Understanding the coupled natural and human systems in Dryland East Asia

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Abstract

Stressors including regional climate change, economic development effects upon land use and an increasing demand for food production have resulted in significant impacts on the dryland ecosystems in the East Asia (DEA) region. Ecosystem services, such as its provisional services in providing forage for grazing as well as its functional services in regulating water and carbon fluxes, have been significantly altered over the past three decades. Conversely, changes in the landscape, particularly land cover types, have also been blamed for intensified climatic events such as dust storms and severe and frequent droughts within the region. The interactive nature of climate, ecosystems and society is complex and not fully understood, making it difficult, if not impossible, to develop effective adaptation strategies for the region. A special synthesis workshop on ‘Dryland Ecosystems in East Asia: State, Changes, Knowledge Gaps, and Future’ was held from 18–20 July 2011 in Kaifeng, Henan Province, China, with the aim of identifying knowledge gaps, quantifying impacts and developing a future research agenda for the region. The specific objectives of this workshop were to answer some key socio-environmental questions, including the following. (1) What do we know about the drylands in DEA? (2) What are the knowledge gaps? (3) What are the solutions to these issues? This paper provides a synthesis of the workshop consensus and findings on the state of knowledge and challenges in addressing these science issues for the DEA region.

Keywords: climate change, dryland ecosystems, coupled natural and human systems, East Asia

1. Introduction

Dryland East Asia (DEA) is defined in this paper as a geographic area that encompasses the country of Mongolia (MG) and four provinces and autonomous regions in China, including Ningxia Hui Autonomous Region (NX), Xinjiang Uyghur Autonomous Region (XJ), Inner Mongolia Autonomous Region (IM) and Gansu (GS) Province of China (figure 1). The total land area is ~4.8 million km²—equivalent to approximately half of the USA or People’s Republic of China total terrestrial area. The majority of soils fall within the arid, high-erodibility clay soil type (Batjes 2010) while the precipitation and temperature vary considerably from west to east and from north to south. The land cover type is dominated by grassland, including desert-steppe (Groisman et al 2009, John et al 2009).

In the DEA region, the lifestyle was traditionally nomadic herding but that has recently changed due to a multitude of factors including climate change and economic development pressures. An increasing occurrence of extreme climate events such as drought and severe winter snow storms has made these nomadic lifestyles involving animal husbandry challenging. Demand for meat production from surrounding countries and provinces imposes additional pressures to change from extensive nomadic grazing production systems to confined feeding by converting grazing lands to highly productive...
but highly intensive, energy dependent cropping systems in the region (Sankey et al. 2009). Recent increases in energy demand have also escalated the commercial exploitation of natural resources, such as coal mining industries, resulting in unexpected socioeconomic and environmental consequences (Fortes 1988).

The complexity of the coupled climate, ecosystems and society presents a major challenge in understanding the nature of these interactions. It is nearly impossible to develop effective, balanced strategies to cope with these continued climate changes (Higgins et al. 2002, Liu et al. 2007) unless we create the basis for this balanced approach. The purpose of this paper is to summarize the current state of knowledge, identify gaps, and advocate future research needs in the DEA region, based on a special synthesis workshop on ‘Dryland Ecosystems in East Asia (DEA): State, Changes, Knowledge Gaps, and Future’, held from 18–20 July 2011 in Kaifeng, Henan Province, China. The specific objectives of the workshop were to answer some key socio-environmental questions, including the following. (1) What do we know about the drylands in DEA? (2) What are the knowledge gaps? (3) What are the solutions to these issues? This paper is a synthesis of the results and discussions presented during the workshop.

2. Climate change is evident in DEA

There has been significant impact upon the dryland region of East Asia in the form of global climate anomalies (figure 2). From 1909 to 2009, temperature anomalies, defined as significant deviations from the mean temperatures of the region, were concentrated in the DEA region and the northern part of the north hemisphere (Hansen et al. 2010). The climate anomalies also exhibited a very heterogeneous spatio-temporal pattern (Das and Parthasarathy 2009, New et al. 2000), suggesting that climate impact assessments and mitigations or adaptations should be location-specific. The frequency of extreme events increased by as much as 5% in some areas over the past 30 yr, in comparison with the average from 1961 to 2010, manifested in the frequent occurrence of extreme low/high temperatures and precipitation intensity and the duration of events such as drought and severe winter storms (figure 2). An increasing number of extreme climate events are occurring in the region (Salinger et al. 2000, O’Brien and Leichenko 2000, Groisman et al. 2009, Lu et al. 2009).

For example, between 1940 and 2008, the air temperature in Mongolia (MG) increased by more than 2 °C and nine out of the ten warmest years occurred after 1990 (Lu et al. 2009). Similarly, records across Inner Mongolia (IM), Ningxia (NX), Gansu (GS) and Xinjiang (XJ) in China exhibited increases in temperature while the precipitation remained unchanged in all areas except XJ (e.g., Liu et al. 2005, Zhang et al. 2009). The fact that XJ experienced a wetter trend, particularly in the northern part of the autonomous region, was likely a result of increased evaporation from the glaciers in the Tianshan Mountains (Chen et al. 2005, Shi et al. 2007), which drifted to the north as a form of precipitation.

