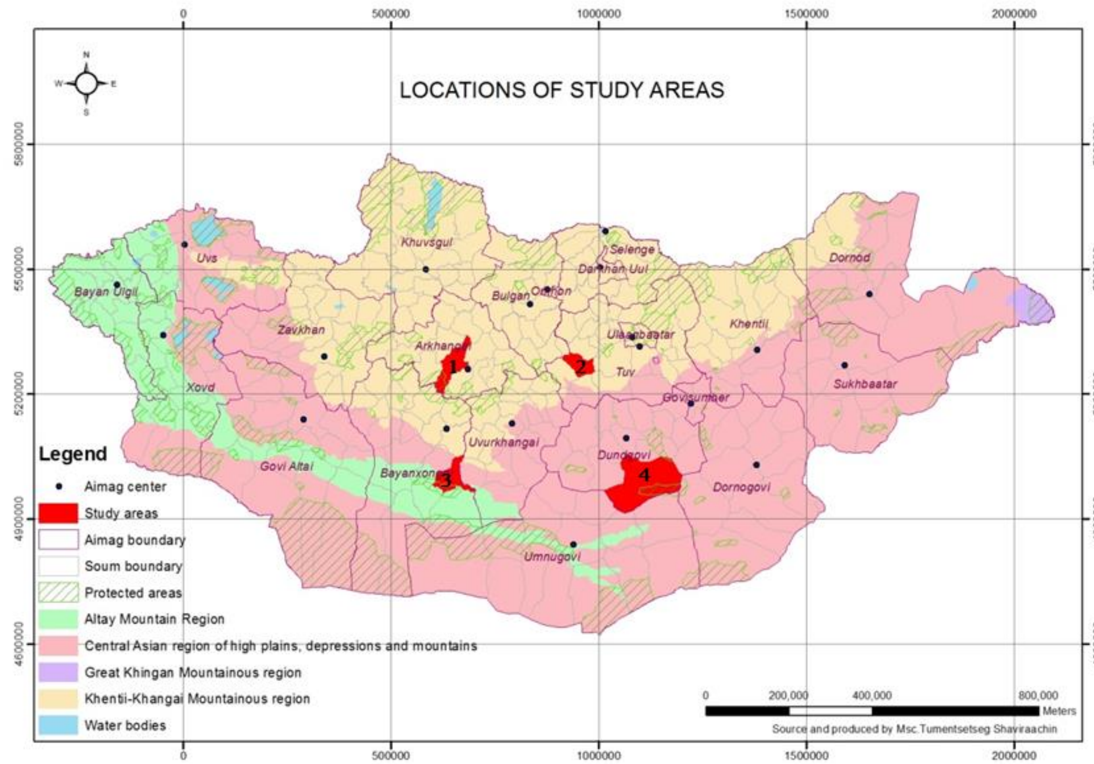

Figure 1. Study sites: 1) Hongor Ovoo *heseg*, Ikh Tamir *soum*, Arkhangai *aimag*; 2) Ikh am *heseg*, Undurshireet *soum*, Tuv *aimag;* 3) Dulaan Khairkhan herder group, Bogd *soum* Bayanhongor *aimag*; 4) Dert *heseg*, Ulziit *soum*, Dundgov *aimag*

METHODS

The following methods were employed with participating herder groups at each of the four sites:

i) participatory mapping of ES, including cultural ES with 300 herder households across four case study sites;
ii) ranking and valuation of ES (including deliberative and group valuation approaches);
iii) household socio-economic surveys;
iv) focus group discussions (with each participating herder group);
v) Key informant interviews;

vi) Participatory photography/ video.

In addition, baseline vegetation and biodiversity surveys were completed for all sites.

These datasets were variously analysed through: statistical analysis of quantitative data (e.g. descriptive statistics, correlations and regressions); conjoint analysis of ES ranking/ valuations (all using SPSS); coding of qualitative materials, interview transcripts, annotated maps etc. drawing on the precepts of grounded theory; use of GIS software and models to explore spatial dimensions of ES values (using the SOLVES model); visual analysis of photographic and video materials. Modelling of C sequestration under baseline and planned (with Plan Vivo project) grazing regimes were also developed using the CENTURY model.

RESULTS AND COMMENTS

The final analyses of project datasets are ongoing. To date, key results highlight the importance of multiple ES categories at sites across Mongolia and thus the importance of holistic assessment of ES. Although provisioning services (grazing, water resources) unsurprisingly feature highly in ES lists and rankings across all sites, cultural services (for example aesthetic, spiritual services) retain importance at all locations, albeit with willingness to trade-off between different services showing significant variation both across sites and by attributes (age, gender etc.) for the dataset as a whole. Attempts to assign monetary values to cultural services are problematic, echoing the findings of others in diverse geographical contexts (e.g. Kenter et al., 2011), although choice modelling/ conjoint analysis approaches do provide tools for the elicitation and, to some degree, the quantitative analysis of these services, with important implications for policymakers. Group and deliberative approaches, as employed here, reveal the importance of shared values, especially in relation to non-economic valuation and to cultural services, and underscore the importance of group approaches and holistic ES (e)valuation in sustainable and equitable rangeland governance (see also Reed et al., 2015). Through analysis of the spatial dimensions of ES provision and valuation, using the SOLVES model, ES are revealed as bundled services, with hotspots in provision of the most highly valued cultural and other ES associated with particular landscape and/or landcover attributes. These 'hotspots' and their cultural ES dimensions are also widely cited by informants across the four sites as important aspects of well-being. Cultural services mapping using SOLVES thus offers insights into management planning and decisions at the landscape scale and emphasizes the resonance of the cultural landscapes concept in the Mongolian context (Pleininger et al., 2013).

Analyses of temporalities in ES provision highlight both drivers of decline and their impacts on perceptions of well-being, with climatic impacts on provisioning services forming a particular area of concern across sites.

The development of a pilot PES scheme at the four sites under the Plan Vivo standard proceeded through *heseg/*herder group led planning, building on the ES identification and valuation exercises highlighted above, and taking full account of socio-economic and local biodiversity contexts, as well as stated values around cultural ES. Specifically, herder groups developed a range of planned activities, which variously contributed to carbon sequestration, biodiversity or livelihood goals. Table 1 provides a brief summary of the results of these exercises. A climate benefit quantification methodology was also developed specifically for Plan Vivo (PV) as part of this project, namely 'Carbon sequestration through improved grassland and natural resources management in extensively managed grasslands' (Values for Development, 2014), drawing on existing work in relation to the Verified Carbon Standard (VCS) (Dougill et al., 2012). CENTURY modelling, an integral aspect of this proposed methodology, in conjunction with unwillingness of herder groups to substantially reduce livestock numbers as part of an initial PES commitment phase, indicates that the carbon (C) metric alone is unlikely to yield substantial marketable benefits at present. This is not an uncommon issue with rangeland PES schemes, as noted above. However, the recent development of a new PV standard (December 2013), for which this project is one of the pioneers, offers a number of opportunities for a ‘carbon plus’ type approach, which may begin to address some of the previous critiques of PES schemes. Specifically, the danger of focusing on single ES or metrics is herein recognized and plans developed for a more holistic approach through the kind of tripartite model set out in Table 1. By emphasizing the livelihoods/ wellbeing and biodiversity conservation aspects of planned activities, issues such as equitable benefit sharing, poverty alleviation and measures to avoid leakage (i.e. negative changes beyond PES scheme boundaries, due to PES related activities), whilst maintaining traditional norms of reciprocity better reflect the norms and values of participating communities at study sites. As a result of participatory planning activities conducted during this study, an initial commitment period of only 3 years has also been agreed. This reflects the status of the PV activities as a pilot intervention with an emphasis on institutional and mutual learning amongst parties.

IMPLICATIONS

From the extensive fieldwork with herders at sites across Mongolia, it is evident that holistic assessment of ES and their values, in particular to include cultural ES and non-economic valuation, is important in planning for more resilient socio-ecological rangeland systems in the future and for ensuring co-ownership of plans with local herding communities. Such approaches are also important in the context of the publication of Mongolia’s 5th National CBD report in March 2014, and the development of a new National Biodiversity Strategic Action Plan. (E)valuation of the contributions of rangeland ecosystem services (ES) to biodiversity and livelihoods/wellbeing are highlighted as priorities for future planning therein. Various methods for elicitation and (e)valuation of ES were trialed during the Darwin project, which will form the focus of training materials being developed for students at MAAS. These will also be set out in further details as part of a briefing for policy makers.

The Plan Vivo aspects of the Darwin project are ongoing. The development of this pilot PES intervention has thus far illustrated the challenges and complexities of translation of local ES meanings and values, biodiversity and livelihood concerns into this market driven standard, whilst nonetheless indicating that the move beyond a purely C metric may offer significant opportunities for PES in rangelands. This learning process, with clear policy applications, will undoubtedly continue throughout the 1st Plan Vivo commitment period (2015-2018).

ACKNOWLEDGEMENTS

This study was funded by the Darwin Initiative ‘Values and Valuation: New Approaches to Conservation in Mongolia’ project (Award 19-021). The authors wish particularly to thank all participating herder groups for their input into this project.

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Table 1. Summary of activities under Plan Vivo, as identified by herders at project sites

Activity type	**Examples**	**Main contributions to Tripartite/ C+ Plan Vivo certificate**
Improved rangeland management	• Restoration/ improvement of traditional seasonal mobility between pastures ('rotational use') • Reduced livestock stocking densities	CARBON C sequestration (soils) Additional contributions to BIODIVERSITY through reduced grazing pressure and rangeland degradation.
Nature conservation	• Group activities for conservation/ protection of named key fauna (wild sheep, deer etc., dependent on key species identified in territory) • Group activities for conservation/protection of named key flora (e.g. medicinal plants, dependent on key species identified in territory). • Group activities for stopping illegal mining	BIODIVERSITY May also contribute to LIVELIHOODS/ WELL BEING (e.g. cultural, aesthetic, environmental ES)
Disaster/ risk preparedness	• Cooperation for haymaking • Cooperation for fodder preparation • Cooperation for repairing wells/ enhancing water supply	LIVELIHOODS/ WELL BEING
Productivity/ income support	• Enhanced production of value-added milk and wool products • Vegetable production, sale and storage	LIVELIHOODS/ WELL BEING

Dzud and Thresholds of 'Property' in Mongolian Pastoralism

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ABSTRACT

Property and its allocation are key elements of resilience within socio-ecological systems. This presentation compares ethnographic and survey data on shifting ideas of property from 2008 to similar data gathered in 2014 in a district of southern Khentii *aimag*. The data illustrate how these attitudes emerged, their underlying logics, and how they articulate with broader historical and political economic conditions. The findings raise concern that *dzud* events could serve as a possible trigger for formal legal transformations in land rights given the increased political rhetoric and calls for land privatization following *dzud* events. This paper argues that crossing such property thresholds would pose considerable problems for both rangelands and livelihoods and suggests some future avenues for strengthening pastoralsystems.

Keywords: Property, mobility, politics, disaster, resilience

INTRODUCTION

Property and its allocation are key elements of resilience within socio-ecological systems (Folke, 2006). However, informal property arrangements often reflect not only highly adapted, habitual norms but also situational and context-specific logics that are dynamic responses to ecological conditions and, as such, they are mutable. This paper compares ethnographic and survey data on shifting ideas of property from 2008 to data gathered in 2014 in a district of southern Khentii *aimag*. The data reveal that ideas about property, particularly natural resources such as pasture and land, have undergone considerable and seemingly contradictory change.

In particular, attitudes concerning the allocation and recognition of more private recognition of claims to resources such as campsites and pasture have abruptly transformed from an unexpected embrace of privatization by many herders in 2008 to a near absence of such attitudes in 2014. These data, however, do not seem to reflect a trend away from private conceptions of rights to land but rather reflect a situational logic attuned to the specific context in which such data were collected. Positive attitudes toward private claims were witnessed in the immediate aftermath of a *dzud* event in 2008 while in 2014 the rejection of such private claims followed several 'good' years with minimal use of *otor* migrations.

These findings are somewhat ironic given that bad years are seen by scholars as justification for highly mobile resource use strategies and common property systems whereas more stable conditions would seem to support increased calls for recognition of private claims. Moreover, these findings also raise concerns that *dzud* events could serve as a possible trigger for formal legal transformations in land rights given the increased political rhetoric and calls for land privatization following *dzud* events. This paper argues that crossing such property thresholds would pose considerable problems for both rangelands and livelihoods and suggests some future avenues for strengthening pastoral systems.

STUDY SITE AND METHODS

The data discussed in this paper were collected in Uguumur, a rural district in Bayankhutag *soum* just south of Undurkhaan (now Chingis) in southeast Khentii *aimag*. The data were gathered primarily over the course of two research periods: 15 months during the period of 2007-2008 and 6 weeks during the summer of 2014. However, ethnographic research by the author has been conducted in this district with the same households for a total of 30 months since 2003. Methods conducted in 2007-8 included a household survey of 68 herding households with in-depth follow-up interviews with 34 of them. Household survey questionnaires gathered data on livestock and other assets, household production and consumption, mobility practices and property distinctions, labor practices, and genealogical data. Interviews focused primarily on resource use decision-making, property practices, and local administration. In 2014, I returned to the district and re-surveyed 24 from the original 34 households and conducted in-depth follow-up interviews along with the original household questionnaire. Additional interviews were also conducted with various administrators, governors, and other officials in both research periods.

RESULTS

Household mobility in the context of hazardous events such as drought and *dzud* is a key risk management stragegy that has severe implications for the continuation of a pastoral lifeway on the Mongolian steppe (Murphy, 2014a). In Uguumur, as livestock herding is the primary productive activity that households undertake the number, timing, distance, and location of migrations is critical and depends on variety factors including access to campistes. Campsites are primary resources that allow households to maintain acces to other resources such as pasture, water, salt/soda deposits, and other essentials for a households' herds. Outside of the good-year annual round of seasonal campsites, households practice *otor* for autumn fattening and to avoid deleterious conditions that threaten the viability of their herds (Murphy, 2011). The ability to make such moves is underwritten and made possible by an institutional foundation including both formal and informal sources of entitlement. Entanglements of local custom, moral economies of use, right and recognition, administrative bodies, legal architectures, and various manifestations of non-governmental policy and practice formulate the institutional landscape that make mobility possible or not (see also Murphy, 2014b). However, wide variations in mobile practices and livestock mortality during 2008 *dzud* demonstrated the institutional inconsistencies, gaps, constraints, and barriers that limited mobility as an option and revealed a deep institutional uncertainty that continues to plague Mongolia's commons.

Property Practices, 2008

In this institutional fog, data gthered in 2008 demonstrate that new conceptualizations about property, access, and rights to resource and the practices surrounding them have come to the fore (se Table 1). Many of these rights, whether ownership, possession, or use rights, are rooted in various articulations of 'mastery' – a Mongolia formulation of the relationship between persons in relation to things. Mastery implies both a right of possession and a custodial responsibility (Sneath, 2001) and as such expresses elements of inalienability. However, mastery cannot be exchanged as it is rooted in individual persons and reflective of their capacity. Nevertheless, mastery can be inherited through descent, kin, and ethnic affiliation (depending on scale), attained through practical experience and engagement with a resource and its spiritual counterparts, or bestowed on a person through spiritual or political favor. Mastery must also be evidenced and justified in recognizable ways. In some ways, current possession leases map onto these practices but in other ways by codifying 'right' through legal bodies such leases displace the social determinants of mastery resulting in a kind of dispossesion (see Murphy, 2014 for elaboration).

Understanding mastery is key to understanding the range of practices observed and witnessed in 2008 including gifting for use of campsites, donations, rents, exchange of bribes, and ultimatey sales (see Table 2 for a compilation of data from questionnaires and interviews). This spectrum of exchange implies a range of distinct understandings about rights to things and those that are exchangeable (for similar transformations in albor see Murphy, 2015). Gifts for instance balance reciprocal relations. Donations are made to appear as 'freely given'. Rents exchange use rights but ot rights of possession or owenrship. Bribes include elements of all three and sales, in contrast to the others, positions rights to campsites as alienable – a key element to privatization. Given that such practices and ideas are novel or, in some sense, re-emerging in Mongolia, such observations, and participant responses, give the impression that ideas about rights to land are increasingly becoming more individuated (See Murphy, 2011 for a description of bribery and corruption surrounding winter otor contracting in 2007).

Table 1. Diversity of rights, claims, and justifications compiled in 2008. The distinctions described here are necessary simplifications.

Right (*erx*)	Key Resources	Claims	Justification
Ownership (*umchlux*)	*Ger*, corrale (*xashaa*, *saravch*, etc)	Individual right	Possession, Documentation
Posession (*ezemshix*)	Campsites, livestock, wells, hayfield	Descent and kin ties, legal recognition	*Buuts*, collective memory, documentation, *tamga* (markings/tags)
Use (*ashiglax*)	Campsites, pasture, public wells, soda	Ethnic, Chinggis Khan, moral economy of steppe	Mongol identity, documentation, collective memory, moral right, citiizenship

Table 2. Various forms of exchange for rights to campsites and other key resources during 2008.

Exchange term	Mongolian term	
Gift	*beleg*	Reciprocity. Considered *talarxalt* or thankfulness
Donation	*xandiv*	
Rent (or wage)	*turees* or *xuls*	Exchange with *ezen* for temporary use right
Bribe	*xaxuuli*	Exchange with official for temporary use right
Sale	*xudaldaa*	Alienable exchange of ownership or possession rights (and use rights)

Interviews with local administrators and governors and case studies of dispute confirm this. Case studies reveal that notions of mastery which stress indvidual right are privileged as a means to settle dispute. Moreover, the possession leasing program further codifies and cements these ideas in practice so that flexible access to campsites and pasture is mediated through the institution of leasing rather than through the social relations that produce customary notions of mastery. In short, in 2008 it appeared that practices and ideas surrounding rights to resources, though still highly uncertain and debated, was becoming increasingly neoliberalized such that rights are inherent not to the social relations that form them but in the individual self.

It shouldn't be surpising then that in this context of neoliberalization and disaster, I also found considerably more support for various kinds of privatization than I imagined prior to arriving at the field (see Figure 1). Given that 31 percent of sample households favored campsite privatization and 28% percent favored pasture privtization, it seemed evident that notions of rights were clearly moving towards individual, private conceptions 'mastery' as alienable. Such a move towards privatzation would render a tectonic shift in pasture management, resetting the very basis of pastoral livestock production in Mongolian. It is also interesting because hazardous conditions like those presented by *dzud* are typically those cited by scholars of pastoralism and in common property sysmtes more broadly, as being fundamental to the rationale for maintain flexibile property regimes.

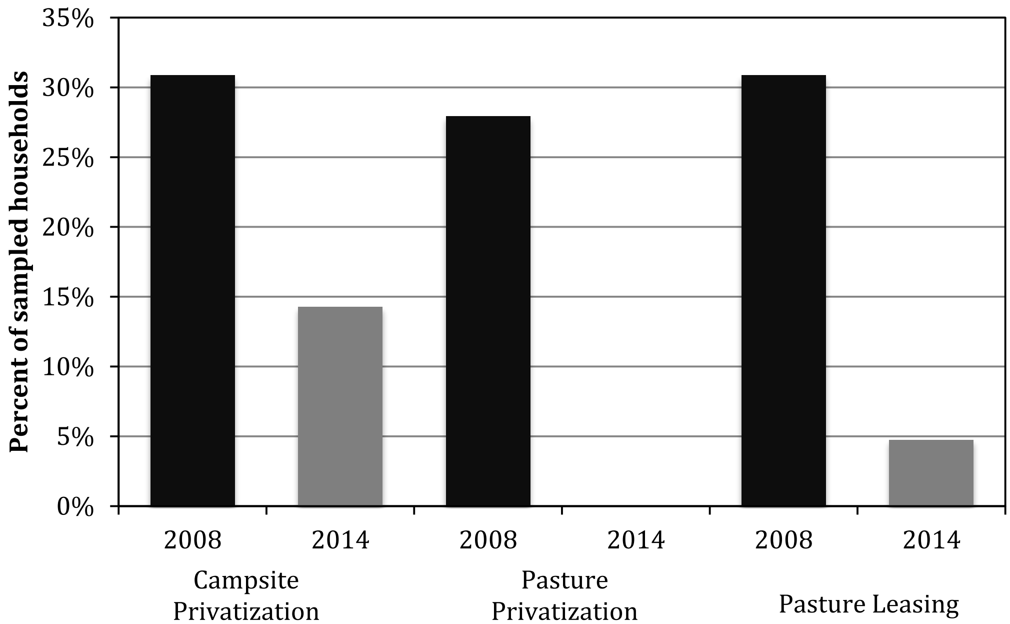

Figure 1. Comparison of 2008 and 2014 household sample in support of privatization and leasing

Property Practices, 2014

Upon return to Uguumur I found that in 2014, such interest in privatization has largely abated. Only 14 percent of the sample responded that campsites should be privatized and no responses refelcted a desire to privatize pasture (a 17% and 28% drop respectively). In fact, there was also a significant drop in the number of responses preferring expansion of the possession lease system to pastures (26% drop). Beyond these shifts, the diverse array of other conceptualizations of right and claim seem to remain in tact. Herders still talk of campsites sales and bribery but much less so than in 2008 and arguments and disputes over pasture continue. Overall I found that though district households seem split on the value of campsite possession leases, responses predominantly support the idea that key resources should be left in the hands of the state as *turiin umch*. And though there still appears to be tension between a notion of relative open access and more entrenched forms of exclusive ‘mastery’ over campsites, I continue to hear the same refrain regarding the possibility of pasture privatization, “*dain bolnoo*” or “there will be war”.

This simultaneous retreat from privatization and entrenchment of forms of mastery open to exchange present an interesting contrast to 2008 because the years since the *dzud* have been comparatively hazard free with sufficient pasture growth and a lack of drought or *dzud* conditions in Uguumur and Bayankhtuag. This preference for flexibility is ironic given that private notions of property are typically linked to such stable conditions.

DISCUSSION

In 2008, it appeared that the logic of the commons in Uguumur and in Khentii more broadly was under threat. Yet, by 2014, the commons as a key element in mitigation and management of risk seemed to re-assert itself. The corresponding dramatic drop in support of privatization (and its allies), albeit with the continuation of the variety of increasingly more individualized notions of rights to things more broadly, raises a number of key questions. Why has support for privatization dwindled and how does this affect the interpretation of events in 2008?

The relatively easy answer for these questions is that possession leasing, which was relatively new in 2008 (started in 2006), has reduced institutional uncertainty by supporting a particular subset of notions concerning rights to campsites, particularly those that support more individuated notions of mastery. However, there is still considerable debate about leasing (see quote above) and legitimacy of various property practices. Moreover, case studies of disputes and exchanges demonstrate that herders in Uguumur still find current institutional arrangements to be lacking and reflect continuing precariousness and uncertainty.

Though the impact of leasing is not negligible, other dynamics I propose are also afoot. In particular, I argue that these findings are understandable if we consider them within what Little (2012) calls the “emotional ecologies of risk mitigation”. In the context of Uguumur in 2008, such institutional uncertainty in the face of hazards shortens temporal horizons for perceiving risks, planning for responses, and ultimately making and executing necessary decisions. Consequently, the institutional uncertainty produced by histories of decentralization, the atomization of household risk management, and amplified by disaster, becomes materially forceful and plays on the anxieties and fears manifest in pastoral survival. As such, in 2008, herders were simply willing to consider other pathways, as drastic as privatization, given what they were in the midst of confronting. By 2014, though, the experience of *dzud* had begun to fade from memory and more deeply entrenched logics eclipse the ‘thinkability’ of such as drastic measures.

IMPLICATIONS

This interpretation is important for a number of reasons. Most studies of pastoral mobility are synchronic in nature and rely on what anthropologists call the “ethnographic moment”. This is highly problematic for the study of pastoral social-ecological systems because the temporal logics of common property systems, much like their spatial logics, operate at the macro-scale but the actors and social relations that make up such systems are practiced at the micro-scale. As such, property must be understood to reflect critical but mutable situational logics as well as shifts in political constellations of institutions and actors. Moreover, understanding that the emotional ecologies of risk mitigation, shaped by the exposures and sensitivities created by the atomization of risk, the unequal distribution of wealth, and institutional uncertainty, play a role in property politics has significant implications for the future resilience of pastoral socio-ecologies. If disaster amplifies institutional anxiety to such a degree as it did in Uguumur in 2008, then the potential for such future events poses the possibility that pastoralism in Uguumur might cross a critical threshold. In this sense, *dzud* has the potential to trigger political transformations of property towards a revolutionary form of "shock therapy" in land management not seen since the early 1990s.

ACKNOWLEDGEMENTS

Financial support for the research period of 2007-2008 was provided by the National Science Foundation (Dissertation Improvement Grant 0719863), Wenner Gren Foundation for Anthropological Research, Institute for International Education Fulbright Program, Lambda Alpha National Honor Society and the University of Kentucky. Research support for 2014 was provided by the Charles Phelps Taft Researcher Center at the University of Cincinnati.

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Contemporary Mobility of Herders in Central Mongolia

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ABSTRACT

Social-ecological changes occurring in recent years have complicated herders' migration patterns, and because of rangeland climate variability, nomadic movement patterns have changed. The aim of this study was to determine how the present movement patterns of herders situated in different steppe regions along the road infrastructure corridor of central Mongolia have been affected by the intensification of community-based natural resource management activities and household livelihood levels, and to identify how herders adapt to those changes in their movement practices. The number and distance of herders' movements increased between 2010 and 2011, depending on regional geographical location and community-based natural resource management activities. In particular, household income and the number of livestock herders owned determined how far they moved. In the period 2010-2011 in central Mongolia there was a trend of movement from the western *aimags* to the forest steppe and from the desert steppe to the steppe and forest steppe, across administrative borders. Herders have a variety of ways to cope with social-ecological change which demonstrates the basic need for developing location-specific policies when establishing movement regulations and implementing risk reduction measures.

Key words: Mongolia, movement patterns, regional geographic location, herders, CBRM, movement across the administrative borders

INTRODUCTION

Livestock herd movements are a traditional household practice with precise steps (Avarzed and Sodnom, 2008), which have existed for many centuries (Bazargur, 2005), and are the optimal way to use rangeland resources (Fernandez-Gimenez and Le Febre, 2006). Heterogeneity of natural resource distribution dictates the location of pastoral herding, herd structure, and defines herders' lifestyle. In conducting movement research it is appropriate to use the indicators of the direction, the distance and the number of herders' movements (Bazargur, 2005).

Since transformation of the political system in 1990, and subsequent social-economic change in Mongolia, livestock has been privatized and herders confronted with the need to independently arrange their household income and other financial issues, which led most herders to increase livestock numbers as much as possible (Saizen et al., 2010). This has changed the distribution patterns and timing of herders' movements, increased livestock density, and created a condition when large numbers of livestock consume key natural resources at the same time (Fernandez-Gimenez, 1997). The distance of herders' movements has shortened, and there has been a tendency for a decrease in the number of movements per year (Bazargur, 2005), which has affected rangeland resource conditions (Johnson et al., 2006).

In response to these changes, international donors and NGOs began supporting herders to improve rangeland use and livelihood sustainability, and this support has been aimed at facilitating community-based rangeland management (CBRM). This approach increased as herders began uniting into groups after the *dzud* of 1999-2002. By acting collectively, herders' capacity to adapt to and cope with social-ecological change, and to access new knowledge and information, as well as their social relationships and experience have improved (Batkhishig, 2012).

The goal of this research was to define the impact of herders' livelihood level and CBRM activities on the number, distance and direction of herders' movements in three ecological zones (forest steppe, steppe and desert steppe) along the road corridor in central Mongolia, and to discover how herding practices have changed. We assumed that the number and direction of herder movements in Central Mongolia would vary with ecological zone, livelihood level and CBRM activities.

STUDY SITES

Movement patterns of herders were studied at the following sites, all of which are close to the road infrastructure corridor of central Mongolia; Saikhan and Bayangol Soum in Selenge (forest steppe), Bayan and Bayantsagaan Soum in Tuv (steppe region), Ulziit and Undurshil Soum in Dundgobi, and Khankhongor and Tsogt-Ovoo in Umnugobi (desert steppe) (Figure 1).

METHODS

In 2010-2011 we collected, using qualitative and quantitative methods, information about the number, distance and direction of movements, household income, and the reasons for these movements, from herders of four CBRM and four non-CBRM *soums* in four *aimags* located in forest steppe, steppe and desert steppe of central Mongolia. A total of 200 household surveys, 48 focus group discussions and 55 individual interviews were undertaken (Table 1). To improve the completeness of the data, we collected additional information using the relay station discussion technique (Creswell, 2003) from central and gobi region discussions conducted in June 2014.

Quantitative data were analyzed using an ANOVA, linear regression and correlation (Quinn and Keough, 2002) in SPSS.17.0 (http://www.spss.co.in). Number of livestock was transformed into sheep units using the standard methods (Bedunah and Schmidt, 2004). Qualitative data were processed based on the classification method of narrowing the general (Creswell, 2003).

RESULTS

The number of movements

There was a significant interaction between ecological zone and year in the number of movements (F-29.08, *p*<0.001). In 2010 the herders in the desert steppe region moved more (2.89 ± 0.17 times) compared to the herders in steppe (1.64 ± 0.16 times) and forest steppe (1.51± 0.14 times) regions (Table 2). In 2011, steppe region herders moved more (3.73 ± 0.15 times), than forest steppe (3.00 ± 0.13 times) and desert steppe (2.94 ± 0.12 times) (Figure 2).

There was a significant interaction between year and CBRM type in the number of movements (F-5.6, *p*=0.01).When comparing CBRM type by the year 2010 with the year 2011 the following result is observed: the number of herders' movements in CBRM (2.03 ± 0.195 times in 2010; 3.25 ± 0.140 times in 2011) and non CBRM (2.53 ± 0.129 times in 2010; 3.05 ± 0.103 times in 2011) has generally increased (Table 3; Figure 3).

The distance of movements

There was a significant interaction between year, ecological zone, and CBRM type (F-3.01, *p*=0.001) (Table 4) in the distance of movements. In 2010-2011 in the desert steppe, CRBM herders' (60.2 ±30.8 km in 2010; 76.2 ± 42.7 km in 2011) distance of movement has increased, but non CBRM herders' (113.3 ± 40.9 km in 2010; 78.5 ± 41.9 km in 2011) distance of movement decreased. In the steppe region between 2010 to 2011, CBRM (51± 31.5 km in 2010; 81.1 ± 19.2 km in 2011) and non CBRM herders' (35.8 ± 43.1 km in 2010; 52.4 ± 40.3 km in 2011) distance of movement are appear to have increased. But in the forest region between 2010 to 2011, CBRM (47.6 ± 9.7 in km 2010; 90.4 ± 34.5 km in 2011) herders' movement doubled, compared to non CBRM herders' (33.8 ± 56.7 km in 2010; 37.7 ± 53.4 km in 2011) distance of movement (Table 4).

According to herders in the steppe and desert steppe, the increase in the number and distance of movements is related to a decrease in rangeland productivity. For instance, a herder from Undurshil *soum* stated: "*Anyone moves where he wishes*. *Because for the household with many herds it's difficult to settle in one area for a long time.*"

The direction of movements

Generally, we observed that non-resident herders from other *aimags* moved to the forest steppe and steppe regions, while herders from the desert steppe region moved out across their *soum* and *aimag* border towards the east and north-east. We categorized herder movement into two kinds: temporary movements in times of drought and dzud, or movements to become permanent inhabitants of the destination *soum*.

In the central research area, movement directions were as follows: from western *aimags* to Selenge *aimag*, from Umnugobi to Dundgobi, from Dundgobi to Tuv *aimag*, and from Tuv *aimag* to eastern *aimags*.

Based on identifying the location of movements, the herders of Bayangol and Saikhan *soums* in forest steppe region move locally in their *soum* or moved to Khushaat in Selenge *aimag*, Bornuur in Tuv *aimag* and Darkhan, and also a number of herders came from other *aimags*, namely from Khovd, Uvs and Khuvsgul *aimags* (Figure 4). For example, during interviews with Bayangol *soum* herders they indicated that many non-resident herders come from outside by saying: "*Our population is growing and growing. Many people come from the western aimags. The reason why many people are arriving might be because our soum is centralized. And the rangeland is degrading more and more.*"

The herders of the steppe region Bayan and Bayantsagaan *soums* mainly moved to Mungunmorit, Bayankhangai and Zaamar, and non-resident herders move in there from Ulziit, Undurshil, Khankhongor and Tsogt-Ovoo (Figure 4). For example, from the interview with the herders of Bayantsagaan *soum* you can see that they move northwards while non-resident herders move into their area from the southern *soums*: "*Many herders from our aimag and Dundgobi aimag are coming to our area. Non-resident herders mostly come during dzud disaster periods while our aimag's herders nowaday move to different soums because of land and water degradation. Due to the last years poor land produce we had to move to Sergelen and Bayanchuluut soums of Tuv aimag, and in winter we move further than Ulanbaatar city to spend winter there. It's the only way for us to keep our livestock.*"

Herders from the desert steppe regions of Tsogt-Ovoo and Khankhongor *soums* moved to Dundgobi and Gobisumber *aimags*, the herders of Dundgobi *aimag* moved to Tuv *aimag* and Khanbogd, Manlai, Mandakh and Tsogt-Tsetsii *soums* of Umnugobi *aimag* (Figure 4). Herders of Umnugobi *aimag* Tsogt-Ovoo *soum* generally move north-east and east: "*We moved to Dundgobi and Gobisumber aimags. When the conditions worsen we move further away and when it gets better again we move around the area. Last summer we moved to Mandakh in Dornogobi aimag*". Herders from Ulziit and Undurshil *soums*, and herders from Khankhongor and Tsogt-Ovoo *soums* of Umnugobi moved into their area (Figure 4): "*When the conditions worsen we split to do the otor movements. Many herders are moving in from Umnugobi aimag*".

Distance and number of movements in relation to number of livestock and household income

Results of linear regression show that the number of movements ($F=12.6$, $p<0.001$), and the distance of movements ($F=0.08$, $p<0.001$) in 2011 was dependent on herders' income in 2010 (Figure 5A). The total distance of herders' movements ($F=11.0$, $p<0.01$) in 2011 also depended on the same year's livestock number (Figure 3B). Qualitative data supports that in any region, the households with greater numbers of livestock and better income moved more times and longer distance. For herders in the Gobi desert, households with higher income and livestock numbers had a need and ability to move more. For instance, a herder from Khankkhongor *soum* stated: "*Nowadays land production is decreasing and those who have more livestock and more wealth move faraway to reach the productive land to raise own livestock well.*"

From the relay station discussion we observed that non-resident herders who came from the forest steppe and the desert steppe region used the rangeland by formally registering their household members in several different *soums*. Based on the interview of participants in the forest steppe relay station discussion: "*Herders make the arrangements for themselves to move to the various areas by registering their family members or their relatives under the several soums. First one of them moves in without the livestock, and then he moves in his kins and the livestock. Even the husband and the wife of one family separate to become the subjects of the different soums.*"

DISCUSSION AND IMPLEMENTATIONS

Patterns of herders' movements in central Mongolia differed depending on CBRM membership and geographical location (forest steppe, steppe and desert steppe) (Bazargur, 2005). The number of herders' movements, increased between 2010 and 2011 in all regions (forest steppe, steppe and desert steppe). CBRM herders moved more than non-CBRM herders. This could be related to the lessons learnt from the previous year's *dzud*, as well as herders' perception of the need to raise their livestock well. We also observed that the lesson learnt from the dzud of 2010 has intensified the use of otor movements for both CBRM (Fernandez-Gimenez et al., 2012) and non-CBRM herders. In 2010-2011 steppe and forest steppe CBRM and non-CBRM herders', but not desert steppe, CBRM herders' distance of movement increased where most of the movements were done to the outside *soum*.

When comparing movements of desert steppe region herders to those in the forest steppe and the steppe regions, there are many instances of crossing administrative borders. This has been linked to vegetation cover and precipitation conditions (Vandandorj et al., 2015), indicating that the herders who reside in the area with non-equilibrium ecosystem condition (Fernandez-Gimenez and Allen-Diaz, 1999) move more in response to weather and pasture conditions, as they always have. When non-resident herders move into a different *soum's* area, the local residents see them as increasing local herders' risk of winter disaster or drought (Fernandez-Gimenez et al., 2012) and this perception leads to social conflict and unfavorable relationships between the herders. Therefore, when the government defines the number of the livestock moving to the target *soum,* social and ecological risks should be considered, so that the conditions of the target area are not further degraded. These patterns of cross-border movement demonstrate the need to improve rangeland use and conservation policies, suitable to the particular area's size and ecological zone characteristics.

At the *soum* level, individual herder movement patterns were related to their household income and livestock number. Therefore it would be reasonable for appropriate policy to manage the herders movements inside the *soum* or bag, considering household livestock number in the rangeland use planning. Herders show many different movement responses in the attempt to deal with the risks in winter disaster or drought. The flexible population registration legislation provides some ways for herders to overcome natural perturbations and exercise rights for the formal use of rangelands in a different *soum*. Therefore it is necessary to consider geographical location and region specifics when establishing *otor* movement relations between *soums* or *aimags*, and when taking measures to protect herders from various risks in winter disaster of drought. Our results also highlight the need for the coordination of winter preparation in each *soum* with other *soums'* policies.

ACKNOWLEDGEMENTS

This "Mongolian Rangeland Resilience" study was implemented with support of the US National Science Foundation (CNH Program Grant No. BCS-1011 Does community-based rangeland ecosystem management increase the resilience of coupled systems to climate change in Mongolia?) in cooperation with Colorado State University and partner Mongolian scientific organizations. The authors would like to thank the project team members, especially the project leader Dr Maria Fernandez-Gimenez.

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Table 1. Study area of movement pattern research.

Aimag	CBRM *soum*	Individual interview	Group interview	Household survey
Selenge	Bayangol	7	6	25
Tuv	Bayantsagaan	7	6	25
Dundgobi	Ulziit	13	10	46
Umnugobi	Khankhongor	6	5	20
Aimag	Non-CBRM *soum*	Individual interview	Group interview	Household survey
Selenge	Saikhan	5	5	20
Tuv	Bayan	5	5	20
Dundgobi	Undurshil	6	5	24
Umnugobi	Tsogt-Ovoo	6	6	20
TOTAL		55	48	200

Table 2. The number of herders' movement in relation to year and ecological region.

Average number of movements (annually)		*n*	mean	*SE* (±)	F	*p*
2010	Desert steppe	98	2.89	0.17	24.7	<0.001
	Steppe	56	1.64	0.16		
	Forest steppe	45	1.51	0.14		
2011	Desert steppe	105	2.94	0.12	7.1	0.001
	Steppe	56	3.73	0.15		
	Forest steppe	45	3.00	0.13		
*Year*regional geographic location interaction*	Desert steppe	203	1.29	0.02	29.08	<0.001
		112	1.21	0.04		
	Steppe	90	1.11	0.03		

Table 3. The number of movements in relation to CBRM and non CBRM herders.

Average number of movements (annually)		*n*	mean	*SE* (±)	*Year* CRBM organizational interaction* F	*p*
2010	CBRM	77	2.03	0.195	5.6	0.01
	non CBRM	122	2.53	0.129		
2011	CBRM	80	3.25	0.140		
	non CBRM	126	3.05	0.109		

Table 4. The distance of herders' movements in relation to year, ecological region and CBRM type.

Interaction to year, regional geographic location and CBRM type			*n*	*mean*	*SE* (±)	F	*p*
2010	Desert steppe	CBRM	55	60.2	30.8	3.01	0.001
		non CBRM	38	113.3	40.9		
	Steppe	CBRM	56	51	31.5		
		non CBRM	37	35.8	43.1		
	Forest steppe	CBRM	25	47.6	9.7		
		non CBRM	19	33.8	56.7		
2011	Desert steppe	CBRM	59	76.2	42.7		
		non CBRM	40	78.5	41.9		
	Steppe	CBRM	59	81.1	19.2		
		non CBRM	38	52.4	40.3		
	Forest steppe	CBRM	25	90.4	34.5		
		non CBRM	19	37.7	53.4		

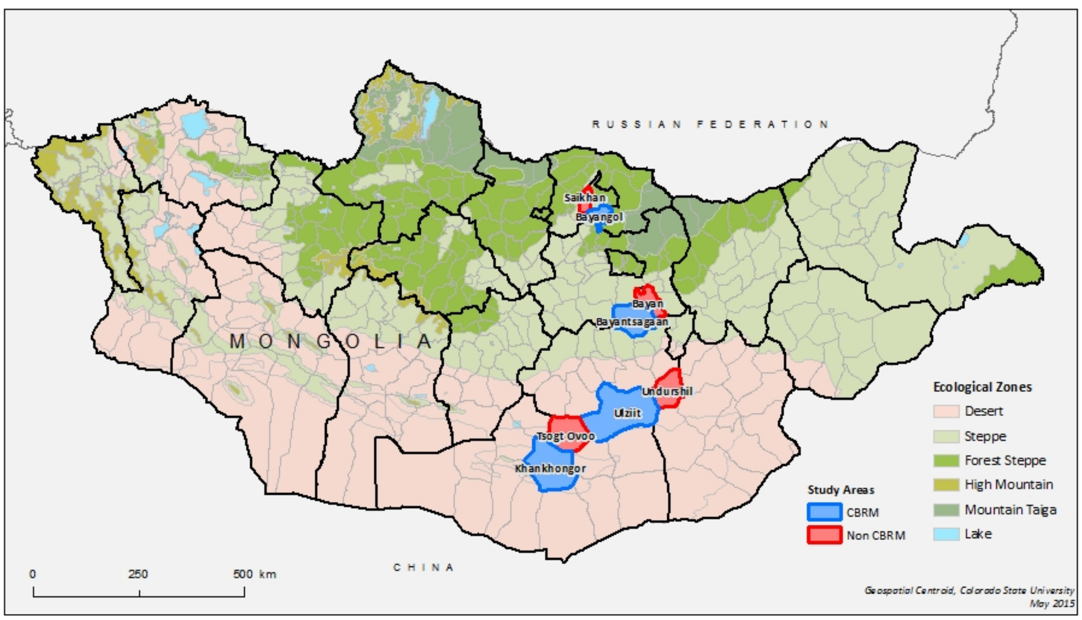

Figure1. Location of the eight paired *soums* with CBRM and non-CBRM grazing practices, located in the forest steppe (Saikhan and Bayangol *soums* of Selenge *aimag*), steppe (Bayan and Bayantsagaan *soums* of Tuv *aimag*) and desert steppe regions (Ulziit and Undurshil *soums* of Dundgobi *aimag*, and Tsogt-Ovoo and Khankhongor *soums* of Umnugobi *aimag*). [Map from MOR2]

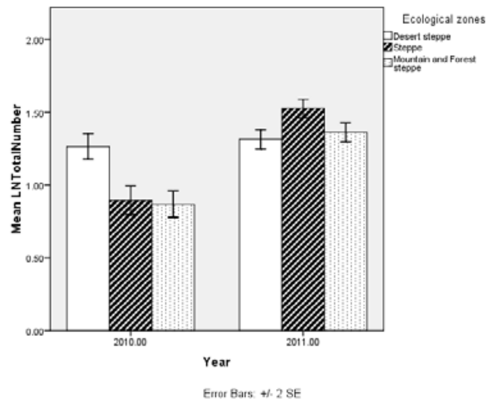

Figure 2. The number of movements in different ecological regions, in 2010 and 2011.

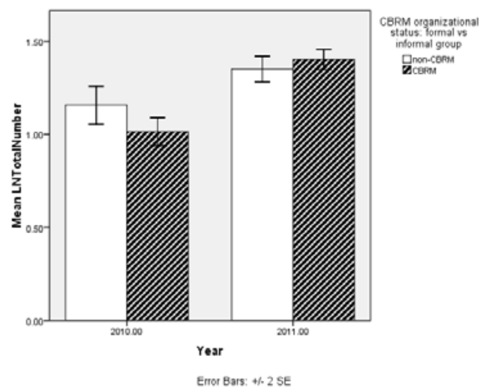

Figure 3. Comparing, in 2010 and 2011, CBRM herders' and non CBRM herders' number of movements.

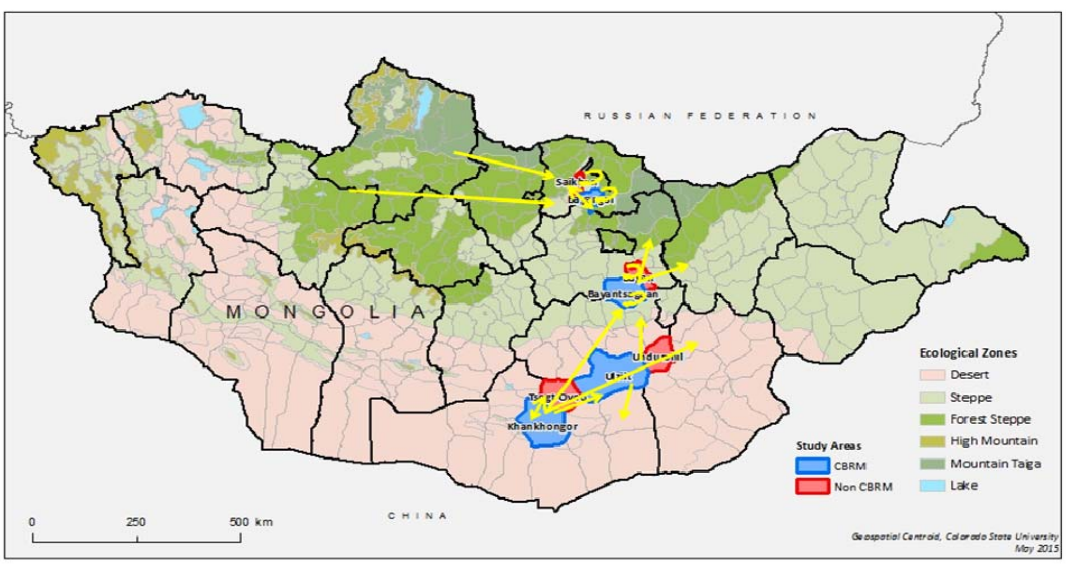

Figure 4. Movement directions of herders in forest steppe, steppe and desert steppe regions. [Map from MOR2]

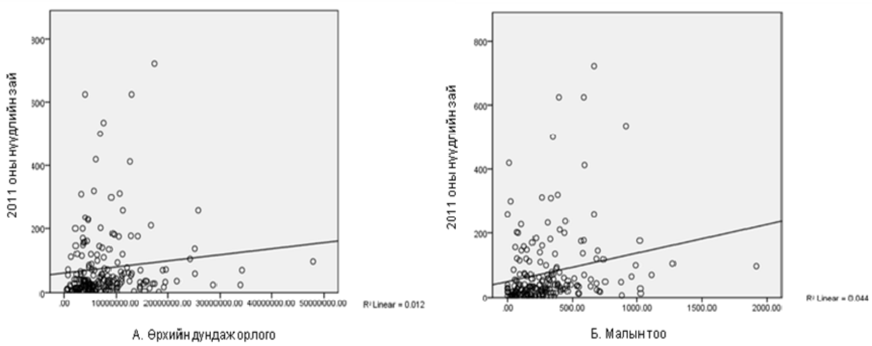

Figure 5. Relation between herders' movement distance in 2011 and a) household income, and b) livestock number.

Evolution of Common Resource Tenure and Governing: Evidence from Pastureland in Mongolia Plateau

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ABSTRACT

Land tenure is to define who hold the land as well as the relationship between tenant and the lord. Most fundamentally tenure and changing tenure is capturing the value of the resource. The nature of the resource and changing relative scarcity are essential to induce or lead evolution of land tenure. Pasture resources have been held in open access and communal tenure for much of the long history on Mongolia Plateau because of the abundant resource with low population density. Historically pasture tenure in this region has been evolving from open and semi-open access to communal tenure (control) to more private ownership, although other forces like political system can only cause temporary departure from the general patterns. Presently the variety of tenure arrangements largely reflects the scarcity of the pastoral resources: Mongolia is still primarily adopting semi-open access with community governing although state is viewed as sole ownership, while Inner Mongolia is more directing privatization of at least the use rights.

Keywords: economic reform, property rights, privatization, community, central planning

INTRODUCTION

A common pool resource can be divided and exclusively to specific owners or users, but is costly to exclude other users from obtaining benefits from its use. Although common resource is often held in communal tenure (a certain group of people can access) to avoid the huge costs of excluding, it can be owned by public or state, or private individuals or corporations, or simply open access. No single tenure is suitable to all circumstances. Pasture has been viewed as a typical common resource for its costly fencing and dividing relative to the land value. The driving forces of the evolution can be from changes in population density, market, grazing methods, economic structure, and political forces among others. Figure 1 illustrates the general pattern from historical perspective. For a long history, pastoral resources had been in communal tenure with various rules of self-governing. The historical evolution and recent economic reforms on Mongolian Plateau provide a good case for the investigation. Understanding how these changes would be important for policy implication.

When population is spare and pastureland is abundant, open or semi-open access or the best in common tenure of tribal group is likely the best arrangement. In open access, the private opportunity cost of pasture is close to zero, the herdsmen are to maximize the rent by adjusting the number of animals. Suppose pasture resource is abundant enough to meet what the optimal size of livestock of the herdsmen's, and still not cause conflict. Not all pasture has the same quality and rents will be determined by the most marginal and open accessed pasture land. When the population is increasing and the resource is becoming scarcer, more pastoral land should be changed from open access to regulated access.

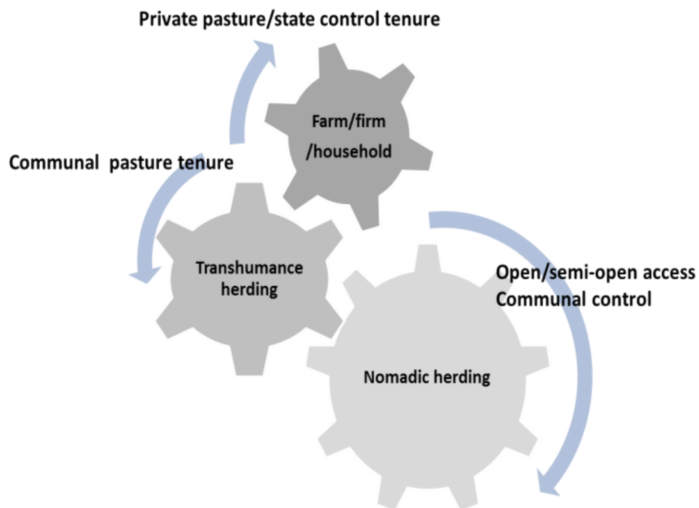

Figure 1. The evolution of herding and pasture land tenure

For the better and regulated pasture, the optimal number will be determined to maximize the rent under given wage. The rent here refers to the value or wealth contributed by the land, while wage refers to best labor income from other activities. If the pasture is also under open access, then more people will flow to the pasture for higher return, and eventually the rent will disappear. In order to protect the land value, some regulation should be introduced, like tribal pasture or other kinds of communal tenure. Not all pasture should be under closed access and most marginal pastureland can be left with open access, only the core and highly valued one should be regulated. Much of the pasture resources for long time had been in communal tenure, like kinship or tribal group on Mongolian Plateau. Pasture with the characters of common resource has its own advantage in communal tenure. For example, the tribe heads provided the protection of the herdsmen (or leadership of the tribal collective action) and set some rules governing the resources from access from other tribes, the herdsmen paid some to the tribe heads.

Privatization does present an important approach: It is when the commons is privatized, divided into parcels, fenced off, and individual responsibility is created. Each herder can now be in full control of the pasture, both the benefits and costs. In fact, most pastureland in developed countries is in private ownership. However, the privatization imposes highest costs of the arrangement. The expected land gain from the land value must justify the costs.

EVIDENCE FROM THE MONGOLIAN PLATEAU

For many thousands of years, the basic herding unit like kinship and tribal group on Mongolian Plateau was at the core of pastoral production and politics. The wealth and power varied from group to group and the leaders of the groups regulated the conflicts within the group and more importantly organized it for defense or aggression against external enemies. Some pastures were protected only use in the winter times, and the rotation and paths of grazing were coordinated, while other resources were in open or semi-open access. The boundary of the ownership was hard and not necessarily clear and well-defined considering the huge space with small population. Fighting for the territory particularly some core resources was normal and constantly throughout the history (Lattimore, 1940).

It was argued that the emerging state among the nomadic pastoralists might not be for the internal needs, but to deal with highly organized sedentary state societies on a continual basis (Burnham, 1979; Irons, 1979). That means open access might not be the major problem. The argument has been supported by the fact that sub-Saharan Africa were the least formally organized nomads were found until colonial period, while Inner Asia had had the most formally organized nomadic societies where closer to China, the world's largest and most centralized traditional sedentary state (Barfield, 1989, p.7). However, when it was established, the nomadic state took advantage of asymmetrical relationships for the military power as mobility (Khazanov, 1985).

Mongolia Empire ruled by Chinggis Khaan (1162-1227) united the nomadic tribes of the Plateau with over some 1 million people. In order to suppress the traditional causes of tribal warfare, he abolished inherited aristocratic titles. "*At the head of nomadic empire there is an organized state let by an autocrat, yet most of the tribesmen within the nomadic polity seem to retain their traditional political organization, which is based on kinship groups of various sizes-lineages, clans, tribes.*" (Barfield, 1989, p.5). Chinggis Khaan also promoted feudalism pasture tenure system. The Empire built by Chinggis Khan was later divided in a few kingdoms ruled by his grant children. It was even more like feudalism society under Qing dynasty created in Manchuria in the mid-1600s. The "Banners" were military-social units, but also feudalism systems allocated by the emperor rather than bribe communal tenure.

Prior to Ming Dynasty in 1641, nomads moved freely across the territory (Linder, 1981). After Ming Dynasty, pastoral territory was re-allocated to groups of tribes, creating administrative units with fixed territory except during harsh winter or draught (Natsagdorj, 1967). Qing Dynasty (1644) further strengthened hierarchy tenure: The emperor had the ultimate ownership, but tribe heads, religion leaders and landlords held the dominate position for pastureland use rights: 1) tribe heads-owned grasslands in the name of the tribe or nation; 2) herd owner leased grasslands, paying some to the tribe or nation; 3) temples and the temple presides took charge of the usage right of the grasslands. It is important to note that not colonization of the Mongolian Plateaus was motivated until Ming and Qing dynasties. The most fundamental economic reason is that the land was too low value and could not generate rent, while the costs required could not justify the owning. The increasing population in Ming and particularly the Qing Dynasties appreciated the land value, particularly the land potentially valuable for agricultural use along the transition zone.

Collectivization and state central planning regime in both Mongolia and Inner Mongolia was really an episode of departure from the general pattern. Central planning was introduced in Mongolia after 1921, the pastoral rights fully centralized into state. Collectivization was a main tool to achieve that goal. Livestock were pooled into collectives by the end of 1950s after years of struggle and violence (1921-1940) (Hibbert, 1967). State decided where to pasture and when to pasture for all collectives livestock. Herders of the collectives were not permitted to immigrate freely without local administrative units. Mongolia was influenced by Soviet Union to become centrally planned economy. In the 1950s and 1960s, pastures and livestock in Mongolia were collectivized. By the early 1960s, Mongolia had completed the dramatic social transformation from the "communal" ownership into more state-controlled collective economy. Herders were forced to sell livestock products to the state at planned price rather than market determined (Fernandez-Gimenez, 1997). Since 1990 after the collapse of the Soviet Union, the economy started to transit from central planning economy to market economy. The livestock was distributed to households, but the pasture resources are still in the state. The incentive of private ownership of livestock has significantly increased the number. Due to the abundant resources and pasture, most of pasture resources are very much in open access although the state is the sole ownership. Only some land close to urban area particularly the Ulaanbaatar was allocated to individuals.

In Inner Mongolia, some dramatic changes in policies have taken place since 1949, first in Cooperative period (1954-1958), followed by the People's commune. The livestock products were allocated through the central planning. Since the early 1980s, the livestock, first, then the grassland, was changed toward privatization. When livestock was privatized, pastureland was in communal without regulation; the number of livestock was sharply increasing in the late 1980s. The driving force changed from production regulated by the state and local government to profit maximization of the each household (Gao et al., 2013). This is exactly the case of open access, and the pasture has been widely over-grazed in the late 1980s and early 1990s. Recent studies show that grassland in IM and MG have had degraded to varying degrees and IM is more serious than in MG (Angerer et al., 2008; Jiang et al., 2006). Unlike the earlier history when population was low and pasture was abundant and open access was not a bad choice arrangement, the unregulated pastoral resource use of the scarce resource in the 1980s was damaging and leading to over-grazing immediately. Dividing the pasture with enclosure was induced to prevent the open access since the mid-1990s. Regulation and limiting grazing intensity was called upon by the central government, and a grassland restoration policy enacted in 1998-1999. Several stages of compensation have been implemented across the region.

DISCUSSION AND CONCLUSIONS

While there is no single tenure would be suitable to all circumstances. Variety of scarcity is the most fundamental force in determining the tenure. The great disparity can be found not only between Mongolia and Inner Mongolia but also with each region. More valuable resources like winter pasture or closer to population center had more specific rights and were subject to more regulation, while remote and marginal pasture were left with open and semi-open access. The evolution has generally been evolving from open access to communal control and finally to private control and management. Today the least populated in Mongolia is still open or semi-open access, but more populated area is becoming to subject more regulation.

The centralized pastoral land tenure in Mongolia and Inner Mongolia from the 1940s to 1980s were departure from the general pattern of the evolution and has been proved less efficient and not effective in pastoral resource use and protection. Current reforms taking place are retreating back to match economic development, new technology and productivity. What tenure we should adopt still depends on the relative scarcity. You can simply get or rent the resources with very little costs (a few cents of US dollars per ha per year): open and semi-open access is still the best arrangement. However, some pastoral resource is becoming very valuable in Inner Mongolia and the rental costs can go as high as annual $30 per ha based on our investigation and household survey in 2014. Open access will cause the rent dissipate.

The pastoral resources have a bundle of rights. In order to capture the value from pastoral land, each right can have its own arrangement. Private owners know best of their management to capture the grazing value, but might not consider its externalities. For example, as grassland has been becoming important in providing ecosystem service which are in the nature of public goods, centralized some pasture resource would be a better arrangement if the market mechanism for ecosystem services like ecosystem service payments have not been developed. Recent policies have been proposed in Inner Mongolia to use ecological compensation to the owners who provide the services and the benefit receivers in other regions. In sum, the variety of value from the grassland largely determines the tenure designed to better capture the value. Changing value should promote to changing property rights arrangement or complementary policies.

ACKNOWLEDGEMENTS

This work was conducted with financial support from the NSF-CNH project "*Ecosystems and Societies of Outer and Inner Mongolia.*"

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To Fence or Not to Fence? Perceptions and Attitudes of Herders in Inner Mongolia

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ABSTRACT

The most important part of recent grassland tenure reforms in Inner Mongolia has been to divide the collective grassland to household level, then fence and enclose grassland. Fencing is a form of strongest signal of private property right and aims to exclude over-boundary grazing, attempting to solve “tragedy of the commons” from open access. Fencing gives herders a “user right”, though ownership still resides at a village level. But fencing significantly limit animal and herdsmen mobility critical to the pastoral society and coupled natural and human systems. The “dilemma of enclosure” has become a key debated issue of grassland management. Positive and negative effects have been widely discussed, but few empirical studies have been conducted into this dilemma. Ecologists in general believe fencing would negatively affect the integrated ecosystem and seasonal rotation of herding. In contrast, economists think the fence would avoid the “tragedy of the commons” and create an incentive to protect herders own resources. Economists also understand that fencing would reduce the scale of economy and fencing itself is costly. After reviewing current fencing policies and the scale of the fencing activities in Inner Mongolia, we surveyed the effects of existing fencing policies and their impact on herdsman households to evaluate herders’ attitudes and perceptions towards fencing.

Keywords: fencing, grassland management, land tenure reform, Inner Mongolia

INTRODUCTION

In recent years, transformation to privatization of grassland use right has become a driving policy for economic reform in rural areas of developing countries. Since 1978, both political and economic reform has been progressively introduced across China, including vast grasslands of Inner Mongolia (IM). HPRS (Household Production Responsibility System) was the main policy change. The goal of this policy is to promote rural household production by the incentive of a semi-private property right reform mainly the user right. Livestock and buildings have been divided and allocated to individual first, while individual households have not been granted user-rights to land until mid-1990s. Herdsmen now manage grasslands based on their own interests and demands. As a result, a “double contract HPRS” was implemented, meaning the contract for herds and grassland (Li et al., 2007).

Under such a property right system, fencing is the signal of private property right and aims to exclude cross-boundary grazing. By clearly claiming the use of the land, herd mobility is limited. The “dilemma of fences”, as some scholars would state, has become a key issue of grassland management, an elementary component in common-pool resource (CPR) problems. Especially in developing areas, the consequences of such a dilemma can have great effects, mainly on negative side. As a result, it is necessary to assess fence policy and examine the effects in these areas as more lands are fenced, with wire and concrete posts. At the same time, some supplementary policies were also introduced, like grassland monitoring stations within the local Animal Husbandry Bureaus, to regulate stocking rates.

Is dividing the grassland really bad for grassland management? The herdsmen know best. We surveyed herders to assess their perceptions and attitudes towards fencing. We believe that herders have the best knowledge of the policy, and their judgements would have significant policy implications for future reforms as well as for pastureland policy in other regions and countries.

LITERATURE REVIEW

There exists debate about whether dividing grassland would be beneficial or not. Williams (1996) argued that although the aim of de-collectivization was to yield maximized pastoral productivity, dividing grasslands into individual-owned parcels had the opposite effect, causing severe degradation, and suggested that other institutional changes like more stable land tenure and equal change of entering common resource for every community member would work better than simple privatization. Unanticipated outcomes, which conflict with the policy’s original purpose, to increase grassland productivity, were also observed by Taylor (2006). Li et al. (2007) argued that semi-private ownership (meaning group-held private rights) in grassland would bring more benefit than the current HPRS, under which it is privatized ownership. At the same time, grassland degradation was observed in areas where HPRS was applied. Similar negative ecological impacts of dividing and fencing grasslands for private use occurred where fences created boundaries leading to poor ecological performance in the face of dramatic climate change (Li and Huntsinger (2011). The inflexible boundaries, pasture movement, which was considered effective in fighting disaster, would lead grassland ecology more damages. Ying and Ruimin (2011) argued that losing mobility would lower the response against urgent situations, which would increase vulnerability facing disasters or droughts. Yan and Wu (2005) demonstrated that privatized land tenure with uneven water resource distribution had lowered the water table and changed the landscape in a study of ecological damage in the Eastern Tibetan Plateau. Li (1993) argued that fencing was proven to have negative effects on biodiversity, causing grassland degradation on fixed grazing grasslands. Fencing might also bring negative impacts on alpine wildlife, increasing the death rate, so we need to examine our current livestock management practices for wildlife conservation in plateau areas (Thwaites et al., 1998; You et al., 2013). Borer et al. (2014) showed that fencing did not consistently affect diversity and biomass on grasslands based on evidence of most recent finding.

In the 1950s, high expenses of fence and loss of production were the major concerns in fencing implementation (Gardner, 1950). In recent studies, it was shown again that fencing was too expensive to be widely accepted: more than 70% of the respondents could not afford the fencing cost (Li et al., 2007). However, Banks et al. (2003) argued that community-based management can reduce the fencing cost, and showed that such management has significantly affected the herdsman livelihood security positively from asset composition and food consumption with more than 10 years of "*Fencing grassland, forbidding grazing and moving user*" policy implementation. Also, such policy helps to restore grasslands (Xu et al., 2012). Fencing in desertified areas could increase the land stability, but will not increase herders' incomes (Wu et al., 2009). Researchers also noted fencing would affect on herders' traditional lifestyle (Zhizhong and Wen, 2008). In privatized grasslands, fencing would rupture the traditional and non-substitutable ecological and cultural functions brought by nomadism. As a result, we should give up fencing, to resume nomadism. Evidence is also shown through the comparison between fenced and non-fenced communities. According to Cao et al. (2011), "*Multi-household management pattern (MMP)*", in which there is no fences would bring more economic benefit than "*Single-household management pattern (SMP)*" because it requires less production costs, while SMP was more likely to cause grassland degradation. Fencing also has impacts on herder demographics. Fencing would greatly reduce men's participation in grazing, making more women and children involved, which could reduce schooling (Richard et al., 2006). What's more, fencing would lower the equity of access pasture (Yangzong, 2006).

DATA COLLECTION

The above review is based on academic research. Is dividing the grassland really bad for grassland management? We conducted a survey in summer 2013 using face-to-face interviews. Questionnaires were written in Chinese and finished by respondents individually at their homes. Most of the questions are closed-ended and few are open-ended. For those who were unable to understand Chinese, interpreters were there to help for the translation. We surveyed 44 households in 3 prefectures (Leagues): Xilin Gol, Ulanqab, and Chifeng by random selection. The survey questionnaire includes respondents' satisfaction about the fence.

RESULTS

The results are presented in Figure 1, Figure 2, and Figure 3. Based on our survey, nearly all of the respondents (91%) have wire fences to demarcate their private grassland. However, not all herders graze inside fenced areas. The fenced grazing is not the dominant method of grazing even though most people have fenced areas. While over 57% of respondents apply rotational or fenced grazing, about 17% still live on pasture or practice other forms of unrestricted grazing (these herders do not have targeted area for grazing), where the results are shown in Figure 1a. Interestingly, we notice that 26% of respondents are raising their livestock in barns. This finding suggests that loose grazing on grassland is no longer the major way of livestock husbandry. Herdsmen are getting more involved in barn feeding. According to Fontaneli et al*.* (2005), barn feeding would bring more livestock product yield, and then increase herders' income if fodder price is low.

As seen in Figure 2a, only 16% of respondents consider seasonal grazing is the optimal option. What's more, controlling grazing intensity (43%) is as important as fencing for better usage of grassland resources (41%). If we combine maintaining appropriate grazing intensity and fenced grazing with rotations it would be is the optimal way of effective grazing. Relating this finding to the question above, the expected optimal grazing method corresponds with their current grazing method, which shows herders are generally satisfied with their current fenced grazing. About two third of the respondents believe that combined fencing and prohibiting grazing is the best way to restore degraded grasslands (see Figure 2b). Such finding corresponds with the commonly accepted fencing effect about recovering degraded grassland. Few people would agree that replanting grass seed or prohibiting grazing is the best solution. To fence is best solution in excluding people who are still pasturing or unrestricted grazing from entering degraded areas. We should also notice that 18% of the respondents claim that there is no way to restore degraded grasslands.

Unlike other findings about the major concern in grazing, we found that more than half of the respondents consider water quality (57%), which is measured by the availability of clean water for herds, is the primary issue in grazing, while overgrazing only accounts for 23% (Figure 3). Traditionally, people would consider seasonal and rotation grazing as the main tool to control overgrazing. But in recent years, with more and more fixed property rights in both residence and grazing, fencing is becoming more widely accepted. Since overgrazing is not the primary issue, people would have less interest in building fences than pursuing steady and reliable water supply for herds. Such finding corresponds with Thwaites et al. (1998) who claimed that one of the major threats brought by fencing is lowering water supply. If we separate grassland into fixed parcels, it would increase the distance of collecting water and thus increase the watering cost. Five percent of the respondents were concerned about under grazing, which is rarely seen in other studies about IM region.

Seen from Figure 1b, more than 54% of all respondents have not changed their grazing method during the past 10 years. For those who had changed, there is a tendency of unregulated grazing to regulated or restricted grazing. However, the survey does not provide us information about whether such changes were voluntary or forced by government.

CONCLUSION AND DISCUSSION

The survey did find that most people had fences, and the herders in general are in favorable to supporting the pastureland reforms which divide the communal pasture into household and using fencing, regarding that fencing is the only alternative under current system. It is considered useful to divide and fence their land to recover degraded areas. The results significantly depart from most literature that sees negative sides of dividing and fencing the grassland. One reason is that the herdsmen are adaptive such as combing loose grading and barn raising with forage and other feed. It seems that water would be another major problem from the dividing pasture resource, and alternative solutions should be investigated. The question is why is overgrazing still occurring on the private and fenced grassland owned and used by each household. The potential reason could be from time preference from poverty or poorer precipitation as expected. All these questions are worth to investigate for better policies in the future.

ACKNOWLEDGEMENTS

This research was supported by the NSF project "*Ecosystems and Societies of Outer and Inner Mongolia*".

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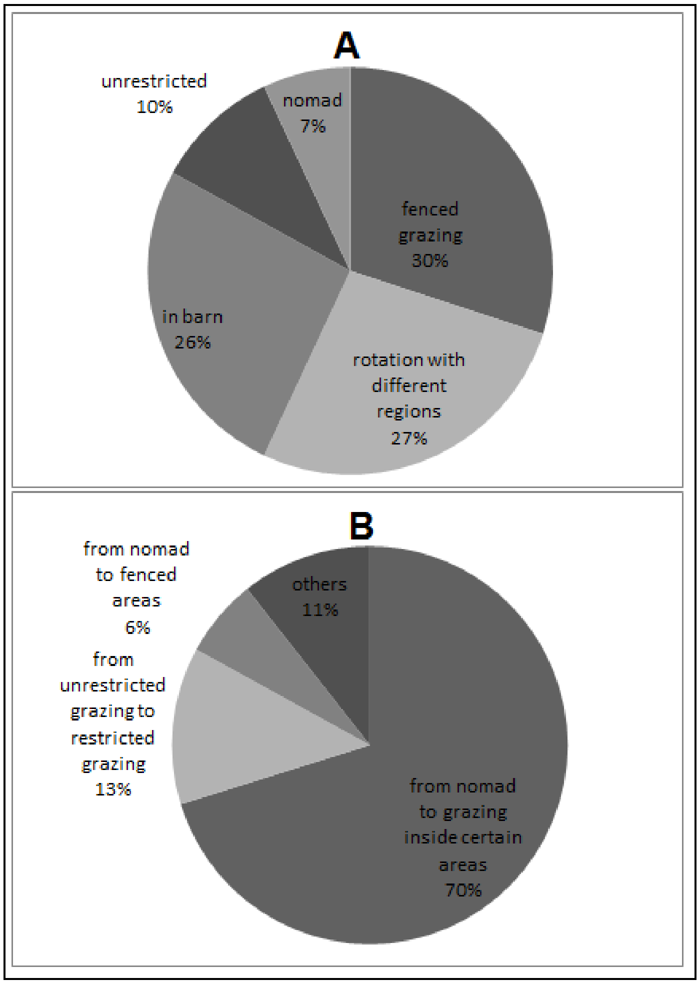

Figure 1 The structure of a) current grazing methods, and b) grazing method change during recent 10 years. Note: **Unrestricted grazing**: herders would graze wherever they want, although private boundary was clearly defined; **Restricted grazing**: herders would only graze inside their own properties; **Nomad grazing**: herders would graze whenever their herds were

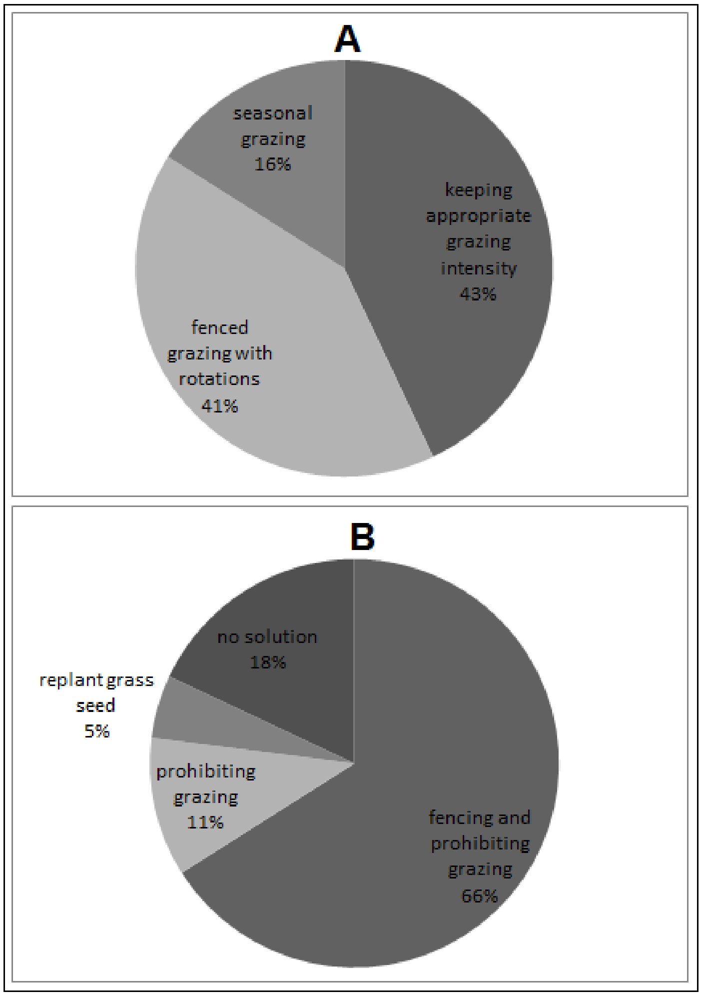

Figure 2. The comparison between a) best way of effective grazing, and b) best way to recover degraded grasslands.

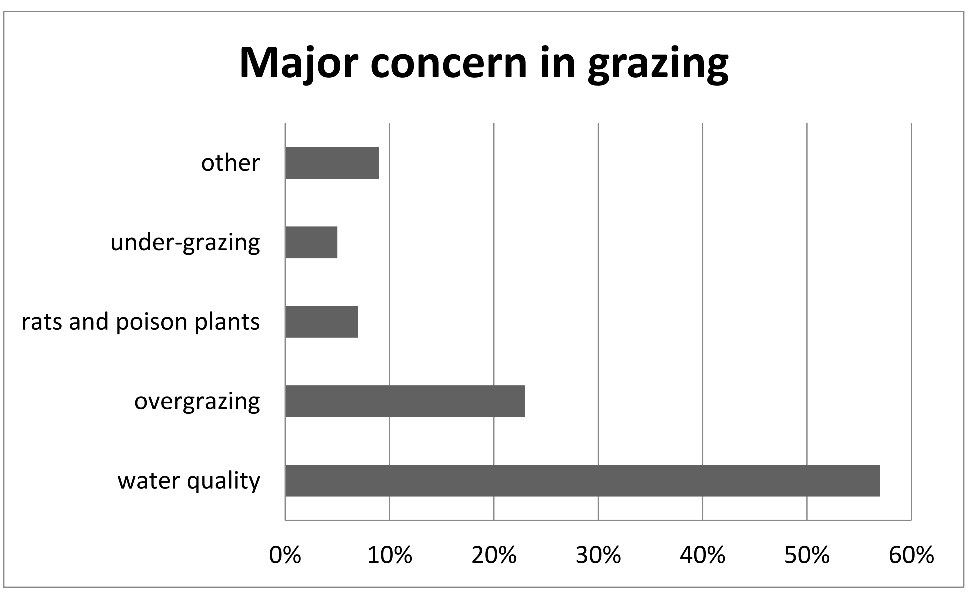

Figure 3. Major concerns in grazing on grasslands.

4 Social and Economic Development in Rural Mongolia

Implementation of Green Development Policy Based on Vulnerability Assessment: Khovd *Aimag's* Case Study

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ABSTRACT

In 2014 the Mongolian parliament approved the Green Development Policy. Out of 21 *aimags*, Khovd, Arkhangai, Uvurkhangai, Khentii and Bulgan *aimags* set an objective of prioritizing green development on their local level. This paper is based on the project "*Conducting environmental and social vulnerability research of soums in five aimags leading in green development and developing strategy recommendation*" and it is written using Khovd *aimag* as a case study. Here, in Khovd *aimag*'s 17 *soums*, we evaluated eight variables including drought-*dzud* index, vegetation index, preventable livestock loss, prepared hay and fodder, pasture use index, degree of desertification, land degradation and surface water loss, allowing us to make an integrated assessment of ecological vulnerability. According to our analysis, the Gobi desert steppe region was defined as most vulnerable among environmental zones, and out of a total of 17 *soums* Altai, Uyench, Zereg, Chandmani and Duut *soums* were defined as most vulnerable, followed by Must, Darvi, Munkhhairkhan, Mankhan and Myangad *soums*. There is a need to give top priority to the planning and implementation of green policy in these ecologically more vulnerable soums by increasing their "green" budget. This will allow them to develop their capacity to adapt to climate change, decrease their vulnerability, to conduct optimal management of pasture use and have targeted preparation of hay and fodder.

Keywords: drought-*dzud*, vegetation, livestock loss, pasture use, desertification, land degradation, surface water loss, ecological vulnerability

INTRODUCTION

Climate change and the consequent natural disasters, such as drought and dzud, as well as shortages of natural resources, ecosystem deterioration and desertification are an increasingly negative influence on the economy, society and human development of Mongolia. According to the drought and dzud surveys, in the 70-year period between 1940 and 2010 droughts increased in intensity by 2% per each year across the country, and in the 20-year period between 1990 and 2010 occurrences of drought in summer and *dzud* in the subsequent winter increased by 0.6% per year having negative impact on citizens livelihood and stability of the society (Altanbagana and Davaanyam, 2011).

As over 50% of the gross domestic product of 14 *aimags* out of total 21 consists of agricultural products, making those *aimags* socially and economically dependent on their natural environment and more vulnerable to climate change (Altanbagana, 2013). As for population distribution, 32.8% of total inhabitants of Khovd *aimag* live in rural areas. 74% of rural population in 16 soums of this aimag are located in countryside, while remaining 26% live in *soum* center (NSO, 2015).

Therefore it is necessary, at both the *aimag* and *soum* levels, to protect and efficiently use natural resources, take measures to reduce ecological degradation, increase green employment and develop local areas with green development approaches which strengthen the capacity of adapt to climate change.

In this research we evaluated relevant environmental variables, indexing them and conducting an integrated assessment of the ecological vulnerability of 17 *soums* of Khovd *aimag*. Research results provided an opportunity for the local authorities to plan and implement spatially diverse green development policy for reducing ecological vulnerability in these *soums*.

STUDY AREA

Seventeen *soums* across different ecological zones in Khovd *aimag* were involved in our research: Buyant, Darvi, Durgun, Jargalant, Zereg, Mankhan, Myangad and Chandmani *soums* located in the great mountain chain lowland; Duut, Munkhhairkhan, Must, Tsetseg, Erdeneburen and Khovd *soums* located in the mountain steppe; and Uyench, Altai and Bulgan *soums* located in the Gobi desert region.

STUDY METHODS

Vulnerability as defined by Adger (2006) is “the state of taking stress or damage caused by environmental and social changes beyond the capacity to adapt or the state of being harmed from exposure to stresses associated with environmental and social changes”, and as described in the Mongolian National Human development report (UNDP, 2011) it is “associated to ability to cope with shocks caused by risks of being exposed to social fragility and vulnerability, and by other internal and external factors”.

Based on the results of research conducted on Bayankhongor *aimag’s soums*, Altanbagana (2013) concluded that “*vulnerability of a given system is a ground condition leading to risks, and when the vulnerability eventually increases to reach certain threshold it entails risks*.” In the process of assessing ecological vulnerability in each of Khovd *aimag*’s *soums*, eight variables were considered.

Drought and dzud (black and white) index was estimated using a weather data array from the period between 1995-2013, specifically data from the summer months of May, June and July and winter-spring months of November, December, January and February. Assuming that temperature data alone is not sufficient to characterize winter and summer conditions, we made estimations similar to the normalized temperature and precipitation slope differentiation or Ped’s (1975) index, using Altanbagana’s (2013) approach of adding black *dzud* to drought-*dzud* integrated index using the estimation method of Natsagdorj and Sarantuya (2003).

Natsagdorj and Dulamsuren (2001) reported biannual occurences of black *dzud* in the Gobi desert region of both the Gobi and Western aimags of Mongolia. During a black dzud livestock are usually crowded around wells or patches of water which freeze late in winter, and they often lose their strength and fatness in a short period of time due to rangeland trampling, separation from water supply and being driven to search for water, and this combined negatively influences the stability of the animal husbandry sector. Due to livestock trampling and other environmental factors such as wind, spring vegetation following the black *dzud* lacks essential moisture, which in turn impacts rangeland ecosystem resilience and thus causing more vulnerability (UNDP, 2011).

Vegetation index. Average values for the annual vegetation index were calculated using vegetation data of May to October of each year for the period between 1998-2013, collected at 10 days intervals by SPOT satellite Normalized Difference Vegetation Index (NDVI), with a 1 km-resolution. In calculating the vegetation index, NDVI value of separate soums cannot alone provide sufficient condition to vulnerability assessment. NDVI value can be high in some soums where rangeland production is abundant due to the specifics of the local environment, weather and ecosystem. At the same time NDVI value can be low in Gobi desert soums where vegetation is reduced or rangeland produce is low, while vegetation increase trend may be seen there. Therefore we considered both multiyear average NDVI values, and the angle coefficient of the linear trend equation of NDVI change for the period of 16 years, which expressed trends of decreasing and increasing vegetation in the given soum.

Pasture use index was estimated using livestock number data from 1990-2013, by performing a normalized comparison between livestock number per unit of hectare of the given *soum*'s rangeland (unit of sheep/ha) and rangeland capacity. Excess livestock numbers in the given soum over the rangeland capacity can negatively impact rangeland ecosystem causing vulnerability.

Land Degradation and Desertification Index. Based on the "*Desertification Atlas of Mongolia*" (IGE and EIC, 2013) we used desertification, land degradation, damage and degradation assessment maps and results. In each soum we estimated the percentage of the total area ranked as having very strong, strong and fair desertification. Stronger desertification rate in the *soum* is predicted to lead to a loss of ecological stability.

Surface Water Loss Index was estimated using the report of "*National Water Census*" (MEGDT, 2011). Higher rates of loss and a shortage of surface water in the given soum was predicted to increase the ecological vulnerability. This estimation was done by comparing the number of dried up surface water bodies, such as rivers, streams, springs and ponds with the total number of water bodies, transferring the expressed percentage value into an index.

Preventable Livestock Loss was calculated by comparing the number of preventable livestock deaths (sheep unit) of the given year with the total number of livestock (sheep unit) counted at the end of previous year, expressed as a percentage. Livestock is the basic source of soum level population livelihood and the main reason for preventable livestock loss is the impact of drought and *dzud*.

Prepared Hay and Fodder was calculated by comparing total amount of prepared hay and fodder (NSO, 2015) in the given *soum* to total number of livestock (tons/sheep units). Lower rate of prepared hay and fodder per unit of livestock in the given soum makes it ecologically more vulnerable. Basic conditions for sustainable pastoral animal husbandry are favorable summer grazing conditions, rangeland ecosystem productivity and sufficient preparation of hay and fodder for wintering use. In the present time of increasing intensification of drought and dzud cause by climate change (Altanbagana and Davaanyam, 2011) preparation of natural and targeted hay and fodder is one of the factors for reducing vulnerability to these threats. We used the data from hay and fodder preparation in each *soum* in 2010-2013.

Data analysis

The following formula was used to normalize each variable estimated in ecological vulnerability assessment, for the purpose of integrated evaluation, the value was distributed to the same number intervals and transferred into index value.

$$\Delta X_{t,i}^{norm} = \frac{\Delta X_{t,i} - \Delta X_{\min}}{\Delta X_{\max} - \Delta X_{\min}}$$

Here $\Delta X_{t,i}^{norm}$ is the normalized value of the given variable, where *i* is number of *soum* and *t* is time period; $\Delta X_{t,I}$ is the value of the given variable, where *i* is number of *soum* and *t* is time period; ΔX_{min} is the minimum value of the given variable; and ΔX_{max} is the maximum value of the given variable.

RESULTS

The results of evaluation of variables estimated in ecological vulnerability assessment, according to *soums*, are shown in Table 1. Of the 17 *soums* of Khovd *aimag*, the Gobi desert *soums* of Bulgan, Uyench and Altai recorded the highest drought–dzud index, and these *soums* had very high preventable animal loss. Duut, Chandmani, Altai and Durgun *soums* had the lowest index of prepared hay and fodder per unit of livestock. According to the value of the vegetation index, the Gobi desert regions of Uyench and Altai, and the mountain steppe Chandmani *soum* were more vulnerable with regard to vegetation, while in terms of rangeland use, Bulgan, Uyench, Mankhan, and Khovd *soums* showed an excess of livestock number per unit hectare over the rangeland capacity. While Durgun, Darvi and Myangad *soums* are more at risk of desertification, Darvi, Munkhhaan, Tsetseg and Uyench *soums* are more at risk of land degradation and deterioration. Duut *soum* has higher surface water loss record (MNEGDT, 2011).

Table 1. Ecological vulnerability assessment by *soums* of Khovd *aimag.* Note: * 0-0.20 very low, 0.21-0.40 low, 0.41-0.60 medium, 0.61-0.80 high, 0.81-1.0 very high

№	*Variable index component of vulnerability* *	**Soums of Khovd *aimag***																
		Great mountain chain lowland							*Mountain steppe*							*Gobi desert*		
		Buyant	Darvi	Durgun	Jargalant	Zereg	Mankhan	Myangad	Chadnmani	Duut	Munkhhairkhan	Must	Tsetseg	Erdeneburen	Khovd	Uyench	Altai	Bulgan
1	Drought-dzud	0.01	0.64	0.01	0.01	0.64	0.57	0.01	0.73	0.64	0.64	0.64	0.64	0.01	0.01	1.00	0.67	1.00
2	Vegetation	0.50	0.42	0.60	0.50	0.44	0.47	0.35	0.54	0.32	0.44	0.43	0.34	0.24	0.21	0.68	0.56	0.45
3	Pasture use	0.44	0.01	0.21	1.00	0.58	0.61	0.57	0.34	0.11	0.14	0.55	0.47	0.57	0.61	0.70	0.28	1.00
4	Land degradation	0.01	0.88	0.19	0.04	0.43	0.37	0.02	0.43	0.06	0.64	0.41	0.64	0.02	0.01	0.52	1.00	0.22
5	Desertificatio n	0.32	0.70	1.00	0.43	0.37	0.20	0.63	0.29	0.17	0.13	0.05	0.29	0.19	0.01	0.08	0.20	0.16
6	Surface water loss	0.01	0.01	0.01	0.01	0.01	0.01	1.00	0.01	0.56	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7	Preventable livestock loss	0.23	0.61	0.74	0.07	0.55	0.43	0.40	0.58	0.42	0.53	0.45	0.01	0.51	0.27	0.92	1.00	0.76
8	Prepared hay and fodder	0.52	0.88	0.92	0.84	0.81	0.85	0.75	0.96	1.00	0.77	1.00	0.89	0.84	0.51	0.70	0.91	0.01
Combined evaluation, by soums		**0.10**	**0.23**	**0.19**	**0.12**	**0.32**	**0.28**	**0.23**	**0.31**	**0.29**	**0.25**	**0.24**	**0.19**	**0.11**	**0.06**	**0.33**	**0.34**	**0.18**

According to our ecological vulnerability assessment most of the *soums* in Khovd *aimag* are in an ecologically vulnerable condition, with the Gobi desert *soums* of Altai, Uyench, Chandmani, Zereg and Duut being the most vulnerable. The ecological vulnerability of Erdeneburen, Buyant, Khovd and *aimag* center Jargalant *soums* are relatively low (Altanbagana et al*.,* 2015).

DISCUSSION

As reported by separate assessment of the total of eight environmental variables and an integrated evaluation of ecological vulnerability, Altai soum was shown to be the most vulnerable due to the highest drought-*dzud* index, preventable livestock loss and land degradation, and the lowest rate of hay and fodder preparation. The basic factor of preventable livestock loss is the intensification and increase in frequency of drought-dzud. It is possible to decrease preventable livestock loss by sufficient preparation of hay and fodder. As for Uyench *soum* the drought-dzud index, preventable livestock loss and rangeland use is high, but the rate of hay and fodder preparation is low. Also Zereg and Chandmani *soums* had lower rate of hay and fodder preparation, higher rate of drought-*dzud* index and lower rate of vegetation. Most of *soums* had low index of surface water loss, which is associated with abundant rainfall in recent years.

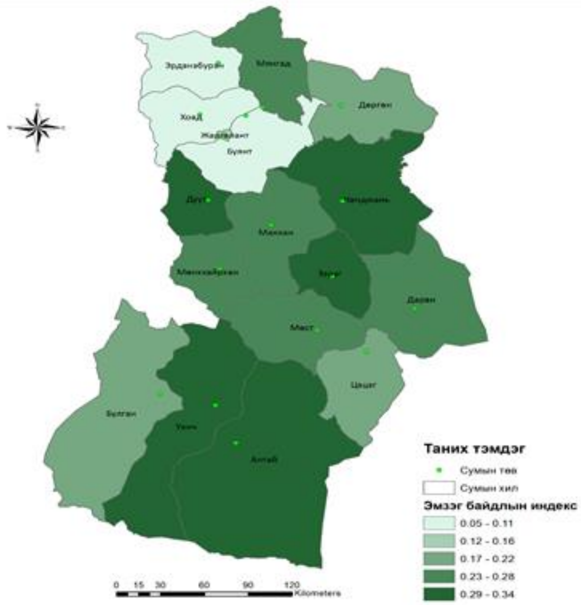

Figure 1. Ecological vulnerability assessment Khovd *aimag*

IMPLICATIONS

These research results provide the opportunity, based on a vulnerability assessment, to implement spatially different green development at the *soum* level. Variables that cause vulnerability differ from in different ecological regions.

Within Khovd *aimag*, Duut, Chandmani, Zereg, Uyench, and Altai are more vulnerable than the others and there is a need to give priority to planning and implementing policies and measures aimed at climate change adaptation capacity building and reducing vulnerability in these *soums*. For the soums with a higher drought-dzud index, there is a need for seasonal rangeland rotation and adjusting the number of grazing livestock to match the rangeland capacity. For *soums* with poor rangeland conditions that limit natural hay preparation, there is a need to give priority to measures of climate change adaptation capacity building by enhancing targeted hay and fodder preparation and increasing the *soum*'s green budget.

In *soums* with high exposure to vegetation decrease, desertification and land degradation, there is a need for technical and traditional measures to reduce land degradation and combat desertification. These can include generating local sustainable land management practices, taking degraded land into localized special protection, and limiting or prohibiting some specific activities in the areas with severe soil degradation and desertification for up to 5 years, according to the relevant legislation.

ACKNOWLEDGEMENTS

We would like to express our gratitudes to the Ministry of Environment, Green Development and Tourism of Mongolia for supporting this policy research project.

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Early Warning System for Pastoral Herders to Reduce Disaster Risk by Using a Mobile SMS Service

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ABSTRACT

Herders in Mongolia are directly affected by climate change impact more than urban residents. This research project is developing an early warning system to prevent disaster risk by using mobile SMS services based on the partnership between a scientific research group, local policy makers, industrial technology developers and support of pastoral communities. The mobile message based forecasting system has included common weather information, forage information and other local requested information and been delivered in current time since August 2013 in a case study in Biger *soum* of Gobi-Altai province, Mongolia. After the system had been implemented 98% of participants agreed they had improved knowledge about adaptation to *dzuds*, understood the importance of information access, found it was manageable for their daily job and believed it would help reduce impacts of climate disasters.

Keywords: Information delivery, SMS, *dzud* risk management, adaptation

INTRODUCTION

Global climate change is a great challenge to Mongolians and requires adaptive solutions for nomadic herding systems to cope with natural disasters of drought and winter extreme *dzud*. The traditional nomadic herding system (*hot ail*, *otor*) has changed a lot due to privatization of livestock, affecting the mind of herders, education of young herders, support of community groups, information sharing mobility for herders, pasture management policy from government and the livestock market system in local areas, all of which play important roles in the herding system management.

Herders in Mongolia are directly affected by climate change more than urban residents. The herders' livelihood is dependent on seasonal climate difference, weather conditions and landscape resources of vegetation, water, natural zones, and soil productivity. In the winters of 1999-2002 and 2009-2010 Mongolia experienced the most severe serious *dzuds* (very heavy winter with heavy snow cover, cold temperature and no forage). A resilience building project to enable better adaptation to climate change by herders has been initiated in a case study area to enable various practices to be tested (Suvdantsetseg et al., 2014).

Biger *soum* located in the Gobi Altai province of Mongolia, experienced large losses of livestock during the *dzud* events in 1999-2002 and 2009-2012. In 2002, the area experienced heavy snows from early to middle February with snow depths from 0.8-1.3 meter, and severe cold temperature that were below -35^{0}C. During this event, most of the big animals (horse and yaks) froze to death in the mountain pasture and small livestock either froze or died of starvation due to snow cover preventing any grazing. There was limited weather forecasting. During this *dzud* local government had no systems in place to help the herders. Biger *soum* has no fodder fund, nor storage of hay, fodder and forage to deliver to herders as the first phase in a national response. Herders relying on traditional knowledge did not think the winter would be so hard and they did not get any early warnings of the *dzud*. Consequently the herders did not sell any extra animals, in part because of poor access to markets, nor prepare in other ways for a *dzud*.

Herders have not been provided with information on how to adapt to severe conditions by managing pasture carrying capacity, nor optimizing livestock numbers and quality. This *dzud* identified the need for information access as a critical part of climate change adaptation to these tough seasons. A national herding information access system can be built on the new technologies now available (more people have mobile phones). In addition training programs can be linked to this system to provide information to herders on adapting to adverse seasons.

Several organizations are now producing information related to forages and pasture carrying capacity (Livestock Early Warning System [LEWS] project 2013), and training herders (Leveraging Tradition and Science in Disaster Risk Reduction in Mongolia [LTS] project 2013 by Mercy Corps and Radio and TV weather forecasting National Agency Meteorology and the Environmental Monitoring (NAMEM). However the information now delivered does not get to the herders in words they clearly understand.

The main objective of this research was to develop an early warning system for adverse climatic events by using mobile SMS services to provide herders with information to improve awareness of weather conditions and to help herders minimize impacts of drought and winter disasters.

METHODS

This research project (started in 2012) used a mixture of quantitative and qualitative methods to develop and test a national herd information access system that included: preliminary survey by interviews with herders and local governors, demonstration workshops, focus group discussions, questionnaires, photo observations, online feedback system (SMS receiving system) and online teaching to design a national herd information access system and then tested that system for information delivery in a case study *soum*. The below steps were followed:

1. Preliminary survey conducted with herders and local governors to identify their system requirements of *dzud* adaptation options and needs of scientific data for decision support. This survey included 7 *soums* of Umnugobi province, 8 *soums* of Gobi-Altai province and 3 *soums* of Tuv province in 2012. While we identified that an early warning system development were required to develop in Mongolian pastoralists' disaster management. The interviews in 2012 identified that 92% of respondents wanted an early warning system, 99% could not access information on daily basis, and 78% wanted capacity building to train herders in traditional and new knowledge (Oba et al., 2014).
2. Then we started to develop the technical system design that resolved to structure the delivery of information into three parts: Weather data - daily maximum and minimum temperatures, precipitation, wind speed; Forage information – herbage mass kg dry

matter/ha; and local social information based on the herders' interest. Other aspects of system design identified the need for a database, device applications and interface design and then presentation to end users considered the targeted customers, and timing and frequency of information.

3. An investigation of information availability was conducted and the most credible data sources were found to be the Norway meteorological institute open source data for weather forecasting information (http://www.yr.no/place/Mongolia) and the Texas A&M University open source data for forage forecasting information (http://glews.tamu.edu/Mongolia).
4. Partnership for the delivery of the system was formed between the operating company, system developer and local government. A contract was established between MobiCom corporate, the National University of Mongolia and Keio University to delivery mobile SMS messages at a cost of 15 tugrug per message to all MobiCom users in Mongolia. We extended partnerships in 2014 to G-Mobile corporate and the National Development Institute of Mongolia.
5. The system test was implemented in Biger *soum* after users had received training in August 2013. In a survey after the system implementation were conducted the online feedback system that is how system useful to improve awareness of *dzuds*, how to use the data delivered, and how useful for decision makers and business mans. We received the customer's comments by SMS reply system which could see in online MobiCom account to evaluate the case study of the system.
6. In order to expand the early warning system in the other cities not only in Gobi-Altai but also other Mongolia cities we organized demonstration workshops and onlite training. Demonstration workshops were held in the 7 *soums* of Gobi-Altai province in August 2014 where users were suggested to use different mobile operators based on their local capability: G-Mobile in Khukh Morit, Darvi and Jargalan *soums*; MobiCom in Sharga, Ysunbulag and Biger *soums*; and Skytel in Chandmani and Erdene. Online training on "The importance and usage of information system to prevent disaster risk via SMS service" was organized in cooperation with Mercy Corps International at 5 regional centers of Mongolia 4-5 September 2014.

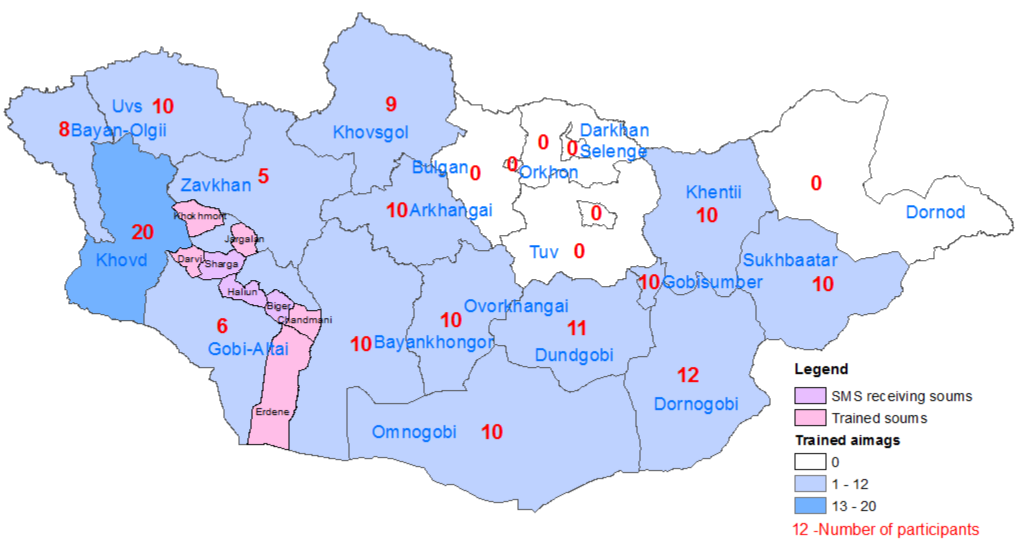

Figure 1. Implementation map of the Early Warning System for disaster risk reduction.

Case study *soum*

Biger city is located in the Gobi-Altai province of south western Mongolia, an area remote from large economic and population centres. There are 5 villages (*bagh* in Mongolian) governed by this city. Biger region covers an area of 3730 square kilometres, with 2249 inhabitants (male 1143, female 1106), 635 stakeholders and 130000 numbers of livestock. The local climate is continental harsh, semi-arid, and salty (Namkhaijantsan, 2006). Summer annual average air temperature is about 25°C, sand soil surface temperature is 45-60°C, annual precipitation is 73mm, and sunshine is 3103 hours/year.

Biger town is an important communication network centre at the meeting point for access roads from other southern towns to the centre of Gobi-Altai city. Mobile phone operators have infrastructure in the town and service 1150 MobiCom and 350 UNITEL users. 24% percent of the population live and work in the town centre, the rest are involved in the pastoral herding industry in neighboring and remote areas. Livestock provide the main local employment and livelihoods for the local economy. This *soum* was very adversely affected by the serious *dzud* in 1999-2002. They lost 34224 (24%) livestock (camel 1276, Horse 2076, Cattle 2678, Goat 13952 and sheep 14246) with medium to long-term effects on the livelihoods of herders and the local economy.

RESULTS

The system development was successfully developed by the Keio University based on integrated database from existing creditable database and management of collaboration between scientific, communication and governmental organizations.

The system test was implemented in Biger *soum* after all users had received training. In a survey after the demonstration workshop, 98% of participants agreed they had improved knowledge about adaptation to *dzuds*, understood the importance of information access, found it was manageable for their daily job and believed it would help reduce impacts of climate disasters.

After the system had been implemented 154 feedback response from users of Biger *soum* were received: 98% of respondents were satisfied with the information received and where using it daily, 43% understanding that early preparedness is important for disaster prevention and managing pasture capacity, 11 % want to get forage information for other *soums* and 17 % wanted improved content of the SMS on agriculture businesses, infectious diseases, raw product market price and other social information.

One hundred and sixty-eight people participated in the online training (Altai region 36, eastern region 33, Gobi region 31, Khangai region 30 and western region 38) from diverse organizations of Agriculture partnerships (APs), Local Emergency Management Agency (LEMA), local Agency Meteorology and Environmental Monitoring (LAMEM), Zoonosis disease research institute, *soum*, *bagh* and provincial officials, herders, local farmers, and agro farmers. Surveys done found that 99% of participants understood the impact of climate change on their livelihoods and how adaptation can limit its impact; 92% percent of participants wanted capacity building training workshop including more young and experienced herders, partnership organization and governors to solve the sustainable use of system in their regions.

DISCUSSION

Even though data accuracy and some operational matters remain problems, the information delivery system itself is providing efficient access to relevant information for herders as acknowledged by their responses.

The operating Company MobiCom has to improve the life time (from 2 minutes to 2 days) of their telemarketing SMS service to improve delivery to users.

The Mongolian weather forecasting agency National Agency Meteorology and Environmental monitoring agency (NAMEM) should cooperate with scientific development agencies on their forecasting technology to align with herder needs.

The local government, development fund should consider including a disaster prevention budget to support the sustainable use of system at the local level to reduce the countries social and ecological vulnerability.

Local adaptation plans should consider the use of forage forecasting information for pasture protection, irrigation needs, improvement of soil productivity, breeding of livestock and hay preparation zone planning.

The national government should expand herder training in traditional and new technology development of adaptation and pasture management, livestock husbandry system, improvement of livestock productivity, marketing system and agribusiness development. The system reported here requires herders to have a higher level of knowledge to interpret the data provided.

The operating organization of this system needs to continue to organize public awareness activities broadly through media, creditability of information, and coordination of customers.

ACKNOWLEDGEMENTS

This is acknowledge that this study supported by JSPS KAKENHI (2012-2015) Grant Number 24310034, Japan" for the implementation of the project. We also thank to Biger *soum* herders for their active participation and local supports during the field work.

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The Influence of the Booming Mining Industry on the Agricultural Sector in Mongolia

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ABSTRACT

Mongolia's extensive mineral deposits and attendant growth in mining-sector activities have transformed Mongolia's economy, which traditionally has been dependent on herding and agriculture. In this paper a Keynesian type equilibrium displacement model is developed to deduce hypotheses about the effects of mining on agriculture. A major hypothesis to be tested is whether the effects have been adverse, as suggested by the "Dutch Disease" hypothesis.

Keywords: agriculture, Dutch disease, mining, natural resource curse, Mongolia

INTRODUCTION

Mongolia is a resource-rich country and also a small open economy which relies on international trade. As mining grows up, the export of minerals increases. Then the Mongolian currency will strengthen and suppress the export of other products, in particular, agricultural products (like mutton, beef, etc.). The idea that currency appreciation associated with a booming natural resource sector might have adverse effects on other sectors of the economy is known as "Dutch Disease" (Corden 1984). The empirical literature on the Dutch Disease is large; notable recent examples include Acosta et al. (2009), Pegg (2010), Scott (2010), Fielding and Gibson (2013), Dülgera *et al*. (2013) and Apergisa *et al*. (2014). Most of these studies found at least some evidence that booming sectors have negative consequences for lagging sectors such as agriculture.

STUDY SITE

The research examines the economy in Mongolia from a macro perspective with particular emphasis on the mining and agricultural sectors. Mongolia's economy between 2006 and 2013 tripled in size from $3.4 to $11.5 billion (Table 1). The service sector over this period grew from 37% to 50% of the economy at the expense of the agricultural sector, which declined from 20% to 16% of the economy. Gross fixed capital investment, which reflects mining activities, increased from 33% to 44% of GDP. Foreign Direct Investment between 2006 and 2011 grew from 10% to 54% of GDP, due at least in part to mining agreement signed by the governments of Mongolia and Canada in October 2009 (Batchuluun and Lin 2010). At issue is whether currency appreciation has been an unintended consequence of the FDI-lead mining boom, and the implications for the agricultural sector.

METHODS

A Keynesian style equilibrium displacement model (EDM) is specified to determine the effects of growth in Mongolia's mining sector on its agricultural sector. The model is similar to the one developed by Glytsos (2005) to analyze the effects of foreign remittances on the growth of selected Mediterranean economies. The basic model in EDM form (Wohlgenant 2011) is:

(1) $C^* = \alpha\, Y^*$ $\quad(\alpha > 0)$
(2) ${I_{mi}}^* = \beta_{mi} Y^* + \theta_{mi} e^*$ $\quad(\beta_{mi} > 0, \theta_{mi} < 0)$
(3) ${I_{ag}}^* = \beta_{ag} Y^* + \theta_{ag} e^*$ $\quad(\beta_{ag} > 0, \theta_{ag} < 0)$
(4) ${I_{ots}}^* = \beta_{ots} Y^* + \theta_{ots} e^*$ $\quad(\beta_{ots} > 0, \theta_{ots} < 0)$
(5) $TB^* = \mu\, e^*$ $\quad(\mu < 0)$
(6) $e^* = \varepsilon_Y\, Y^* + \varepsilon_{FDI}\, \overline{FDI}^*$ $\quad(\varepsilon_Y > 0, \varepsilon_{FDI}\ (?\,))$
(7) $Y^* = k_c C^* + k_{mi} {I_{mi}}^* + k_{ag} {I_{ag}}^* + k_{ots} {I_{ots}}^* + k_{TB} TB^* + k_G \bar{G}^* + k_{FDI} \overline{FDI}^*$ $\quad(k_i > 0\ \forall\, i)$

where asterisks denote relative change ($Z^* = dZ/Z$); C is personal consumption expenditures; Y is national income; I_{mi}, I_{ag}, and I_{ots} are the values of production in mining, agriculture, and other sectors of the economy, respectively; $TB = X - M$ is the trade balance where X and M are the values of exports and imports, respectively; $\bar{G}$ is government expenditures; $\overline{FDI}$ is foreign direct investment (which includes remittances and foreign aid); and e is the exchange rate defined so that an increase in e implies currency *appreciation* from Mongolia's perspective. The Greek symbols are elasticities and the k terms ($k_i = i/Y$ ($i = C, I_{mi}, I_{ag}, I_{ots}, TB, \bar{G}, \overline{FDI}$) are income shares that sum to 1.

Economic theory suggests consumption and investment are positively related to income; hence α, β_{mi}, β_{ag}, and β_{oth} are assumed to be positive in sign. The Marshall-Lerner condition implies that for small open economies such as Mongolia currency appreciation reduces the trade balance; hence μ is assumed to be negative in sign. Theory is less informative about the effects of exchange rates. In a small open economy, the prices of traded goods are exogenous. Hence, higher domestic consumption associated with increased FDI will raise the price of non-traded goods only. To the extent the change in relative prices induces a re-allocation of resources between sectors the output of traded goods falls relative to non-traded goods. This could worsen income inequality if the resources employed in the traded-goods sector are owned primarily by the poor. Also, aggregate production efficiency could decline if technological progress is faster in the non-sheltered export sector (van Wijnbergen 1984, p. 41). The latter effect, in essence, is the "Dutch disease." Based on the foregoing, θ_i, θ_{ag} and θ_{ots} are assumed to be negative in sign. Since income growth in general is associated with a stronger currency, ε_Y is assumed to be positive in sign. The standard DD model predicts an increase in FDI causes the real exchange rate to increase. However, empirical evidence is not fully consistent with this prediction (Fielding and Gibson (2013) and references therein). Hence, ε_{FDI} is left unsigned.

The model contains seven endogenous variables (C, I_{mi}, I_{ag}, I_{ots}, TB, Y, e) and two exogenous variables exogenous variables ($\bar{G}$, $\overline{FDI}$). Given this structure, what hypotheses can be deduced about the effect of an isolated increase in FDI on the agricultural sector? To determine that, we solved equations (1) – (7) for simultaneously for ${I_{ag}}^*$ in terms of $\overline{FDI}^*$ to yield

$$(8)\quad {I_{ag}}^* = \frac{\overbrace{\varepsilon_{FDI}\beta_{ag}(k_{mi}\theta_{mi}+k_{ots}\theta_{ots}+k_{TB}\mu)}^{A} + \overbrace{\varepsilon_{FDI}\theta_{ag}\left(1-\frac{\partial C}{\partial Y}-\frac{\partial I_{mi}}{\partial Y}-\frac{\partial I_{ots}}{\partial Y}\right)}^{B}+\overbrace{k_{FDI}(\beta_{ag}+\theta_{ag}\varepsilon_Y)}^{C}}{\Psi}\overline{FDI}^*$$

where $\Psi = \left(\left(1 - \frac{\partial C}{\partial Y} - \frac{\partial I_{ag}}{\partial Y} - \frac{\partial I_{mi}}{\partial Y} - \frac{\partial I_{ots}}{\partial Y}\right) - \varepsilon_Y (k_{mi}\theta_{mi} + k_{ag}\theta_{ag} + k_{ots}\theta_{ots} + k_{TB}\mu)\right) >$ 0 under the maintained hypothesis that the marginal propensities to consume and invest to sum to less than 1. The signs of terms A, B and C are uncertain. Hence, the model yields no prediction about the relationship between the agricultural sector and FDI when the mining sector and the exchange rate are permitted to adjust. The relationship is an empirical issue that rests importantly on the signs and relative magnitudes of ε_{FDI} and ε_Y. Hence, in the empirical analysis we will focus on estimating these parameters.

RESULTS

To determine the sign and relative magnitude of ε_{FDI} and ε_Y we estimated the ARDL model

$$(9)\ \ln ER_t = \alpha + \beta_1 \ln FDI_t + \beta_2 \ln Y_t + \tau\, TREND + \sum_{j=1}^{p} ø_j \ln ER_{t-j} + \sum_{j=0}^{p_1-1} \gamma_{1j}\, \Delta\ln FDI_{t-j} + \sum_{j=0}^{p_2-1} \gamma_{2j}\, \Delta\ln GDP_{t-j} + v_t$$

where $t = 1, 2, \dots, 21$ (1993 – 2013 annual observations); $ER_t = (FCU/F\_CPI)/(DCU/D\_CPI)$ is the real exchange rate defined as the deflated foreign currency unit divided by the deflated domestic (Mongolian) currency unit; $FDI_t = (\text{nominal } FDI/D\_CPI)$ is real foreign direct investment; $Y_t = (\text{nominal } GDP/D\_CPI)$ is real gross domestic product; $TREND = t$ is a linear time trend; Δ is the difference operator; p is the lag order; and u_t is a serially uncorrelated error term. A trend term is included to control for unmeasured factors such as technical change that may have a systematic effect on the exchange rate. FDI_t and GDP_t are expressed in Tugriks (MNT), Mongolia's currency. Three exchange rates are considered: US dollar (USD/MNT), Chinese yuan (CN/MNT), and the euro (EURO/MNT).

Prior to estimation we tested if the data are I(0) or I(1), as required for the model. The Phillips–Perron test indicated that $\ln FDI_t$ and $\ln Y_t$ are I(1) with trend. To determine the appropriate lag length p and to confirm whether a time trend should be included, equation (9) was estimated by OLS with and without $TREND$ for $p = 1, 2, 3$. The three regressions were run over the same period from 1996 to 2013 in order to make them comparable. (The first three observations are lost due to the lag structure.) Akaike's Information Criteria (AIC) and Schwarz's Bayesian Information Criteria (SBC) were used to compare regressions under different orders. Lagrange multiplier (*LM*) statistics were used to test for residual serial correlation. *F*- and *t*-tests were used to determine the existence of a levels relationship $\ln ER_t = a + b_1 \ln FDI_t + b_2 \ln Y_t$ using the bounding test intervals in Pesaran *et al*. (2001). Because there are three equations, one for each exchange rate, the testing procedures were conducted three times to decide the orders for the three equations respectively. Results indicated a lag order of 3 when the response variables are USD/MNT and CN/MNT, and a lag order of 1 when the response variable is EURO/MNT. The bounds test indicated the levels relationship exists for USD/MNT and CN/MNT, but not for EURO/MNT. Hence, attention is restricted to the U.S. dollar and Chinese yuan relationships.

DISCUSSION

The augmented ARDL models with proper orders are obtained for equation (10) after selection from 128 models. They are the ARDL (3, 3, 3) for the USD/MNT relation and ARDL (3, 0, 3) for the CN/MNT relation. The regression results are shown in table 2 along with the long-run estimates of ε_{FDI} and ε_Y. Results indicate $\varepsilon_{FDI} = 0.39$ for USD and $\varepsilon_{FDI} = 0.01$ for CN, with both elasticities significant at the 1% level. This suggests an increase in foreign direct investment does indeed lead to appreciation in Mongolia's currency, although the effect is much stronger for the U.S. dollar than for the Chinese yuan. The estimated long-run income effects are also positive and significant at the 1% level, with $\varepsilon_Y = 0.48$ for USD and $\varepsilon_Y = 0.26$ for CN. The USD/MNT exchange rate is about twice as responsive to income growth as the CN/MNT exchange rate, although both responses are inelastic. Overall, results support the hypothesis that mining-induced increases in FDI or income leads to currency strengthening, an essential condition for the DD hypothesis to be valid.

IMPLICATIONS

Our analysis suggests each 1% increase in foreign direct investment is associated with a 0.48% increase in the value of Mongolia's currency against the U.S. dollar, and a 0.01% increase in the value of the currency against China's yuan. Hence, the necessary conditions for Dutch disease to exist are present. Whether they are strong enough to explain the relative decline in Mongolia's agricultural sector must await further research.

ACKNOWLEDGEMENTS

This research is supported by the NSF project "Ecosystems and Societies of Outer and Inner Mongolia," by the Alabama Agricultural Experiment Station, and by a stipend from the China Scholarship Council (CSC) that supports Wei Ge's doctoral studies in the United States.

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Table 1. National Economy Data for Mongolia, 2006-2013 (source World Bank).

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
GDP (million US dollars)	3,414	4,235	5,623	4,584	6,200	8,761	10,322	11,516
Foreign direct investment (% GDP)	10	9	15	14	27	54	43	19
Agricultural output (% GDP)	20	20	21	20	16	14	16	16
Industrial output (%GDP)	39	38	31	30	33	31	28	29
Services (% of GDP)	37	38	44	47	46	49	52	50
Imports (% of GDP)	64	53	58	67	58	62	87	77
Exports (% of GDP)	59	60	54	50	55	62	51	45
Government expenditure (% of GDP)	12	13	15	15	14	13	14	11
Consumption (% of GDP)	46	47	54	58	53	49	49	49
Exchange rate (per USD)	1,180	1,170	1,166	1,438	1,357	1,266	1,358	1,524
Gross fixed capital formation (% of GDP)	33	35	36	29	33	49	53	44

Table 2. Estimated Exchange-Rate Relations for Mongolia based on Annual Data for 1993-2010

Variable	Parameter	U.S. Dollar Relation - ARDL (3,3,3) Model		Chinese Yuan Relation - ARDL (3,0,3) Model	
		Estimated Parameter[a]	Long Run Elasticity[b]	Estimated Parameter[a]	Long Run Elasticity[b]
$\ln ER_{t-1}$	$ø_1$	-0.75**	--	-0.85***	--
$\ln ER_{t-2}$	$ø_2$	-0.31	--	-0.92***	--
$\ln ER_{t-3}$	$ø_3$	0.18	--	-0.68***	--
$\ln FDI_t$	β_1	0.73***	0.39***	0.03	0.01***
$\ln Y_t$	β_2	0.91***	0.48***	0.91***	0.26***
$\Delta\ln FDI_t$	γ_{10}	-0.53***	--	--	--
$\Delta\ln FDI_{t-1}$	γ_{11}	-0.32**	--	--	--
$\Delta\ln FDI_{t-2}$	γ_{12}	-0.08	--	--	--
$\Delta\ln Y_t$	γ_{20}	-1.03***	--	-0.61***	--
$\Delta\ln Y_{t-1}$	γ_{21}	-0.57**	--	-0.42**	--
$\Delta\ln Y_{t-2}$	γ_{22}	-0.35**	--	-0.06	--
$TREND$	τ	-0.23***	--	-0.05***	--
$Constant$	α	-49.6***	--	-41.2***	--

[a]Single, double and triple asterisks denote significance at the 10%, 5%, and 1% levels respectively.

[b]Computed using the formulas $\varepsilon_{FDI} = \frac{\hat{\beta}_1}{1-\sum_{j=1}^{3}\hat{\vartheta}_j}$ and $\varepsilon_Y = \frac{\hat{\beta}_2}{1-\sum_{j=1}^{3}\hat{\vartheta}_j}$.

How does Local Mining Impact on Rural Immigration: Case of Mongolia

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ABSTRACT

After 70 years of communist regime, Mongolia chose a radical transition for democracy and a market economy in 1990. Since the 2000s, the Mongolian government has been promoting the mining industry to increase its foreign exchanges. The mining sector may offer local job opportunities and revenues, but might also cause loss and degradation of pasture land the local people depend on. An empirical study is conducted to investigate whether the immigration of rural people from a mining area is different from that of a non-mining area using a probit model based on a 2013 workforce survey of Mongolia. The result shows that mining *soums* receive fewer outsiders than the non-mining *soums*, suggesting local mining activities exert limited economic linkage in local community for a case of Mongolia.

Keywords**:** probit model, rural immigration, mining activities, economic linkage, rural community

INTRODUCTION

Mongolia was a communist country from 1921 through 1991, with a population of 2.7 million. In 1990, Mongolia chose a radical transition for democracy and a market economy. Supported by international donors, Mongolia managed numerous crises, yet pressures differ between rural and urban areas. Since the 2000s, the Mongolian government has been promoting mining industry to achieve various missions. In the strategic paper of Government of Mongolia, government stated that it will promote mining sector led growth. One of the missions is that mining sector-led growth will lead industrialization which will promote to establish local small and medium enterprises SMEs. The mining sector became a main policy tool to achieve economic growth and development. On the other hand, the Ministry of Tourism, Environment and Green Development, claims that due to mining activity there are 551 rivers, 483 lakes and 1587 springs that disappeared (dried up) as of 2011. Therefore the impacts of a mining sector-led growth strategy in Mongolia are mixed and debatable. Does a mining sector offer extensive job opportunities and boost local demand?

There is an extensive literature analyzing the economic, political, and environmental effects of resource-led growth. Following Heinrich (2011) we will classify it into four strands:

1) *Economic performance*. It claims that natural resource dependence represses growth of other non-resource sectors, mainly manufactured goods, undermining long-term competitiveness and the appreciation of domestic currency which is called as "Dutch Disease" (Gordon and Neary, 1982). Primary commodity exporters would be disadvantaged in trading with industrialized economies due to worsened terms of trade of primary commodities in long run (Singer, 1950; Prebisch, 1950) and eventually, crowds out manufacturing sector (Frankel, 2010). Also it stresses on limited economic linkages from primary export commodity, namely, less generation of local employment and economic opportunity (Davis, 2005) because mainly it imports supplies and skilled workers from abroad. This strand also argues that the resource revenue exerts price/revenue volatility (Medina, 2010).

2) *Economic Policy*. It focuses on behavior of those who manage country. It points out poor resource management cases, such as when the resource generates huge income on state budget, it fuels incentive for corruption (Humphreys et al., 2007). Huge inflows from export revenues to mainly state budget favor decision-makers to maintain authority through allocating resources which contributes to corruption and rent-seeking behavior.

3) *Political conflict*. As Isham et al. (2005) have explained, property rights and economic freedoms are more depressed in resource-extraction societies because resource income flows only into the elite part of a society. To strengthen their political position, elites discourage mass democracy and economic freedom (Ross, 2001), resulting in social unrest, civil war or elite power struggles.

4) *Socio-economic development*. It focuses on the impact of resource-led growth on social welfare and most of the cases show that dependence on resource exports exerts negative impact on social welfare of the country (Carmignani et al., 2010).

This study attempts to clarify linkage effect of local mining activities in order to test how resource-led growth generates local economic opportunities using local migration data for Mongolia. We used 2013 workforce survey data at the *soum* level of Mongolia which was held at the national level.

EMPIRICAL MODEL

The people always migrate to more favorable places if they are allowed to make a choice. Immigration to mining areas should differ from that to non-mining areas if mining increases local economic opportunities. The hypothesis is that if local people receive more economic opportunity from local mining activity, then there would be more incentive to stay or migrate to the mining areas from non-mining areas. In contrast, if local mining degrades pastoral territory and water sources, then there should be a tendency to leave the mining area.

There could be many factors that would explain rural immigration, such as environmental disaster, civil war, increased economic opportunity in other places, attaining better education in cities and etc. Generally, we could classify those factors into extreme factors (serious environmental disaster, internal conflict, etc.) that force residents to leave the place without any choices, and socio-economic factors that could be decided through behavioral changes based on information or the rational decision-making process of the residents.

In our case there were no such extreme conditions for Mongolia, therefore we assumed that social factors such as age, sex, education, marital status, household size, and employment status are key factors on immigration influence. There is no argument that weather condition and pasture availability can be key factors on immigration decision of rural herding community in Mongolia. In fact, when there is shortage of pasture for certain areas, the local herders temporarily (most of the case for a season) move for survival but when the situation gets better they move back. In this study, we did not consider that regular and temporary leave as immigration. However, if there is continuous environmental disaster due to mining activity then local herders would decide to switch local *soums* where there is less environmental impact. We take into consideration if the mining *soums* differ than the other non-mining *soums* in order to test whether the local mining *soums* has a different immigration tendency compared to that of the non-mining *soums*. According to our assumption, if local mining *soums* are attractive in terms of economic and employment opportunities, then there would be more immigrants in that *soum* who resided in different places in last 5 years at a time of the survey (i.e, the immigrants in our model). If we find more immigrants in non-mining *soums*, then it may suggest that mining *soums* are not an attractive place for rural residents.

To test whether people in a mining area has a higher tendency to migrate to another area, the following empirical model is used:

$$IM_i = \beta_1 + \beta_2 AGE_i + \beta_3 EDU_i + \beta_4 MAEE_i + \beta_5 MINE_i + \beta_6 HHS_i + \beta_7 SEX_i + \beta_8 EMP_i + u_i$$

Where, IM_i=1 if respondent answered s/he lived in a different place from the current place for more than 6 months in the last 5 years, otherwise 0; AGE_i is the age of the respondent; EDU_i= 1 if the education level is more than secondary, otherwise 0; $MARR_i$-=1 if the respondent lives with a spouse, otherwise 0; $MINE_i$=1 if the respondent currently lives in a *soum* where mining takes place, otherwise 0; HHS_i is the number of the respondent's household members; SEX_i=1 if the respondent is male otherwise 0; EMP_i=1 if the respondent is economically active for at least for less than 1 month, otherwise 0.

We introduced these factors into the model. Economic factors such as income opportunity have been introduced as the employment variable. After controlling these factors, we tried to estimate whether there is a difference in *soum* immigration between mining and non-mining *soums*.

DATA

We used 2013 workforce survey data at the *soum* level of Mongolia which was held at the national level. The survey covered 11613 respondents of 21 *aimags* and 311 *soums*. The socio-economic status data such as age, employment, marital status, education and household size are extracted from National Statistical Office of Mongolia. It represents working aged (male respondents are from 18 to 60 years old and female respondents are from 18 years old to 55 years old) rural residents (s*oum* center and rural area) of Mongolia. The rural residents includes both herders and non-herders residents who registered as *soum* residents.

The data summery is presented in Table 1. Employment variable suggest that 78% of the sample is at least economically active for 1 month during the interview. Moreover, the sample shows that 73.6% of them are employed at least 1 year. Since our sample consists of working age residents, 72.3% of them live with spouse. Education variable indicates that 31.1% of them attained post-secondary education. Whereas, mining *soums* are identified from Mineral Resource Authority where extraction license of certain territory of the *soums* have been already issued from the authority. The data suggest about 3% of the households moved from other places. Our dependent variable is outsiders who had lived at least 6 months in a different place in last 5 years during the interview.

Table 1. Data Summary

Variables	Obs	Mean	Std. Dev
Outsiders	11613	.030	.172
HHSize	11613	3.99	1.45
Sex	11613	1.48	.499
Age	11613	36.3	10.705
Marriage	11613	.732	.442
Education	11613	.311	.463
Employment	11613	.741	.437
Mine *soum*	11613	.613	.486

RESULTS AND DISCUSSION

This empirical model tried to incorporate several socio-economic factors that might explain why local people immigrate. The results were obtained using a probit model and presented in Table 2. The results show that age shows negative effect on local immigration by 0.034 % meaning that the more aged the residents tend to immigrate less to a different place. Also employment exerts negative impact on it by 0.192% meaning that the respondent with employment less likely to immigrate. While education level impact is positive on local immigration by 0.249%, suggesting that local people with diploma or degree level education more likely to migrate.

Our findings also suggest that the respondents from mining *soums* were less likely (0.133%) to live in different areas other than their current *soum*, suggesting that the mining *soums* do not receive many outsiders from other places of Mongolia- at least for a case in Mongolia in 2013. It may suggest that local mining activities exert limited economic linkages in local areas as the previous researchers argue.

We found that gender and marital status are not important factors to explain the rural immigration of Mongolia. However, this study should be compared for other years in order to find out the dynamics of the rural immigration.

Table 2. Probit model results on immigration analysis

Variables:	Model Results Values
Constant	-0.647 (0.144)*
Age	-0.034 (0.003)*
Sex	0.016 (0.049)
Household size	0.015 (0.017)
Marital status	-0.059 (0.059)
Education level	0.249 (0.051)*
Employment	-0.192 (0.055)*
Mining *soum*	-0.133 (0.049)*

Standard errors are shown in the parenthesis showed; *-significant at 5% level

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Planning an Agent-Based Network for Livestock Production and Meat Distribution in Mongolia

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ABSTRACT

This paper reviews the problems of livestock production in Mongolia and proposes an agent-based meat distribution network composed of multiple players. Agents sell and buy products and services, equipped with intelligent capacity of knowledge and phsycial capacity of Freezing meat stock, livestock, and forage stock. local governments and communities are the key for enhancing food security. The network, as a whole, is green, clean and resilient to climatic and market disturbance.

Keywords: food security, agent-based network, local development, meat freezing storage

INTRODUCTION

Mongolia is a land-locked country that spans arid and semi-arid ecological regions. The ecological systems are extremely vulnerable to climate change and intensive human development. The steppe has low primary productivity, rendering it suitable for the sparse scattering of the nomadic people over a large area. However, today, half of the 2.8 million Mongolians live in the capital city, Ulaanbaatar (UB). Except in such cities as Erdenet and Darkhan, the population in each of Mongolia's *aimags* (i.e., provinces) is less than 30,000 persons. Food is produced in the vast land while consumers are extremely concentrated in the capital. This geographic imbalance of production and consumption renders the issue of food security in Mongolia special in three dimensions. First, the government must secure safe and nutritious food for all of its citizens, including those in remote lands; second, the highest priority is to ensure sufficient food for citizens living in the capital; third, it is critical to sustain the nomadic society while its people tend to prefer the convenience of urban life. The first dimension requires the erasure of poverty. The second demands a high level of productivity by connecting the remote countryside with cities. The third pursues inclusive development. Each dimension sheds light on different temporal and spatial scales. We believe that only when these three dimensions are tackled together will resilient and sustainable food security be achievable.

This research reviews the problems of livestock production in Mongolia and proposes an agent-based meat distribution network equipped with freezing meat storage in addition to livestock and forage stock. This network could collect livestock from herders, rather than conventional peddlers and wholesalers, and store frozen meat to protect them from climatic disasters and market disturbance. The network would empower the local government and communities by activating the food industry. This would help reach the national goal of food security by being clean, green, and resilient in the long term.

PROBLEMS OF MEAT DISTRIBUTION IN MONGOLIA

Undeveloped market economy in rural areas

Nomadic Mongolians move around the steppe to migrate alongside water and grass. Livestock have traditionally been a living food storehouse, as people acquire food by killing animals whenever and wherever, as need dictates (Siurua and Swift, 2002). This lifestyle based on self-producing and self-consuming subsistence has been conserved by half of the population in over 99% of the national land in Mongolia. This is an extreme example of a low-cost and low-carbon lifestyle. However, productivity is low. In total, 150,000 households and 300,000 herders owned 52 million animals in 2014. Most herders have kept animals for self-consumption rather than production for a wider market. Mongolians consumed 273,700 tons of meat in 2013 and only 965 tons were exported in 2012 (http://ubpost.mongolnews.mn/?p=4852). The large number of animals has raised grazing pressure on the pastureland, which has resulted in the over-grazing and general degradation of the ecological system in every *aimag* (Olonbayar, 2010). This has also left ecosystems and livestock alike vulnerable to extreme weather. *Dzuds* (i.e., severe winters) have occurred recurrently in past decades, resulting in the death of tens of millions of animals (ERST_UNDP_NEMA, 2010; Sternberg, 2010). Herders who consequently lost animals have had to work at mining sites or migrate to cities (Mayer, 2015). This accelerated the population concentration in Ulaanbaatar, and again aggravated the imbalance between meat production and consumption.

Poor infrastructure for meat distribution and processing

Mongolian livestock was state-owned during the socialist era before 1990. Production and distribution were centrally planned. Every year, the government made production plans and allocated products to *aimags* and then *soums* (i.e., districts) in the spring. Each *soum* would collect the required number of animals, and then trek the herd to Ulaanbaatar while fattening the animals. Herders would reach the city in the autumn, which would be the best time to ship the herds to market (Edstrom, 1995). The trip would be harsh and risky, extending for several months and spanning thousands of kilometers. After the 1990s, the trekking system collapsed. Livestock became privatized and meat distribution opened up to the market. Individual merchants or private traders became the main power holders in rural areas, collecting animals and transporting them to slaughterhouses in nearby large cities, mainly Ulaanbaatar (Ichinkhorloo and Thrift, 2015). The increased stocking rates closer to the capital severely degraded the grassland landscape. Meanwhile, herders in rural areas continued to migrate each year from winter to summer while grazing lands and keeping animals for survival, although they could still suffer significant losses through *dzud*. Moreover, they would discount the prices heavily when selling because they did not know the market very well.

Regarding the market-based meat distribution process, transportation and slaughtering are conducted under poor hygienic conditions, without freezing and refrigerating. Wholesalers buy meat at slaughterhouses and sell to the central market, food markets, and supermarkets. Meat products from small slaughterhouses are distributed to food markets and retailers in unrefrigerated trucks. Only 13% of meat products are processed in plants with reasonable hygienic standards. Food markets sell meat products, of which almost 100% is contaminated with chemical components, bacteria, and heavy metals

(FAO/WHO, 2002). All of these effects can result in bacterial growth on the meat with a higher risk of food poisoning, among other risks.

Lack of policy integrity and implementation

Meat is a staple of Mongolian culture. About 42% of the Mongolian labor force engages in agriculture, mainly herding livestock, and contributes 20% of their gross domestic production (GDP) to this activity <http://www.nationmaster.com>. With shrinking food reserves and soaring food prices, the Mongolian government recognized the importance of stable food supply and introduced a national meat reserves program in 2005. The country has initiated the National Programme for Food Security in 2009 (Mongolia, 2009). This program's overall goal of food security is to provide the entire nation with secure supplies of accessible, nutritious, and safe food to enable healthy livelihoods and high labor productivity. However, the policy has not led to any significant reductions of price fluctuations (Goodland, 2010). Despite the price subsidies for consumers and direct funding for participating meat packers the consumer prices have continued to rise rapidly (Ichinkhorloo and Thrift, 2015). We think this is not solely a food security issue but a matter that involves the rebuilding of the nomadic society while balancing the development of the capital and rural areas. In the transition to the market economy, the development of supportive food industrial infrastructure for meat logistics was ignored. Storehouse closed, cooperative production collapsed, community facilities were abandoned, and public services of the local government degraded (Finke, 2003). It would be time again to develop the food security that would be entrenched on the endemic resources of the vast land while favoring nomadic culture.

AGENT-BASED MODEL OF LIVESTOCK PRODUCTION AND MEAT DISTRIBUTION

Food security is supported by three models in modern Mongolia (Figure 1). Model A is bartered with limited exchange among relatives and neighborhoods in *soums* and *aimags*. The supply chain is short with less intermediate costs, consequently with no value added. Model B builds on the semi-formal connections intermediated by merchants and wholesalers. The food of the capital is mainly supplied in this way today. This model is vulnerable to weather conditions and diseases. Model C is formal business between large-scale herders and slaughterhouses. Sellers and buyers in this model are powerful in their facilitation of transportation and even maneuvering of market prices (Ichinkhorloo and Thrift, 2015). This model is often recommended as a favorite solution to secure food supply because of its high productivity; however, it produces less interaction with local governments and yields limited effects on local economies.

A problem common to the three models above is the lack of local players: *soums*, *aimags*, and herders. *Soums* and *aimags*, as governing authorities, take the responsibility of managing pasturelands. They also have to develop the local economy and preserve nomadic culture. In one word, they are the stewards of their national land. For most *soums* and *aimags*, livestock is essentially the only resource, and therefore, the ways through which the potential of these resources may be activated are the key for local development. Here, we introduce an agent-based network of model D by improving food industrial infrastructures, especially freezing storage.

According to the agent-based simulation theory, an agent is an actor behaving autonomously and interactively in an explicit space on bounded rationality (Epstein 2007). The agents in Model D are herders, livestock traders, enterprises, *soum*/*aimag* governments, wholesalers, retailers, and consumers. Agents collect sparsely distributed livestock from herders, store meat in freezing storage, and deliver meat products to beneficiary markets. Different from the agent-based systems on established infrastructure (Liu, 2014). The agent of model D is embedded with intelligent and physical capacities.

By the notions of alertness, efficiency and risk-taking (Ross and Westgren, 2009). The intelligent capacity here is defined as the alertness of an agent to environmental change. The physical capacity is the size of freezing stock, livestock and forage stock of an agent. Multiple agents autonomously act and interact in an explicit landscape by the rational use of the physical capacity of the three stocks. While pursuing individual efficiency, the network as a whole must meet the national requirements of sustainable development: green (low CO_2 emissions), clean (good hygiene), and resilient to disturbance (i.e., disasters). For comparison, we summarized the features of the four models in Table 1.

Regarding risk-taking, this model integrates the socio-economic and -ecological goals in the long term and the short term, in which the development of pooling capacity of the three stocks shall be essential. In the short-term, the priority of the network is to secure the food supply to urban residents, which requires the prioritization of efficiency in the quick collection of livestock and meat storage that is close to the urban market. In the long-term and broader definition, consumers include both city residents and local herders. A planned agent network should reduce the number of value chains and increase the profits of small- and middle-scale herders. Herders and communities with storage facilities may directly sell and send produced food to urban consumers.

REQUIREMENTS FOR IMPLEMENTING THE AGENT-BASED MODEL

Integrated management of natural resources, products, and markets

The agent-based model considers livestock production and meat distribution to be nation-wide in the long term. When enough livestock is fed and food is reserved in freezing and storing facilities, the market becomes more resilient. The agent-based model operates at the intersection of livestock feeding, meat production, and the consumer market. In this sense, the stock of animals, storage of meat products, and market demand should be managed in integrative ways. This would require collaboration among government offices, central and local departments, as well as enterprises and herders' communities (Balval and Baljinnyam, 2013).

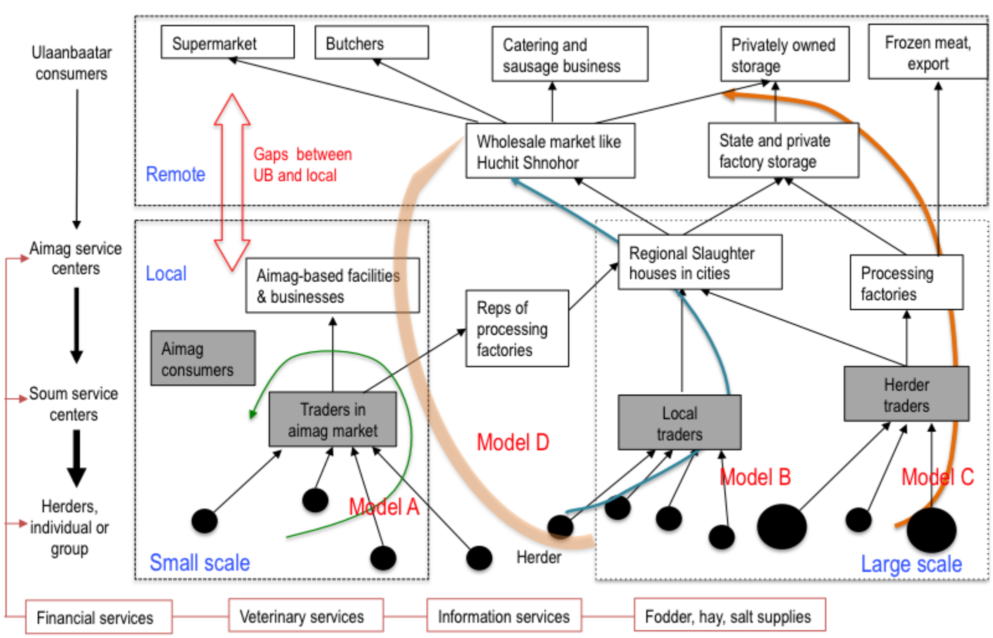

Figure 1. Agent-Based Network for Meat Distribution

Table 1. Comparison of Meat Distribution Models

Model	A	B	C	D
Feature	Local markets	Cooperation with wholesalers	Working with large-scale herders	Enhancement of local centers (soums, aimags)
Merit	Local production, local consumption	Low investment	Independent transport by herders	Development of attractive aimag/soum centers
Demerit	Low economic development	No improvement	Large gaps between poor and rich	No established business model
Policy & Strategy	Culture preservation	Market economy	Meat supply to UB first	Decentralization from UB
Cleanliness/ Hygiene	Not easy to maintain	Not easy to maintain	Easy to improve	Well-controlled
Greenness/Low CO_2 emissions	Very low	Low	High	Well-controlled
Resiliency	Vulnerable	Vulnerable	Vulnerable	Resilient

Infrastructure required for Model D:
❶Veterinary services -> ❷Grassland management (ex-ante, during, and ex-post dzuds) -> ❸ Collective program

Shared information and communication

One significant problem currently in Mongolia is the lack of data and communications among governmental departments, providers, and consumers. Fortunately, the Mongolian government initiated the National “Mongolia Livestock” registration system in 2010 (Resolution based on the Law of Great Khural of Mongolia, Article 43 and clause 43.1), by which 40% of animals are tagged with a bar code and registered to a central database in pilot aimags. Only tagged animals are certified to be marketed or exported. The system is even designated to connect with the Mongolian Agriculture Commodity Exchange (MACE). With this registration and market information, the potential of livestock across the country could be activated, and the meat market would be expected to prosper in the near future.

Empowerment of local governments, herders, and communities

Mongolian herders maintain tight ties through informal networks, as 31% of livestock is owned by non-herders (Ichinkhorloo and Thrift, 2015). In rural area two to twelve households move, live, and work together in a herding management unit called a *khot ail*. A number of *khot ails* settled together around a small water source is known as a *neg usnihan* (meaning “users of the same water”). The population within a given area neighboring a *neg usnihan* with similar herding management practices constitutes a *neg nutgiinhan* (meaning “people of the same area”). This *khot ail→neg usnihan→neg nutgiinhan* structure (Nyamsamba, 2000) constitutes a community-based social network. In the process of urbanization, rural areas are faced with problems related to aging. The sustainable management of pasturelands and livestock will largely depend on the revitalization of these informal connections. The agent-based model aims to enhance the capacity of local centers with communities by developing the capacity of capital assets. By using modern modes of communication, information can be delivered to agents easily. Market information of MACE or that of the local market, as well as knowledge of grassland management and breeding animals, could be shared in a manner similar to that of the service that has delivered weekly weather information via short message service (SMS) to herders (Suvdantsetseg et al., 2015).

CONCLUSIONS

This paper proposed an agent-based network of livestock production and meat distribution in Mongolia. This proposed model defines herders, merchants, governments, and wholesalers as agents with intelligent and physical capacity. The main difference of this model from conventional ones is its ability to empower *soum*/*aimag* centers through the rational management of freezing stock in addition to livestock and forage stock. By introducing freezing meat storage as the third food industrial infrastructure, the agent-based network can overcome the vulnerability of the food chains from livestock production to meat distribution and create opportunities to local communities. The implementation of this network is expected to reduce long-distance transportation, enhance market value of meat, and thrive herders' life. This idea shares the direction of the New Soum Center Project of the Mongolian Government, by perspective of food security. We argue that freezing meat stock must be planned, introduced, and maintained as the important food industrial infrastructure of the country with livestock and forage stock of pastureland together.

ACKNOWLEDGEMENTS

This research is supported by the JCM project 2014, MOE, Japan and the JSPS KAKENHI Grant (2012-2015, No. 24310034).

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5 Methods of Knowledge and Data Integration in Coupled Natural-Human Systems

The MOR2 Database: Building integrated datasets for social-ecological analysis across cultures and disciplines

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ABSTRACT

This paper describes the construction of a complex database for social-ecological analysis in Mongolia. As a National Science Foundation (NSF)-funded Dynamics of Coupled Natural and Human (CNH) Systems, the Mongolian Rangelands and Resilience (MOR2) project focused on the vulnerability of Mongolian pastoral systems to climate change and adaptive capacity. To study this phenomenon, our team is made up of a group of hydrologists, social scientists, geographers, and ecologists collecting data across the Mongolian landscape over three years. This dataset is unique in that it captures multiple types of field data: ecological, hydrological and social science surveys; remotely-sensed data, participatory mapping, local documents, and scholarly literature. We describe the content, structure, and organization of the database and explain the development of data protocols and issues related to access and sharing. Descriptions of data analysis are included to demonstrate the utility of the database as well as its limitations. We conclude with a description of the challenges in creating a cross-cultural and multi-disciplinary database and lessons learned.

Keywords: database, interdisciplinary, Mongolia, social-ecological analysis

INTRODUCTION

This paper describes the database created for the National Science Foundation (NSF)-funded Mongolian Rangelands and Resilience (MOR2) research project. Comprehensive, complex databases are needed to address complex problems. The MOR2 database is designed to provide researchers with data for assessing socio-ecological aspects of climate change and herder adaptations in Mongolia. Data were collected to examine different management activities and outcomes on Mongolian rangelands in places that adopt community-based rangeland management (CBRM) and those adhering to traditional herding practices (non-CBRM). The MOR2 database is comprised of multiple types of data, organized into different thematic datasets and databases, which have been gathered by an interdisciplinary, multi-cultural research team (e.g., hydrologists, ecologists, geographers, and social scientists; US and Mongolian scientists) using different data collection methods, scales and units of analysis, and analytical techniques.

The database has evolved organically over the course of the five-year project. Database discussion and development has been ongoing, adaptive, and reactive to data collection activities. A central component of the database is the multiple types of field and secondary data collected by sub-teams (Table 1). Note that the research teams are fluid, with some members participating in multiple aspects of the project, strengthening the interdisciplinarity of the research.

This paper provides an overview of the MOR2 database and discusses some key challenges and lessons learned. Data content and collection are described for the study sites across Mongolia. For thematic parts of the database, data collection, access and sharing protocols have been created. Examples of preliminary analyses and challenges are presented. The paper concludes by highlighting the creation of a comprehensive database built into a simple storage structure of multiple thematic folders. Central to the database design is a common set of geographic study sites, which created the foundation for developing coded linkages between datasets. This database was constructed prior to many of the technical advances made in web-based data sharing and cloud technology for data repositories. These new options will be considered for archiving and long-term data maintenance.

STUDY SITES, DATA CONTENT AND COLLECTION

The MOR2 study sites span four ecological zones across the Mongolian landscape: mountain and forest steppe, steppe, Eastern steppe, and desert steppe. In each zone, paired *soums* (counties) were selected with and without formal CRBM groups for a total of 36 *soums* (18 with CBRM and 18 non-CRBM). Within each *soum*, 3-9 herder groups (CBRM) or traditional neighborhoods (non-CBRM) were selected for study. Geospatial data were used to visualize sample study locations using a Geographic Information System (ESRI, ArcGIS Version, 10.2) (Figure 1). Extensive fieldwork took place over four field seasons where ecological, social, physical, and boundary data were collected. Each research team collected data using a mixture of tools including global positioning systems (GPS); photographs; digitally recorded and paper survey questionnaires, focus groups and interviews for social and herder observation data; and ecological and hydrological sampling protocols. Teams collected existing *soum*- and group-level data and documents, government livestock and population statistics. A nested social database includes three social tiers: 1) household questionnaires, 2) organizational profiles of CBRM and non-CBRM groups that synthesize qualitative data collected through focus group discussions and leader interviews, and 3) *soum*-level survey from focus groups, and demographic and socio-economic data. Social data were collected from 142 pastoral groups and 706 member households. Ecological data include vegetation cover, biomass, plot level soil pit descriptions, soil surface and environmental characteristics collected at three different grazing distances from 143 winter camps in four different ecological zones. Physical data include meteorological and stream flow measurements collected in selected study sites to examine sub-watershed stream dynamics. Precipitation, temperature and hydrologic data collected from the Global and Mongolian governmental databases were used to derive national level, point and interpolated climate datasets. Tree cores were collected from two sites for comparison and analysis with existing datasets stored in the International Tree-Ring Data Bank. Remotely-sensed satellite data spans Mongolia and includes data with multiple resolutions (AVHRR at 1km and MODIS at 250m). Participatory mapping resulted in hard copy maps, digital maps, global positioning system (GPS) points, and interview data used to analyze social, ecological, physical and administrative boundaries. In addition to field-collected data and existing statistics and data sources, the database includes additional GIS databases for the country, government and NGO reports, and scholarly literature.

In the field, data were collected on datasheets for both ecological and social information and entered into digital databases after the conclusion of fieldwork each year. Two Microsoft Access databases, with input forms (for the household questionnaire and organizational profiles) were developed and data from hard copy forms were entered into these databases. Quantitative data from household questionnaires and organizational profiles are stored in two MS Access databases and exported to SPSS for statistical analysis. Ecological data were entered into the Database for Inventory, Monitoring & Analysis (DIMA) developed by the Agricultural Research Service (ARS), at the Jornada Experimental Range, New Mexico (http://jornada.nmsu.edu/monit-assess/dima). DIMA provides automated analysis routines for vegetation, biomass, and soils indicators. A separate DIMA dataset was developed for each ecological field season (2011, 2012, 2013) to facilitate consistency of data entry and quality assurance. The ecological data are stored in both DIMA and in exported Excel files and imported into SAS or SPSS for analysis. Quality assurance and control procedures (QA/QC) were established for transferring data from hard copy forms to DIMA. All data were documented with metadata.

STRUCTURE, ORGANIZATION, TYPES, AND MANAGEMENT

Data discussions were ongoing throughout the project creating a flexible and adaptive structure in which to manage and store the data. These data are housed at Colorado State University on a shared drive within the Warner College of Natural Resources. Data are protected and backed up on external hard drives and on the CSU-WCNR computer servers. Data are organized thematically within a series of folders. Versioning of datasets follow a naming convention based on dates (DD/MM/YYYY) and new folders created by field season for the ecological data. The social data are organized by data type: household questionnaire, organization profile, and *soum* data. Spatial data obtained from other sources were assessed and organized thematically for reference use and spatial analysis.

To create linkages and relationships between the distinct ecological, social and physical databases, a numbered coding system was established to create an unambiguous label for each administrative unit (*soum* and *aimag* or province), organization, household, winter camp and ecological plot (Table 2). The coding system enables cross-referencing and merging of data across the various databases, using a spatially explicit hierarchy, to facilitate integrated analysis of social, ecological and physical data. The coding system is used in each of the project's separate databases. The code is the "key" that links the spatial data, the ecological data, and the social data (both the household and organizational database).

DATA PROTOCOLS AND ACCESS

Formal written protocols were created for all data collection activities to ensure consistency. Protocols for the database were also created, including the development of internal metadata standards. The metadata for the database has been created through a series of dynamic README files that are located within each folder. Team members can access the different data in the folders, but any changes or updates are recorded in the README file within that folder. This essentially creates a distributed, living data dictionary. However, it is incumbent upon team members to maintain these README files. Additionally, as new data have been added and transferred to the latest version of the database, an overall spreadsheet is maintained to track these data changes. All thematic databases have a data steward to oversee these processes.

A Data Ownership and Use Protocol provides guidance for database use and encourages young researchers to develop their research skills. Each researcher must apply to use the data and explain their research questions, methods, and analysis. The protocol provides for and ensures oversight of analytical approaches, scientific peer review, and appropriate referencing of credit for data development. The process is meant to be flexible and to further the adoption of sound scientific approaches in using a unique database.

DATA ANALYSIS

The research teams are conducting numerous types of analyses using these compiled MOR2 datasets. GIS layers and physical landscape data provide the basis for analysis to create derived data products. For example, flow analysis, stream networks, and digital elevation models were created for Khangai Mountain region river basins using the suite of ArcGIS Spatial Analyst tools (ESRI, ArcGIS 10.2). Household-level data are aggregated and combined with organizational profile data to analyze social outcomes of community-based management. Ecological field data are analyzed to assess effects of grazing gradients and community-based management, and combined with remote sensing to compare patterns in ground and remotely-sensed data. Participatory maps are coded using visual grounded theory to identify a typology of boundary types associated with herder management practices. Next steps include merging full ecological and social databases to examine reciprocal relationships between social and ecological functions and how these differ between CBRM and non-CBRM communities.

CHALLENGES

The MOR2 database is diverse and complex, which has inherent challenges. MOR2 illuminates cross-cultural challenges that include language barriers, differences in scientific approaches between the US and Mongolian researchers, communication barriers due to different cultural norms and differing political and social contexts. These issues are beyond the scope of this paper but are embedded in the praxis of trans-disciplinary and multicultural research. The MOR2 project reveals the complexity of transdisciplinary, trans-cultural research and database development.

An examination of interdisciplinary communication by a MOR2 graduate student through transcribing and coding meeting minutes and interviews reveals new data types, data collection methods and underlying team dynamics. The word map depicts themes on data sharing, communication, access, and its challenges (Figure 2). Common themes involve concerns about data sharing among the MOR2 team, differing scientific standards, analyses, authorship, and publications. Sharing and accessing data, particularly for our Mongolia colleagues remains challenging as the data are stored and processed in a shared drive housed within CSU. While more in-depth narratives underlie these themes, our challenges reflect our efforts to collaborate and communicate among MOR2 team members with differing norms, epistemologies, and ways of approaching science.

Language barriers provide a unique set of disciplinary and cultural challenges. Disciplinary vocabulary demands definitions to address both communication and conceptual misunderstanding. The different languages and alphabets of Mongolian and English, influences data collection, development, sharing, and access. However, the MOR2 project supports a number of Mongolian graduate students and researchers who have been invaluable in bridging this cultural divide through providing translation, oversight, and participation in data entry.

The long term status of database for maintenance, access, and research need resources and support. Recent advances in web-based data sharing provide multiple venues to explore for long-term data storage and access. The development of derived data for long-term management is another concern. For example, proprietary data from Mongolian institutions were provided for hydro-climatic analyses. A key question is the format for derived data that maintains the integrity of the original data sources but protects the confidentiality of the original data.

LESSONS LEARNED

The lessons learned from three general categories: 1) data collection; 2) database development; and 3) data use. Training and education on data collection is essential to high quality and consistent socio-ecological data. In a multi-lingual environment, rigorous translation and back-translation of surveys, and field testing and revision before field use are needed to reduce ambiguity. A simple database design organized around research themes of the project provides a comprehensive, organizational framework. The coding scheme creates a spatially-explicit hierarchy to link the different thematic datasets, allowing for the creation of customized linked databases to address specific research questions.

Methods for database versioning are needed to ensure the best data is captured and organized for use and analysis. Naming conventions with dates should be adopted early in the data development process to maintain metadata, data provenance, and reduce redundancy.

Access and use of the data must come with disclaimers. Users must be aware of the limitations of the database, what is included and what is not included and guidelines on how the database can be use. The involvement of many researchers means that data are used for multiple purposes where future use by project partners may require a level of oversight and management not yet identified.

The MOR2 database is not explicitly an integrated database, but integration is achieved through analytical approaches that link the social, ecological, and physical databases. Integration is also achieved through the team-based approach to the research. The team dynamic has strong and long-term collaborative research relationships built on trust and respect. These are fundamental to the long-term use of the MOR2 database as access, curation, maintenance, and potential further development will need to be undertaken. This paper focuses on a description of the database and only alludes to the complex, underlying issues associated with building a transdisciplinary database in a cross-cultural environment. An examination of issues associated with large research teams, the challenges of international research, and designing approaches to complex problems are all avenues for future research.

ACKNOWLEDGEMENTS

This project would not have been possible without the support from the herder groups in Mongolia that provided their insights, time and hospitality. The authors express their thanks for all the work done in the field to collect the data that comprises the MOR2 database – colleagues and students in Mongolia and the United States. We are also grateful for the support from those that provided support in developing the structure and framework of data collection tools and database framework. This project is supported by funds form the NSF Dynamics of Coupled and Human Systems (CNH) Program award BCS-1011801.

Table 1. MOR2 sub-teams and field data collected

Sub-teams	Field Data
Social	Focus groups, interviews, and surveys at *soum*, herder group and household levels
Ecological	Rangeland soil, plant community composition, diversity and production
Physical	Hydroclimatic surveys/assessments and tree-ring analyses
Herder observation	Surveys and interviews of herder observations of hydroclimatic and rangeland soil and vegetation changes
Boundary	Participatory mapping of herders' socio-ecological boundaries
Interdisciplinary team observations	Interviews with US and Mongolian research team members, Participant observation, transcripts of research team meetings

Table 2. Coding system for survey data

AIMAG	***SOUM***	**ORGANIZATION**	**HOUSEHOLD**
Given a TWO DIGIT code, based on alphabetical order. *Aimag* codes are assigned beginning with the number 10 through 32.[1]	Given a FOUR DIGIT code. The first two digits = *aimag* code. The second two digits are based on alphabetical order of the *soum* names.[2]	Given a SIX DIGIT number. The first two digits = *aimag*; the second two digits = *soum*; the third two digits are assigned randomly. Each year new organizations are added.[3]	Given an EIGHT-DIGIT code. The first two digits = *aimag*; second two digits = *soum*; third two digits = organization. The final two digits will associated with household winter shelter number (the 1-st digit) and plot numbers (the last digit) [3]

[1]Ulaanbaatar is included in this list, even though it is not officially an *aimag*.
[2]The districts of Ulaanbaatar are assigned two-digit codes as if they are *soums*.
[3]Alphabetical order is difficult to maintain for organizations and households.

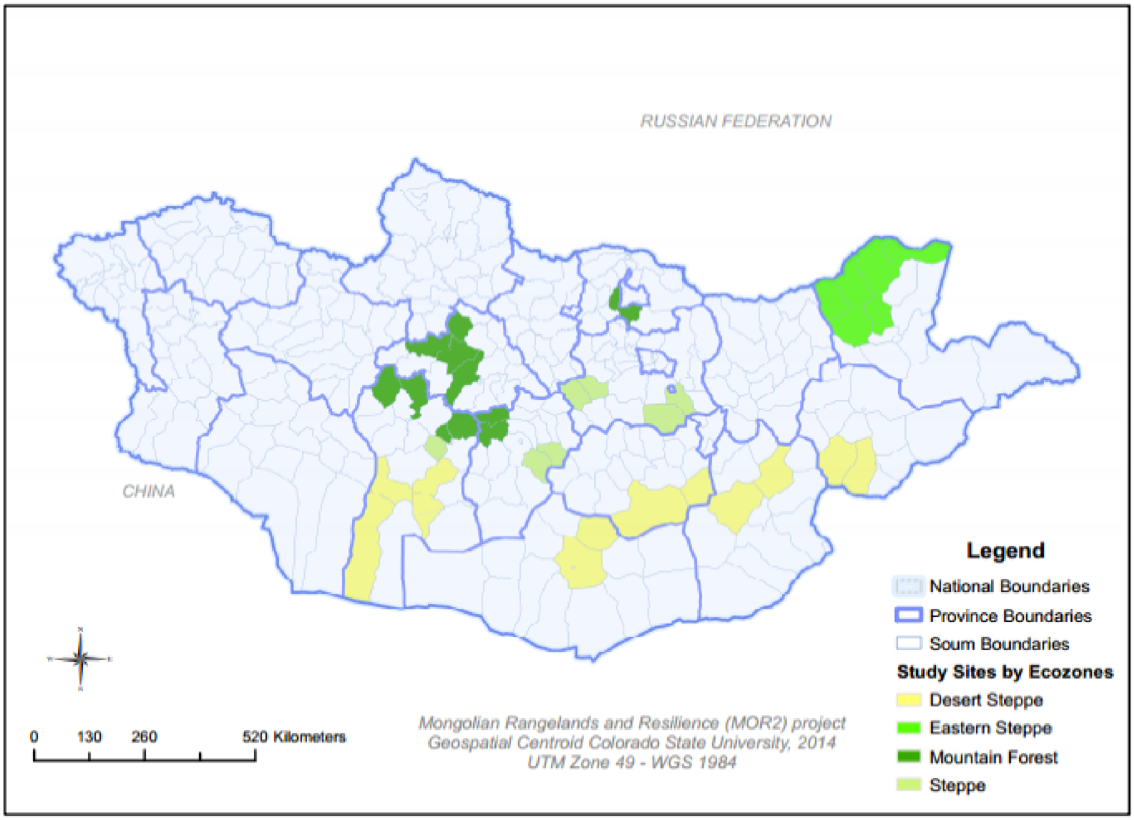

Figure 1. MOR2 paired *soum* study sites.

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.

ACKNOWLEDGEMENTS

We gratefully acknowledge funding support from the NASA Land Cover Land Use Change (LCLUC) program (grant # NNX14AD85G) and participants in the Scenario Planning workshop, funded in part by this grant, held in Ulaanbaatar, Mongolia in June 2014.

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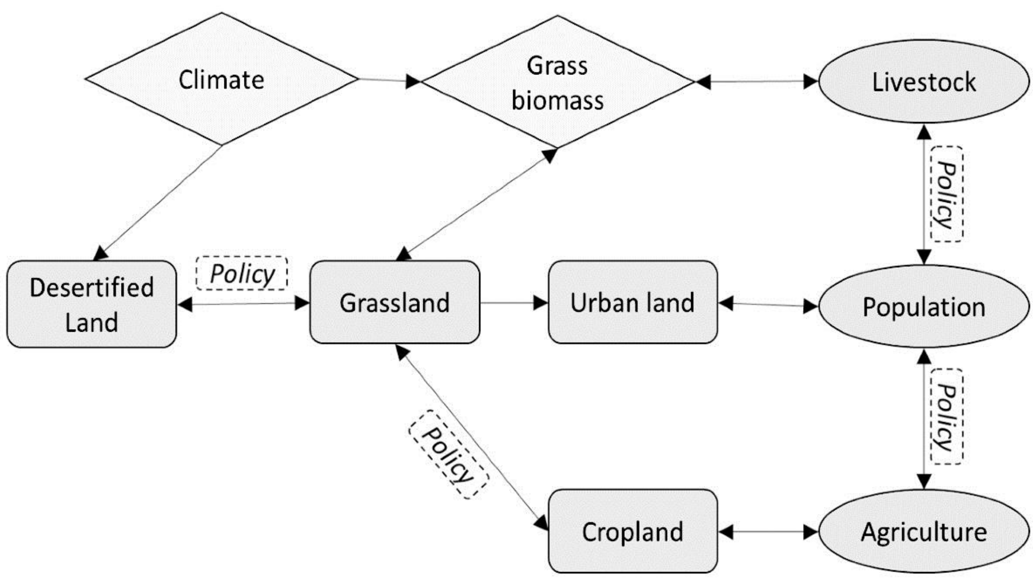

Figure 1. Conceptual diagram of the structure of the system dynamic model for Xilingol League.

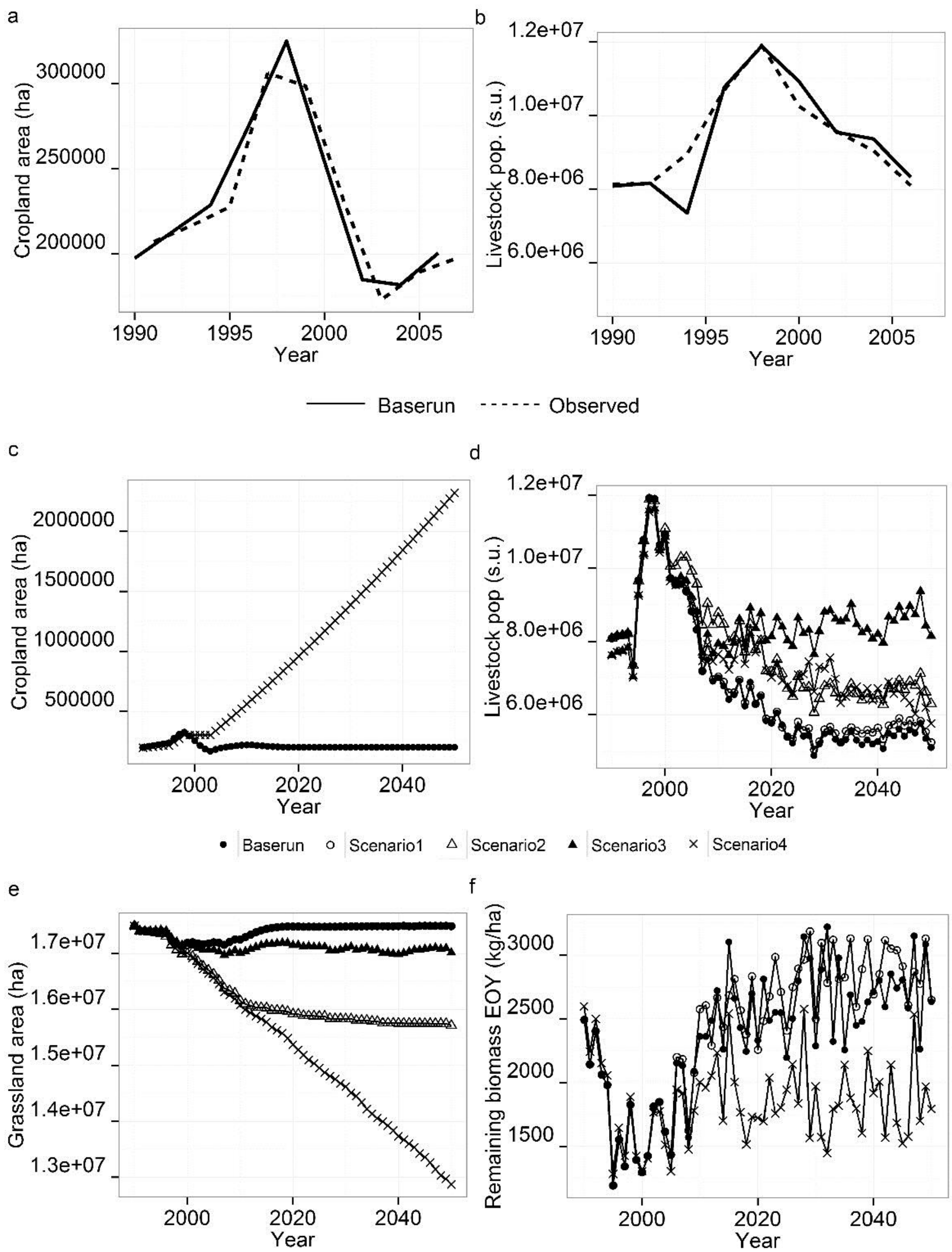

Figure 2. Model validation and comparison of scenarios. Validation: (a) Timeseries of observed cropland area plotted against the area predicted by the baseline model; (b) Observed livestock population

Participatory Mapping and Herders' Local Knowledge on Mongolia's Landscapes and Socio-ecological Boundaries

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ABSTRACT

Socio-ecological boundaries delineate landscapes containing natural resources that are differentially accessed and managed by stakeholders. These boundaries may be human-demarcated and biophysical serving as tangible and intangible features delineating landscapes. Our purpose is to explore Mongolian herders' perceptions of their pasture and boundaries through participatory mapping processes. Our research questions include: 1) what boundaries are depicted on herders' participatory maps? and 2) how are boundaries discussed through herders' participatory mapping narratives? We conducted participatory mapping and informal interviews (n= 35) with herder groups and district officials in Arkhangai, Tuv, Dornod, and Dornogovi. We qualitatively coded participatory mapping narratives and applied visual grounded theory. Tangible features on participatory maps included economic, hydroclimatic, geomorphological, and ecological boundaries portrayed as springs, landforms, vegetation types, seasonal camps, wells, and roads. Non-physical intangible boundaries such as governance arrangements were evident in participatory mapping narratives and served as human demarcated boundaries for accessing seasonal camps, markets, government assistance, and resources for herder migration. The relationships among herder mobility, governance boundaries, and biophysical pasture boundaries are coupled and dynamic, resulting in multi-dimensional outcomes of herder livelihoods.

Keywords: socio-ecological boundaries, local knowledge, participatory mapping

INTRODUCTION

Livelihoods and adaptive practices are shaped by the intersection of boundaries, institutions, and access to natural resources (Ostrom, 2009). Socio-ecological boundaries delineate landscapes containing natural resources that are differentially accessed and managed by diverse stakeholders. Examining socio-ecological boundaries integrates local ecological knowledge, acquires a systems view for investigating complex socio-ecological research questions, and develops practical frameworks useful for effective decision-making and policy (Barham, 2001). Investigating how socio-ecological boundaries are perceived, managed, and transformed by stakeholders and boundary spanning institutions is crucial to achieving sustainability goals (Buzinde and Manuel-Navarrete, 2013). This paper aims to explore herders' perceptions of their pastures and pasture boundaries in Mongolia. We apply participatory mapping to examine 1) what boundaries are depicted on herders' participatory maps? and 2) how are boundaries discussed through herders' participatory mapping narratives? We focus this paper on Mongolian traditional and community-based rangeland management (CBRM) herder groups examined by the Mongolian Rangelands and Resilience (MOR2) project.

Socio-ecological Boundaries

Socio-ecological boundaries may be comprised of human-demarcated and biophysical boundaries. Human-demarcated boundaries involve patterns of human behavior that characterize socio-ecological systems and establish the separation among ecological, socio-economic, and political spaces (Newman, 2003). For example, human-demarcated boundaries may demarcate areas with ecological and socio-economic resources managed by distinct individuals and/or institutions. Socio-ecological boundaries may be both intangible and tangible. Tangible boundaries visibly or materially delineate landscapes, such as fences signifying administrative boundaries or visible vegetation communities influencing wildlife species habitat and livestock grazing areas. Intangible boundaries include invisible social and biophysical processes delimiting landscapes. Examples include soil types influencing vegetation communities and cultural norms driving human behavior for managing landscapes.

CBRM Context

CBRM institutions include herder groups engaging in formal activities facilitated and funded by donors. Activities involve collectively sharing pasture resources through formal agreed-upon rules and informal rules for grazing. An approach to CBRM is facilitating pasture-user group (PUGs) that includes herders grazing within a territory. The preparation of pasture management plans (PMP) is required from the PUG. PMPs guide land use contracts among herder groups and regulate pasture resting, well management, seasonal rotations and the fencing of haymaking areas. The creation of new territorial boundaries based on PMPs inevitably influences the existing human relationships, norms, and boundaries on pastures (Fernandez-Gimenez, 2002). PUGs, PMPs, and land use contracts formalize rules and demarcate territories, thus serving as human-demarcated boundaries. The formalization practice involves processes and structures by which stakeholders make decisions and share power (Ostrom, 2009).

Participatory Mapping Processes and Nutag Framework

Participatory (PAR) mapping is a form of counter-mapping, a technique used to challenge power relations in cartographic processes and products (Gilmore and Young, 2012). PAR mapping involves multiple participants drawing and negotiating diverse representation of their landscapes and sense of places. PAR mapping is also a process and technique to involve diverse world views about their landscapes, including the socio-ecological boundaries represented in practices, norms, and landscape outcomes. In Mongolia, PAR mapping is certainly not a new process and has been applied by many donors to map herder's territories and PMPs, particularly with using Geographic Information Systems (GIS). Our motives differ from the latter in that we are interested in applying the process of participatory mapping to explore how herder's discuss their world views about pastures and boundaries. Thus, we focus on herder's narratives about their PAR maps rather than a final GIS map of their pastures.

We combine PAR mapping processes with the *Nutag* approach and framework to explore herder's view of their pastures (Baival, 2012). *Nutag* is a term depicting indigenous worldviews about hometown, territory, pasture resources, common knowledge and ties to nature (Baival, 2012). *Nutag* is also a conceptual space signified by a physical central point, such as a campsite, dictating practices, norms, and mobility (Murphy, 2011). Baival (2012) recommends a *nutag* framework to donors and NGOs, where local ecological knowledge and adaptive practices are incorporated in pasture management plans and land use contracts. The nutag framework may also guide participatory research tools for examining the role of socio-ecological boundaries in herders' adaptive practices and livelihoods.

STUDY SITE

Study sites were selected within MOR2 research locations and represented diverse ecological zones (Figure 1). Participatory mapping sessions occurred during the summers of 2013 and 2014 in six counties (*soums*): Ikh Tamir in Arkhangai province (*aimag*), Undurshireet in Tuv *aimag*, Tsagaan Ovoo and Sergelen in Dornod *aimag*, and Saikhandulan and Altanshiree in Dornogovi *aimag* (Figure 1).

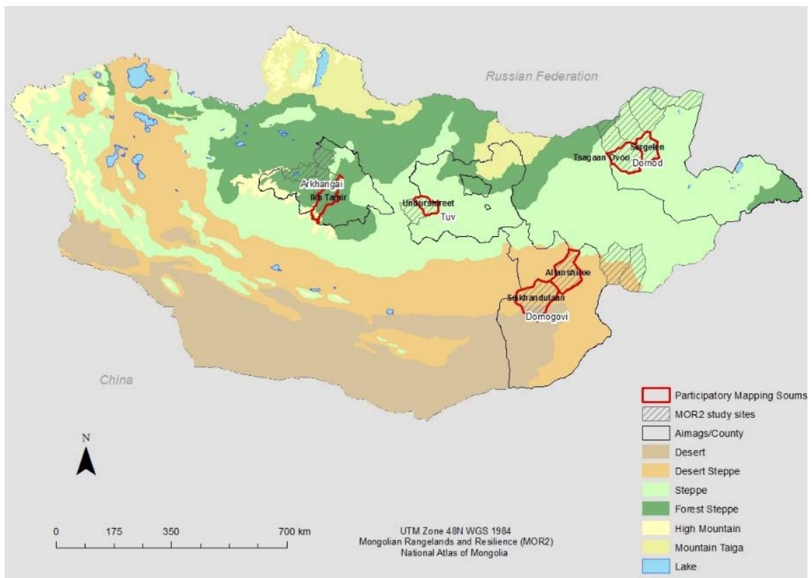

Figure 1. Participatory mapping study sites.

METHODS

We requested the herders to draw places of significance as well as natural and human made features on their *nutag* after herder leaders granted us permission. We purposely gave very little instruction to avoid our western conceptions of boundaries and integrate participant's own ways of thinking. We handed them a blank paper and markers, where families drew their pastures and determined the legend, extent and scale of their map. The participatory mapping processes took 1-2 days for each herder group, particularly as herders negotiated the representation of their pastures. Herders and researchers engaged in conversations about their pastures, especially as we asked questions of why certain places were important to them. As participant observers, we considered these conversations important for developing relationships and learning about herder views of their pastures.

Data sources included the participatory maps, narratives, and informal interviews with herder leaders and APUG representatives (n= 35). Herders' narratives during participatory mapping allowed researchers to move beyond map content for revealing emic perspectives. Field notes documented translated narratives, informal interviews, and personal observations of the participatory mapping process.

Participatory maps and herder narratives were qualitatively coded using grounded theory and visual grounded theory respectively (Konecki, 2011; Strauss and Corbin, 2007). Grounded theory includes the process of generating codes from qualitative data where recurring patterns, themes, codes, and a general theory emerge. Visual grounded theory concentrates on slices of visual data (i.e., maps) and involves constructing categories, memo writing, selective coding, theoretical memo writing, and comparative analyses of images for validating relationships among codes for examining research questions. These analyses allowed for a greater examination of the context and content behind the participatory mapping process.

RESULTS AND DISCUSSION

Participatory Maps and Views of Boundaries

Boundaries in herders' maps included biophysical and human demarcated boundaries of their pastures. We consider these as tangible boundaries since these materially delineate territories belonging to their kin and/or PUG. These boundaries can be categorized into economic, ecological, hydroclimatic, geomorphological, and political. Economic boundaries included seasonal camps, pasture reserves, wells, and roads. These boundaries may be tangible to herders since these delineate visible assets or resources on landscapes. Roads and wells delineate pastures and resources significant for herders. Winter shelters are visible on a landscape and symbolize ownership and exclusion of resources in the surrounding winter camp. Tightly coupled with economic boundaries include vegetation serving as ecological boundaries in delineating suitable pastures for certain types of livestock. Vegetation such as palatable grass for sheep distinguishes pastures and influences forage quality significant for livestock types and livelihoods. Herders' local knowledge on locations of palatable grass was consistently conveyed in herder's maps and noteworthy in determining pastures deemed suitable to herders with a certain livestock composition.

Geomorphological, hydroclimatic, political, and economic boundaries are interlinked, mainly since these influence placement and access of seasonal camps and shelters crucial for herder movement. For instance, the placement of winter camps is partially influenced by geomorphological and hydroclimatic boundaries in rangelands. Geomorphological boundaries such as leeward areas of valleys are ideal sites for winter camps because they shelter livestock serving as economic assets for herding families. Natural springs serve as hydroclimatic boundaries because they delineate water access points for livestock and serve as drivers for seasonal movement and placement of winter camps and shelters. Acquiring winter shelters is mainly driven by inheritance, usually by the senior herder (Fernandez-Gimenez, 2002).Winter shelters serve as economic boundaries and assets that can be owned, bought, and sold by families. Access to winter shelters and reserve pastures especially in times of natural disasters such as *dzuds* involve herders from other *soums* and PUGs crossing political and geomorphological boundaries to access resources.

Narratives of Non-Material Human Demarcated Boundaries and Governance

Herders referred to human demarcated boundaries when they discussed arrangements and contracts for mobility and grazing. These included processes and contracts that influence how pasture resources or assets are accessed, allocated, and utilized (Murphy, 2014), hence serving as *governance boundaries*. These boundaries separate grazing territories, and guide movement for accessing pasture resources and markets.

Narratives of governance boundaries included accessing winter camps, markets, government assistance, and inter and within *soum* migration. The process of accessing winter camps involves traditional arrangements among kin and bureaucratic arrangements among PUGs, Associations of PUGs, soum land officers responsible for developing their pasture management plans and land use certificates. Winter shelters are accessed and secured through long-term leases registered with the soum government. Herding families may have exclusive ownership and secure access to their winter shelters, but do not have legal ownership over the pasture surrounding their winter shelters. Despite the lack of legal ownership of winter camps, it is customary for herders to respect winter camp boundaries. These intangible human-demarcated boundaries are determined by norms, local knowledge, and herder conceptions of their pastures.

Differing views of pastures included the need of flexibility and security to pasture resources, markets, and government assistance especially times of *dzud* (Fernandez-Gimenez et al., 2012). The capacity for accessing goods and government services may create governance boundaries between donor- funded and traditional herder groups (Baival, 2012; Upton, 2008). Significant goods and services evident in herder's narratives included acquiring government loans and donor aid for cashmere processing, haymaking capacity, well maintenance, and transportation services. Accessing markets and government assistance are significant for PUGs who have formal agreements among local soum government.

IMPLICATIONS

Examining socio-ecological boundaries respected by herder groups may be helpful for local and national policy-decision making. The Mongolian parliament has introduced pastureland legislation to provide clear guidelines for legal decision-making in accessing and sustaining pasture resources (Fernandez-Gimenez et al., 2008). Similar to past land laws, gaps exist in allocating access to pasture resources and winter shelters. Integrating herders' perspectives of their pasture boundaries into land laws may address some policy gaps in facilitating herder mobility, promoting stewardship and securing access to pasture resources crossing boundaries. For example, addressing the existence of these pasture boundaries may reveal specific compliance challenges with pasture reserves targeted by multiple aimag and soum officials. Soum officials currently may consult with herder groups across administrative boundaries for improving pasture management plans and securing access to pasture reserves.

Donors and local governments providing assistance to herder groups may focus on human-demarcated boundaries tied to accessing markets and pasture resources. Donors and local governments emphases on biophysical boundaries coupled with livelihood concerns are common approaches for managing sustaining rangelands. The integration of intangible human-demarcated boundaries allows donors to integrate herders' norms into policy for accessing pasture assets, markets, and facilitating herders' mobility.

Participatory mapping is a common donor strategy for integrating herders' local knowledge and perceptions of territories. However, the focus on the sole content of participatory maps may only highlight the tangible physical boundaries and neglect the intangible human-demarcated boundaries influential in herders' livelihoods. The work presented in this paper highlights the significance of participatory mapping narratives in revealing intangible human-demarcated boundaries vital to herders' livelihoods and pastures. Participatory mapping processes may incorporate the nutag approach/framework crucial for co-learning about socio-ecological boundaries in Mongolian rangeland management. Participatory mapping is a recommended process for local governments to use as a meaningful tool for linking herder's knowledge and perceptions with governments and expert knowledge for adaptive capacity building (Baival and Fernández-Giménez, 2012).

ACKNOWLEDGEMENTS

The authors acknowledge Ms. Zulaa's work for documenting field notes and sincerely thank the following herder groups and herders for sharing their world views of their pastures: Ishghent, Bulag, Nogoon Khuv, Bayan nuuriinkhan, Chuluun, Purev, and Amarsanaa. This study was funded by the National Science Foundation Dynamics of Coupled Natural and Human Systems Program (Award BCS-1011801).

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Integrating Herder Observations, Meteorological Data and Remote Sensing to Understand Climate Change Patterns and Impacts across an Eco-Climatic Gradient in Mongolia

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ABSTRACT

Mongolia has one of the strongest climate warming signals on Earth, and over 40% of the human population depends directly or indirectly on pastoral livestock production for their livelihoods. Thus, climate-driven changes in rangeland production will likely have a major effect on pastoral livelihoods. We examined patterns of climate change and rangeland production over 20 years in three ecological zones based on meteorological records, remote sensing and herder observations. We found the strongest trends in both instrument records and herder observations in the steppe zone, where summers are getting hotter and drier, winters colder, and rangeland production is declining. Instrument records and herder observations were most consistently aligned for total annual rainfall, and consensus among herders was greatest for changes in rainfall and production and lowest for temperature changes. We found more differences in herder observations between neighboring *soums* within the same ecozone than expected, suggesting the need for more fine-scale instrument observations to detect fine-scale patterns of change that herders observe.

Keywords: local knowledge, traditional knowledge, climate change, monitoring

INTRODUCTION

Multiple studies using coarse-resolution meteorological station and interpolated data have shown significant warming trends in Mongolia over the past century (Batima et al., 2005; Dagvadorj et al., 2009; Venable et al., 2015). Trends in precipitation are more variable (Dagvadorj et al., 2009). Much less is understood about fine-scale climate changes or their impacts on the amount and timing of forage production (Marin, 2010).

A major concern for Mongolia is how climate change will alter pasture conditions. The combination of significantly increased temperature and minor changes in precipitation leads to increased evaporation, less moisture for plant growth and "pasture droughts" (Nandintsetseg and Shinoda, 2013). Remote sensing studies have demonstrated declines in greenness (Liu et al., 2013), while some long-term field studies show no change or an increase in total biomass (Khishigbayar et al., 2015). In response to predicted changes in temperature and soil moisture, the desert steppe ecoregion is expected to expand in extent, and the steppe and mountain and forest steppe are expected to contract (Angerer et al., 2008; Dagvadorj et al., 2009).

Local ecological knowledge (LEK) provides observations on climate and pasture changes that may complement and enrich instrumental records and ecological field data (Klein et al., 2014), including information at finer spatial resolutions (Marin, 2010; Klein et al., 2014). Past LEK studies on the Mongolian Plateau and Tibet have focused on herder observations of changes in streamflow (Fassnacht et al., 2011), increasing temperature and increasingly variable rainfall (Marin, 2010), and pasture condition changes (Bruegger et al., 2014; Klein et al., 2014). In some cases, herder observations were directly compared with instrument records and found to align with them (Fassnacht et al., 2011), while in others herders observed changes in precipitation not detected with instrument records (Marin, 2010; Li et al., 2014).

Objectives and Hypotheses

To better understand climate change trends and their impacts on herders, and whether coarse-resolution climate and remote sensing data identify local-level impacts observed by herders, this study examines and compares patterns of change in climate and rangeland production across an ecological gradient based on herder observations, interpolated meteorological data, and satellite imagery. Based on previous climate and LEK research in Mongolia and nearby regions, we hypothesized that both meteorological records and herder observations would detect strong warming trends, and that both satellite imagery and herders would detect declines in production/greenness over all study sites, with the greatest changes observed at higher latitudes and elevations. We expected trends in precipitation would be more varied across zones with less agreement between meteorological records and herder observations. We further expected that herder observations would be similar between *soums* in the same ecozone and that herder consensus on change would be greatest regarding temperature and production, and lower regarding rainfall amount and frequency.

STUDY SITES

Our study sites include 2 *soums* per ecozone for 3 ecozones lying in a north-south gradient from the mountain and forest steppe (Bayangol and Saikhan, Selenge *Aimag*), to the steppe (Undurshireet and Erdenesant, Tuv *Aimag*) and desert steppe (Ulziit and Undurshil, Omnogobi *Aimag*).

METHODS

Meteorological and Remote Sensing Data

We used the Global Historical Climate Network dataset for temperature (Lawrimore et al., 2011) and the Climate Prediction Center Unified Precipitation dataset for precipitation (Chen et al., 2008). Both are 0.5º x 0.5º resolution. We used 1993-2013 for temperature and 1993-2012 for precipitation in our analysis, and for precipitation we calculated a 5-year moving average. We used number of days without rainfall as an indicator of rainfall frequency. We used GIS to calculate average values for each pixel in the grid by year and then calculated *soum* and ecozone averages for each variable**.** We used AVHRR-NDVI (normalized difference vegetation index) data at 8 km x 8 km resolution (Pinzon and Tucker, 2014) from 1993 to 2009 as our proxy for rangeland production (Tucker et al., 1985). We used TIMESAT software (Eklundh and Jonsson, 2009) to extract time series variables, which included small integral NDVI, an estimate of annual production that excludes residual biomass from prior years, start of season (green-up), and end of season (brown-down). We used the non-parametric Mann Kendall test to evaluate the significance of changes over time for all variables and when significant calculated the Sen's slope (Gilbert, 1987).

Herder Survey

We surveyed a spatially representative convenient sample of herders in the 6 *soums* using a closed-ended questionnaire that asked about their observations of climate and rangeland changes from 1993 to 2013. Responses were on a 5-point Likert-type scale from -2 "decreased a lot" to +2 "increased a lot". Respondents included 62 men and 47 women ranging in age from 29 to 87 years old and had lived in their area from 10 to 87 years.

To compare the direction and magnitude of herder-observed changes among ecozones, we used one-way ANOVA, with Bonferroni-corrected post-hoc comparisons. To compare herder-observed changes between *soums* within each ecozone we used t-tests. To assess the level of consensus in herder observations within and between communities and ecozones, we used the Potential for Conflict Index (PCI_2) (Vaske et al., 2010). A PCI_2 of 1 represents the least amount of consensus and the greatest variability among herder observations. A PCI_2 of 0 illustrates a distribution with 100% at one point on the response scale, indicating complete consensus among respondents (Vaske et al. 2010).

RESULTS

Changes in Climate, Production and Phenology from Meteorological and Remote Sensing Observations

Meteorological observations showed that summer temperatures increased significantly in both steppe *soums* and one desert steppe *soum* (Undurshil) over the past 20 years (Table 1). Winter temperatures decreased significantly in all mountain and forest steppe and steppe *soums*. Annual precipitation declined significantly in all steppe and desert steppe *soums*. The number of days without rainfall significantly increased in all mountain and forest steppe and steppe *soums*, indicating declining frequency of rainfall events.

Small integral NDVI decreased significantly in both steppe *soums*, and increased in one desert steppe *soum* (Undurshil). Although there were no significant changes in spring green-up times, the direction of the trends differed among zones, with a trend towards earlier green-up in the mountain and forest steppe and desert steppe and later green-up in the steppe. Brown-down in one steppe *soum* (Erdenesant) was significantly earlier over time.

Herder Observations of Change

A majority of herders in all ecological zones observed that spring temperatures are cooler than 20 years ago (Figure 1). Herders in Saikhan observed more extreme cooling than those in Bayangol ($t = -2.001$, $p = .053$). Most observed that summer temperatures have cooled but others, especially in Undurshireet (steppe), observed warmer summer temperatures in contrast to their neighbors in Erdenesant ($t = 4.078$, $p = .002$). Herders were divided in their observations of fall temperatures with about half observing cooler falls and the rest observing no change or warmer fall temperatures (Figure 1b). Again Undurshireet and Erdenesant herders differed significantly in the trends of their observations ($t = 3.321$, $p = .003$), with 75% of herders in Undurshireet observing warmer falls. Observations of winter temperatures were variable, with nearly half of all desert steppe herders observing warmer winters, and half of steppe herders and more than half of mountain and forest steppe herders observing cooler winters. Observations of winter temperature trends differed significantly between the desert steppe and each of the other zones ($F = 6.006$, $p = .003$).

Most herders observed moderate to extreme declines in rainfall amount over the past 20 years. Observed changes were greatest in the steppe and desert steppe with a substantial minority of herders in the mountain and forest steppe observing no change or a slight increase in precipitation. Mean observations differed significantly between the mountain and forest steppe and the other two zones ($F=5.449$, $p=.006$). Most herders observed an increase in the time between rainfall events (rainfall interval), but a substantial minority of herders in Bayangol (mountain and forest steppe) saw no change or a slight decrease in rainfall interval, leading to a significant difference in mean observations between the mountain and forest steppe and other zones ($F=9.696$, $p<.001$).

Across all ecological zones, herders observed moderate to substantial declines in pasture production over the past 20 years. However, herders in neighboring *soums* in the mountain and forest steppe ($t=-2.657$, $p=.013$) and steppe ($t=-2.405$, $p=.024$) differed significantly in the extent of decline observed, with Saikhan (mountain and forest steppe) and Undurshireet (steppe) observing more extreme declines. All herders observed later green-up than 20 years ago, with similar differences in the observed degree of delay between *soums* within the mountain and forest steppe ($t=2.465$, $p=.019$) and steppe ($t=2.00$, $p=.055$). A majority of herders observed earlier brown-down at the end of the growing season, but in the desert steppe, Ulziit herders observed earlier brown-down than Undurshil herders ($t=2.073$, $p=.045$).

PCI_2 analysis revealed the least consensus about changes in summer, fall and winter temperatures, and most consensus on production, green-up time, rainfall amount and rainfall frequency (Figure 1). In the steppe, there was complete consensus ($PCI_2=0$) that pasture growth decreased, green-up is later, and rainfall interval increased.

DISCUSSION

Meteorological records, satellite imagery, and herder observations all indicate that the steppe study sites are experiencing the strongest changes in climate and rangeland production, with increasingly hot and dry summers, colder winters, and declining production. These findings do not support predictions that the largest changes will be observed in the highest latitudes and elevations, i.e., the mountain and forest steppe.

Contrary to our hypothesis, we found more differences in herder observations between *soums* than between ecozones. Most within-zone differences between *soums* related to observed changes in production, phenology and spring, summer and fall temperatures, whereas differences between zones concerned rainfall and winter temperatures. Between-zone differences in herder observations mirrored instrument records for those zones. Within-zone differences between *soums* may indicate that herders are responding to real differences in local conditions not detected by coarse-resolution meteorological and remote sensing measurements.

We hypothesized that herder consensus would be greatest about temperature and rangeland production and lowest about rainfall amount, frequency and vegetation phenology. Instead, consensus was greatest about production, phenology and rainfall amount and frequency, and lowest about temperature. One explanation is that herders pay closer attention to rainfall because it is directly linked to pasture production amount and timing, on which their livelihoods depend (Marin 2010).

Across all *soums* and zones, both herders and the meteorological record observed negative trends in total rainfall amount. The greatest concordance between local observations and the instruments was in the steppe, where observations of the direction of change matched for 7 of 9 variables, and 5 of these were statistically significant in the instrument record. Mountain and forest steppe herder observations aligned with instrument records for 5 variables, of which 2 showed statistically significant trends in the instrument record. Desert steppe herder observations only aligned with one instrument record (annual rainfall), and contradicted instrument record trends in brown-down (Ulziit) and summer temperatures (Undurshil). Rather than concluding that herder observations are inaccurate, as some have done (Li et al. 2014), we suggest that finer-resolution meteorological and pasture production data are needed to explain the apparent inconsistencies. As Klein et al. (2014) showed, herder observations may contribute to understanding fine-scale variability in important climate change impacts such as phenology.

Table 1. Rate of change in temperature (degrees Celsius per year), precipitation (mm per year), greenness (NDVI) and phenology based on meteorological and remote sensing data. Changes analyzed using the Mann-Kendal test (Z-statistic) and Sen's slope. Significant trends are highlighted, and significance is indicated as * p<0.05, ** p<0.01, *** p<0.001. All variables are from 1993-2013 except for amount of rainfall (1993-2012) and NDVI, green-up and brown-down (1993-2009).

	Mountain and Forest Steppe		Steppe		Desert Steppe	
	Bayangol	Saikhan	Undurshireet	Erdenesant	Ulziit	Undurshil
spring temp	-0.015	-0.027	-0.011	-0.027	0.03	0.022
summer temp	0.04	0.028	0.084*	0.084*	0.05	0.086*
fall temp	0.104	0.108	0.097	0.081	0.029	0.051
winter temp	-0.234*	-0.266*	-0.174*	-0.218*	-0.091	-0.076
amount of rainfall	-2.085	-1.508	-4.5*	-5.417*	-2.734***	-2.199*
days between rainfall	1.778***	1.458**	1.303*	1.545***	-0.226	0.127
greenness (small integral NDVI)	-0.039	-0.028	-0.09*	-0.82*	-0.003	0.082*
green-up	-0.491	-0.494	0.554	1.215	-0.531	-2.676
brown-down	-0.045	0.141	-3.57	-0.666**	1.295	0.042

CONCLUSION AND IMPLICATIONS

Our findings suggest that herder observations are generally highly consistent within communities and that where significant changes are detected by instruments, herders are also observing these changes (i.e. steppe zone). Across all ecological zones the greatest concurrence between instrument records and herder observations was declining rainfall amount. The significant differences in herder observations within ecozones for some variables could indicate that herder observations detect changes at finer spatial resolutions than some coarse-resolution instrument measurements. The lack of instrument data at resolutions meaningful for local pasture management suggests the need to build capacity for rangeland and meteorological monitoring to track changes and communicate local impacts to higher-level decision-makers. Herder observations can complement existing instrument records and highlight areas to prioritize for fine-resolution formal monitoring. Further research is needed to document the livelihood and management impacts of the changes herders are observing.

ACKNOWLEDGEMENTS

We thank Purvee Galmandakh for his assistance with the herder survey. This work was supported by the National Science Foundation under CNH Program Grant No. BCS-1011 *Does community-based rangeland ecosystem management increase the resilience of coupled systems to climate change in Mongolia*?

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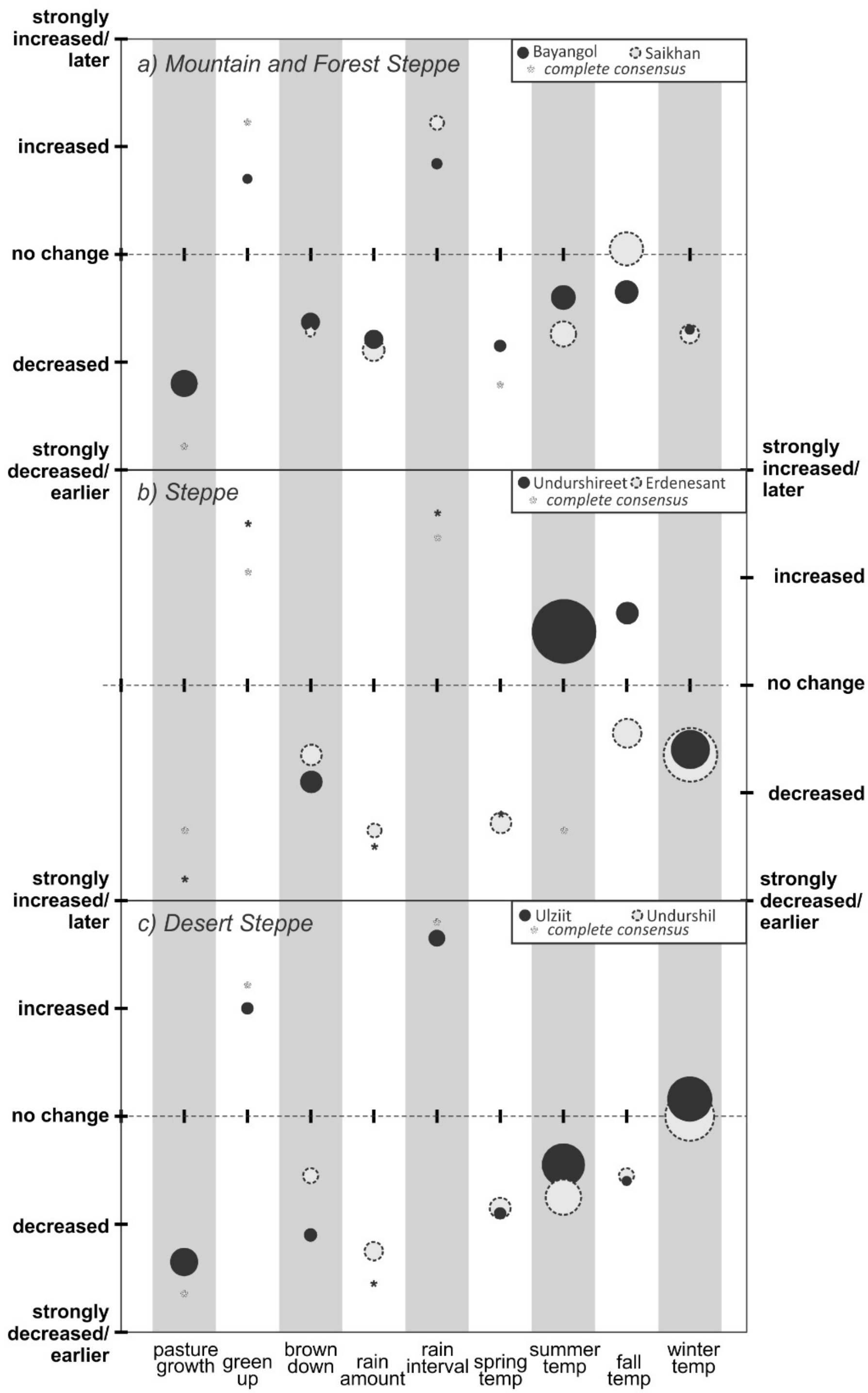

Figure 1. PCI2 results reflecting the amount of consensus regarding a given observation in the a) mountain and forest steppe, b) steppe, and c) desert steppe. A small bubble represents high consensus and a large bubble represents low consensus. Bubble centers represent the mean response.

Evaluating the impact of climate change based on herders' observations and comparing it with hydro-climatic and remote sensing data

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ABSTRACT

Studying the impact of recent years' climate change on Mongolian rangeland livestock husbandry and on pastoral herders' livelihoods, based on herders' observations and their experience, is an approach that is of considerable interest to many scientists. Our research identifies changes in natural conditions and climate, as well as the changes in rangeland conditions, as observed by herders, and compares them against weather stations' multi-year observations and remote sensing data. Our research region of Khanbogd, Manlai and Bayan-Ovoo *soums* of Umnugobi *aimag* has been, in the recent years, experiencing a rapid development of the mining industry and human population growth. According to local herders, current rangeland quality greatly decreased compared to the period before the year 2000, while the area of barren land, sand movement and soil erosion increased. Herders also said that the amount of rainfall diminished and the rainy season's duration shortened, short high intensity rains grew in number, and it became extremely hot in summer. Soum weather station records of air temperature, precipitation and evaporation confirmed herders' observations, and were consistent with Normalized Difference Vegetation Index (NDVI) or the results of observations of rangeland vegetation phenology. To develop local adaptive capacity in the face of changing social-ecological systems it is important to use and integrate multiple sources of information that are essential for making policy implementation mechanisms and measures more locally appropriate and relevant.

Key words: herders' observations, climate change, rangeland degradation

INTRODUCTION

In Mongolia, there are relatively few climate and rangeland monitoring points in the national network of hydro-climatic and environmental research, and consequently data coverage is poor and inconsistent (Addison et al., 2012). Due to this situation, the traditional knowledge of local environments can be used as one of the sources of information revealing rangeland transformation and change (Berkes, 2008; Bruegger et al., 2014). Herders are able to observe and indicate climate and rangeland changes which not yet been confirmed by weather measurement (Fassnacht et al., 2011; Addison et al., 2012; Venable et al., 2012). Climate change in Mongolia in recent years has been 2.4 times more intense than the world average, and the agriculture sector is more vulnerable than other sectors to its impact (MARCC, 2014). Temperature increases are clearly observed in the mountain regions, while they are relatively less revealed in the gobi desert zone (Batima et al., 2005; Hilker et al., 2013; Liu et al., 2013), although the desert steppe area's northerly expansion has been detected (Angerer et al. 2008). The desert steppe region is a non-equilibrium ecosystem, thus it is transforming because of climate change rather than livestock grazing (Fernandez-Gimenez and Allen-Diaz, 1999). Combining herders' long-term observations and experience with the expert-generated hydro-meteorological data, for the purpose of adaptation to climate change, can be seen as an indicator of capacity building suitable to particular region specifics (Batkhishig, 2012).

According to The Second Assessment of Climate Change, while generally the amount of winter precipitation is gradually growing in Mongolia, it is increasing more in the western and central parts of the country than in other areas, whereas in the southern and south eastern parts the summer precipitation is declining, the aridity index is increasing, the number of extremely hot days is growing, and this situation is likely to persist (MARCC, 2014).

Based on the assumption that herders' observations and their traditional practices and experiences can play an important role in evaluating local climate and rangeland change (Bruegger et al., 2014), we evaluated the changes occurring in the rangeland of our target region by comparing herders' observations with multi-year weather and remote sensing data. We predicted that the perceptions of herders, who observe the weather and their local rangelands on the daily basis, would be consistent with the multi-year observation data from weather stations.

STUDY SITE

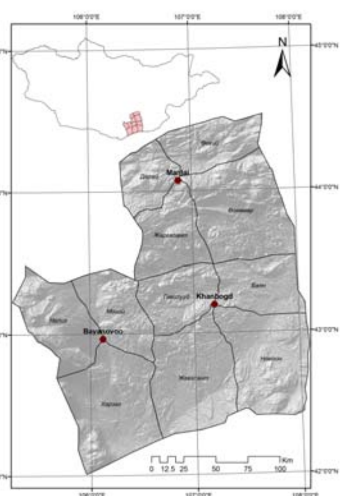


Figure 1. Study region

Research was undertaken in Khanbogd, Manlai and Bayan-ovoo *soums* of Umnugobi *aimag*, and these *soums* belong to the desert and desert steppe region, where the dominant vegetation includes *Anabasis brevifolia*, *Nitriria sibirica*, *Caragana gobica*, *Salsola passerine, Cliestogenes songorica and Stipa gobica* (Ulziikhutag, 1989; Grubov, 2008). 63-102 mm of precipitation per year falls in this region. Due to the recent intensive development of the mining industry in this region, the human population and number of livestock in the area is rapidly growing. In particular, in Khangai *soum* 43,725 head of stock, in Manlai *soum* 65,517 head of stock, and in Bayan-Ovoo *soum* 53,375 head of stock were counted in 2003, while in 2013 that number became 126,003 head of stock in Khanbogd *soum*, 117,787 head of stock in Manlai *soum* and 89,577 head of stock in Bayan-Ovoo *soum*.

STUDY METHODS

A survey of herders, time-series of precipitation and air temperature data from the weather stations and AVHRR Normalized Difference Vegetation Index (NDVI3g) were the data used in the study.

In June 2014 a field research team together with the team leaders met with the herders of above mentioned three *soums*, and interviewed them using a closed-ended survey. A total of 124 herders participated in the survey, out of which 40 were from Khanbogd *soum*, 46 were from Manlai *soum*, and 38 were from Bayan-Ovoo *soum*. When choosing the survey participants the research team randomly select herders who have lived in the particular *soum* for a number of years and who were qualified and experienced in raising livestock. The survey had in total 15 questions and included questions about changes in rangeland conditions, vegetation, precipitation, air temperature, lakes, water wells, water table, sand and dust storms and the distribution of animals.

Statistical analysis of precipitation and air temperature data using regression and correlation were done on data collected between 1981 and 2012 by the weather station in Khanbogd *soum,* and between 1993-2012 by the weather station in Manlai *soum*. Analyses were conducted using SPSS software. Data quality from the weather station at Bayan-Ovoo *soum* was inadequate for statistical analysis, and only qualitative data are presented for this *soum*. Evaporation is rarely measured in Mongolia, and so was calculated using the Penman–Monteith equation (1) by Instat software (Stern et al., 1998).

$$ET_0 = \frac{0.408\,\Delta\left(R_n - G\right) + \gamma\,\frac{900}{T + 273}\cdot u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34\,u_2\right)} \qquad (1)$$

where ET_o = evapotranspiration (in mm/day), R_n = net radiant flux received by vegetation cover surface (in W/m^2 per daytime), G = soil heat flux (in W/m^2 per day), T = daily average air temperature (in °C), u_2 = wind speed at 2 meters height (in m/sec), e_s - e_a = humidity deficit (in kPa), Δ = humidity deficit curve slope (in kPa /°C), and g = psychrometric constant (in kPa $°C^{-1}$).

To evaluate vegetation condition AVHRR Normalized Difference Vegetation Index (NDVI3g) we used data from 1982-2012, the processing was done by cartography software such as GIS 10.1 and ENVI 4.4.

RESULTS

Changes in the weather and rangeland according to herders' observations

Herders believed that less precipitation, higher air temperature and more soil erosion and consequent dust storms in the research area over the last 20 years have led to rangeland degradation. Specifically, 54% of herders thought that rangeland production had decreased, and 64% thought that the number of plant species had decreased, in the last 20 years (Table 1). Herders said that nutritious livestock grasses such as *Artemisia frigida*, *Allium polyrrhizum*, *Allium senescens*, *Psammochloa villosa* had stopped growing, and plants such as *Artemisia adamsii* and *Corispermum mongolicum* had become dominant in the steppe, which they used as evidence of rangeland degradation. 61% of herders thought that nutritious edible plants had diminished in number and 37% said that size of bare patches in the rangeland had expanded, and they explained the reason as being due to increases in sand movement (39.5%) and soil erosion (50.8%) due to loss of topsoil. Also herders said that 20 years ago medicinal herds such *Rhodiola rosea* and *Thymus gobicus* were abundantly growing, but had now become scarce.

Table 1. The changes in rangeland, soil and vegetation, as observed by herders. Note**:** Values show the number of herders which observed each change and the percentage rate for the total survey.

Changes occurring in the rangeland (*compared to the period before the year 2000*)	Khanbogd (n=40)		Manlai (n=46)		Bayan-Ovoo (n=38)		Total (n=124)	
	%	(n)	%	(n)	%	(n)	%	(n)
Rangeland production worsened	57.5	(23)	47.8	(22)	57.9	(22)	54.03	(67)
Vegetation species number decreased	77.5	(31)	50	(23)	68.4	(26)	64.5	(80)
Nutritious plants stopped growing	70	(28)	45.7	(21)	71.05	(27)	61.3	(76)
Size of barren patches expanded	40	(16)	32.6	(15)	39.5	(15)	37.1	(46)
Sand movement increased	45	(18)	36.9	(17)	36.8	(14)	39.5	(49)
Soil erosion increased	60	(24)	36.9	(17)	57.9	(22)	50.8	(63)

When comparing current climate conditions with conditions before the year 2000, herders perceived that in the last 20-30 years the rainfall amount had dropped, its intensity increased, and its duration shortened (Table 2). Herders thought this had led to heavy intense rainfalls with a short duration and flooding, causing topsoil erosion, and a shorter plant growing season. Herders also reported that the amount of snow has slightly increased, and has started melting earlier. In the last 20 years they thought that the water levels of rivers, lakes, springs, and wells have declined and there have been more instances of water bodies drying up.

Table 2. The changes in weather and climate, as perceived by herders. Note**:** Values show the number of herders which observed each change and the percentage rate for the total survey.

Weather changes (*compared to the period before the year 2000*)	Khanbogd (n=40)		Manlai (n=46)		Bayan-Ovoo (n=38)		Total (n=124)	
	%	(n)	%	(n)	%	(n)	%	(n)
Amount of precipitation reduced	82.5	(33)	73.9	(34)	44.7	(17)	67.7	(84)
Temperature changes (Intense heat, increased cold weather)	35	(14)	36.9	(17)	47.4	(18)	39.5	(49)
Drop of water level of wells and springs	87.5	(35)	93.5	(43)	73.7	(28)	85.5	(106)
Increase in frequencies of dust storms	55	(22)	43.5	(20)	52.6	(20)	50	(62)

Khanbogd *soum's* Gaviluud *bag's* herder S.Bud (age 71) said: "In the last years the rain either doesn't fall for some time or when it rains it falls very heavily and intensily in a short period of time", Manglai *soum's* Oekhii *bag's* herder B.Luvsannorov (age 62) said: "Now even the rainfall has ceased happening, only sometimes when it rains it falls heavily and intensily, pulling out a little remainder of short grass by root", Bayan-Ovoo *soum's* Kharzag *bag's* herder Tseren (age 64) said: "The soil lost its strength to hold plant roots and when a little heavy rain falls plants are washed away with it".

Climate and remote sensing (NDVI)

In order to compare the herders' observations with multi-year data documentation we analyzed each *soum's* air temperature, precipitation, evaporation and vegetation conditions (Figure 2).

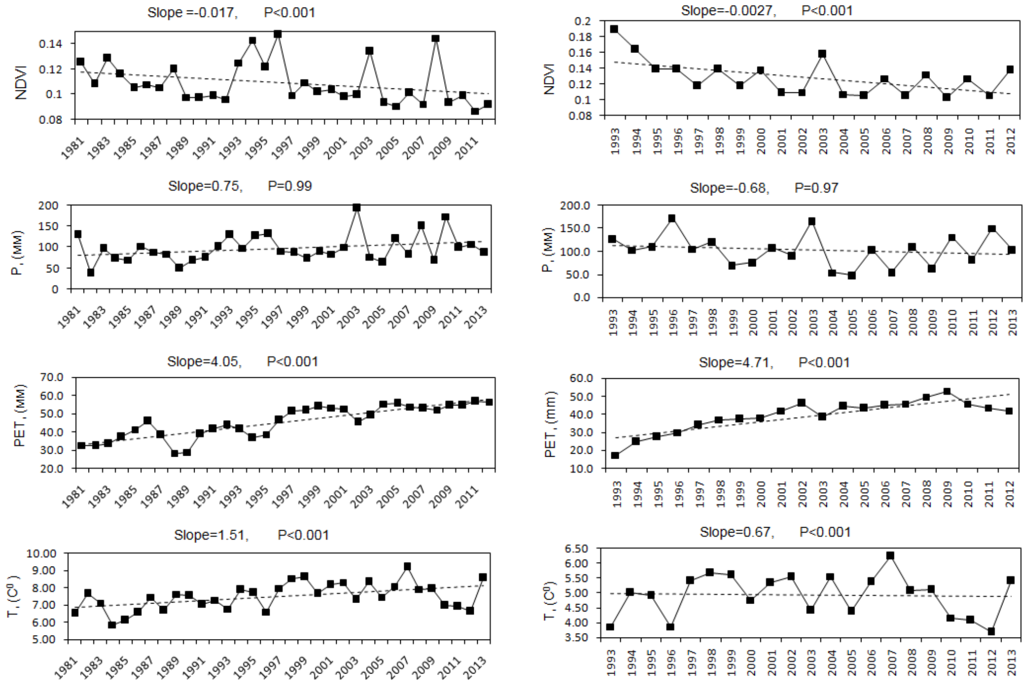


Figure 2. Changes in NDVI, precipitation (P), evaporation (PET) and air temperature (T) and in (a). Khanbogd *soum* of Unmugobi *aimag* (b). Manlai *soum* of Unmugobi *aimag*.

From the last 32 years pattern in Khanbogd *soum* (Figure 2a) the vegetation condition or NDVI value has decreased on average by 0.017 (p<0.001), air temperature increased by 1.51 degrees (p<0.001) and evaporation increased by 4.05 mm (p<0.001). While a trend in precipitation increase by 0.75 mms was observed, this was not statistical significant (p=0.99). From the last 20 years pattern in Manlai *soum* (Figure 2b) the vegetation condition or NDVI value has decreased on average by 0.0027 (p<0.001), precipitation decreased by 0.68 mms was observed, this was not statistical significant (p=0.97), evaporation increased by 4.71 mms (p<0.001) and air temperature increased by 0.67 degrees (p<0.001).

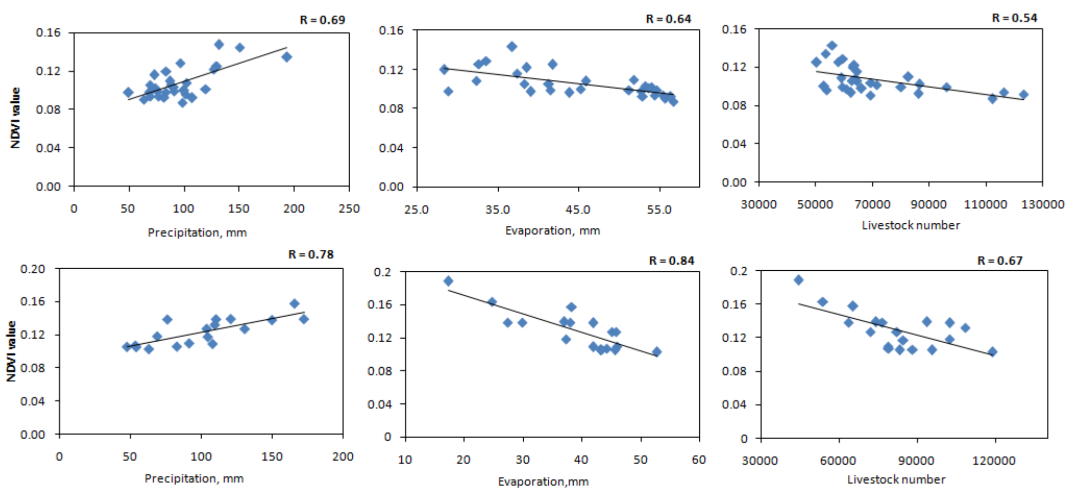


Figure 3. Correlation of precipitation, evaporation, livestock number and NDVI value in (First row-Khanbogd *soum* of Unmugobi *aimag,* Second row- Manlai *soum* of Unmugobi *aimag)*.

The results above indicate that precipitation, evaporation and livestock number considerably influence vegetation growth in Khanbogd and, Manlai *soums* (Figure 3). As seen from the figure, relation between NDVI value and precipitation or correlation coefficient in Khanbogd *soum* is r=0.69 and in Manlai *soum* is r=0.78, and as for evaporation in Khanbogd *soum* it is r=0.64, and in Manlai *soum* it is r=0.84 and as livestock number in Khanbogd *soum* it is r=0.54 and in Manlai *soum* it is r=0.67.

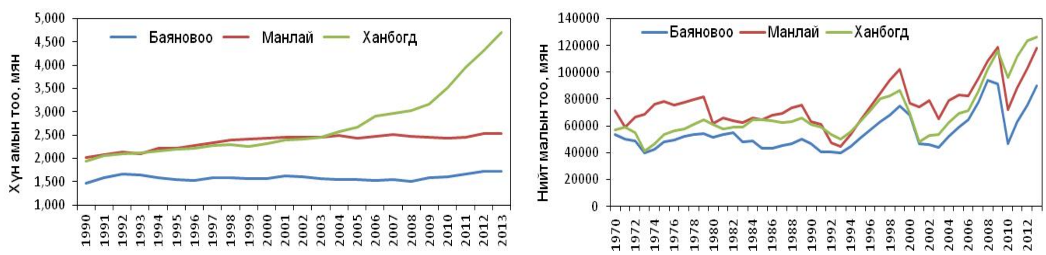
THE ROLE OF EXTERNAL FACTORS

Herders said that the changes occurring in their local rangeland were not only influenced by climatic factors, but also impacted by human activities. In particular, they attributed changes to factors including many new boreholes being sunk, high levels of groundwater use, a large number of heavy machines roaming over the land causing breaking and crushing of soil layers, multiple new roads being formed, and widespread mining.

The Oyu Tolgoi mine in Khanbogd *soum* of Unmugobi *aimag* began intensive activities in 2008, and mine site occupies 0.67% of total *soum* territory of 10058.67 ha[1]. There are several other projects are being operated in this *soum, such as* other small-scale private mines, China Sonhua LLC[2], and road infrastructure associated with these mining projects. As of 2014, all these small to large scale projects occupied an area 572779 ha or 38.2% of total *soum* territory. In Manlai soum the area affected by mining and associated roads takes up 6.5% of the total *soum* area, and in Bayan-Ovoo *soum* the area affected by coal mining and roads is 22.7% of the total *soum* area. These values support herders' observations of the rangeland diminishing in size in the recent years.

We compared human population and livestock number (Figure 4). In recent years, the population of Khanbogd soum has rapidly grown, and livestock numbers have grown gradually, especially after *dzud* 2010 the livestock number has grown rapidly.

Based on our results, it is seen that climate indicators and increase in livestock number have a complex impact on the rangeland vegetation. In other words, the trend is observed that in the years with increased precipitation, NDVI value increases, and in the years with higher rate of evaporation and higher livestock numbers, NDVI value decreases. In all three *soums* the multi-year average of air temperature and the evaporation increased, and, compared to the year 2000, livestock number increased by 42% in Bayan-ovoo *soum*, by 68% in Manlai *soum*, and by 83 % in Khanbogd *soum*, and by 2014 reached highest level ever registered (96,465 in Bayan-ovoo *soum,* 128,835 in Manlai *soum* and 126,467 in Khanbogd *soum*).



(а) (б)

Figure 4. Human population and livestock number changes in three *soums*: (a). Population number, (б). Livestock number (*Source:* National Statistical Office)

[1] Source: "Oyu Tolgoi" LLC, Local and regional development department officer N.Munkhbayar

[2] The chief of Khanbogd *soum* "Gobi land and soil" NGO L.Battsengel and the governors of *soums*.

DISCUSSION AND IMPLICATIONS

Herders of the three *soums* share a common conviction that the decrease in rangeland area size contributes to rangeland degradation by increasing the grazing pressure on the remaining rangeland area. The rapid development of the mining industry in recent years was responsible for rangeland loss, as some areas previously used for pasture were converted to mining infrastructure and road construction.

Our general hypothesis that herders' daily observations of the weather and local rangeland conditions will conform to the results of statistical analysis of the weather stations' multi-year observation data, was confirmed by our study results. However, the station data did not show significant declines in precipitation, as herders observed. Herders, using their long term knowledge and experience, have acquired their own concept of exploring natural conditions (Berkes, 2008), which tends to guide their daily decisions and practices (Gadgil et al., 2003). Appropriate adaptation to the social-ecological changes would require ability to use information from different sources (Batkhishig and Fernandez-Gimenez, 2012) and there is potential to integrate expert and traditional knowledges at local soum level to inform rangeland management.

In this study, we compared the time series of climate data collected from the stations with herder knowledge that guides their livelihoods and it could be considered as relevant only for the local scale (Sillitoe, 1998). It appears that herders' knowledge could serve as one of the information sources to explain the trends in local scale rangeland vegetation and local climate change. Recognizing the limited network of rangeland monitoring stations in Mongolia, herders knowledge and observation of climate and vegetation changes could complement climate time-series of data and provide more accurate and practical explanations to the trends.

The question of carrying capacity in the face of changing climate, livestock growth and decreased rangeland area has become a main concern for three *soums*. The local government and community herders are eager for prompt implementation of locally and ecologically appropriate rangeland management practices. It may be helpful to consider using local knowledge to understand climate and vegetation trends and inform local and *aimag* policy and planning on rangeland and risk management and early warning.

ACKNOWLEDMENTS

The authors of this paper would like to thank all supporters who helped with data and material. We are grateful to Nutag Partners national which collected the basic material for this research work, as well as to Oyu Tolgoi LLC., the herders from Khanbogd, Manlai and Bayan-Ovoo *soums*, who participated in the research, and members of united rangeland team. Texas A&M University professor Jay Angerer provided satellite data, IRIMHE, ERS research scientists B. Gantsetseg and S.Sunjidmaa gave methodical advice about NDVI data processing and two reviewers who provided valuable ideas and recommendations for our research paper.

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