3. The socioeconomic consequences of climate change are significant

Extreme climate events have caused major economic disasters, reflected in the reduction of livestock in the DEA region (Shi et al. 2007, Qian and Lin 2005). For example, the amount of drought or severe winter storms closely coincided with severe losses of livestock in both Mongolia and Inner Mongolia (figure 3), where the majority of livelihoods rely on livestock husbandry under extensive systems of production (Retzer et al. 2006). Yet, the number of livestock over the past half a century grew at an increasing rate. The primary regional drivers of this herd increase have been a growing demand for food production in Mongolia and a concurrent shift in diet from grain to meat in neighboring provinces around Inner Mongolia (Li et al. 2007). It should also be noted that this steady increase in animal production has periodically been interrupted as a result of political changes and policy shifts in both Mongolia and China (figure 3). For example, during and shortly after the Cultural Revolution in the early 1970s in China and during the New Land Policy era started in the late 1970s in Mongolia, the total number of livestock animals declined briefly and then basically remained unchanged for a short period (e.g., Jiang 2005). Subsequent economic reforms started in the late 1980s, particularly after the implementation of the livestock and grassland tenure system in China and the new Free Market Policy in Mongolia, triggered major growth in the total number of livestock animals. The growing economy in the livestock industry took a large blow in 2002 when the region had a historical record of droughts and winter storms (figure 4), resulting in a major setback for the local economy. This combination of political and policy changes in concert with extreme climatic events created a tipping point for herders to switch from a nomadic grazing lifestyle to...
confined feeding with corn and other agricultural products as an adaptation strategy to these regional drivers (Chuluun and Ojima 2002). In spite of the escalating impacts of extreme climate events and political uncertainties in both Mongolia and Inner Mongolia, the economic engine and pursuance of a better life seemed to continue driving further growth of the livestock industry, as evidenced in the increasing number of livestock across the region (figure 3). The gross domestic product (GDP) has grown in the region by as much as three times from its 1980 base (Ying 1999, Tan and Khor 2006, Fan and Qi 2010). For example, the economic growth in Inner Mongolia caused it to be among the top-ranked provinces in China and has made great advances in grassland animal husbandry and human living standards, while Mongolia has seen steady progress, particularly since the collapse of the former Soviet Union in 1990 (Jiang 2005).

However, these drivers and their consequences present new challenges to the local people in DEA (Mason 2001, Angerer et al 2008, Qi et al 2012). Recent energy crises worldwide and particularly increasing energy consumption in China to support economic growth have sparked new pressure on these grasslands. Grasslands are being converted to cash crops and coal mining operations, both of which have significant environmental consequences, including soil erosion and water pollution (Brogaard and Zhao 2002). The key issue facing the local people is how to achieve a balance between economic development and ecological conservation.

4. Ecosystems degraded

Under the influence of both climate change and intensified human activities, the grassland ecosystems in the DEA region have been degraded and their productivities have declined (figure 5). The overall grassland above ground primary productivity (804 and 1871 kg km$^{-2}$ for MG and IM respectively) declined by $\sim$43% for MG and 53% for IM from 1961 to 2009 based on the studies by Lkhgvajav (2006) and reports by the Inner Mongolia Grassland Survey Institute, China (Brown et al 2011).
The changes in livestock in IM and MG appear to be directly affected by the changes of biophysical and socioeconomic conditions. The green and brown arrows represent the El Niño and La Niña years, respectively.

Severe winter storms resulted in a massive number of sheep deaths, because of either starvation or extreme cold weather. Photo courtesy of Dr Guodong Han, Inner Mongolia Agricultural University, China.

faster in recent years as a result of overgrazing to meet the rapidly increasing regional demand for meat production (Zhen et al 2010). During the same period of time, the price of meat has almost tripled or quadrupled, which economists believe to be a major driver of grassland degradation and/or conversion (Waldron et al 2010).

Not only has existing grassland above ground primary productivity declined, but the total acreage of more productive grassland has also diminished with conversion to traditional croplands, urban development, and coal mining operations (Jiang et al 2006). Grassland conversion to croplands, such as for potatoes and corn production, occurred primarily along the traditional boundaries between agricultural and grazing lands (Williams 1996). However, institutional interventions in land uses, through environmental policies and economic incentives, have made the grassland conversion a current focus of study and research. Although the total areas of grassland, by definition, were not reduced significantly, the more productive grasslands and those adjacent to urban developments have been selectively converted. In discussions with local herders and farmers in Inner Mongolia, it has become clear that urbanization around major cities converted the traditional agricultural lands. The agricultural lands, in order to meet the increasing urban demand for food production (particularly vegetables), were expanded to take over marginal grasslands. The conversion from grassland to agricultural land caused major environmental issues as the tillage of thin layers of marginal soils destabilizes the deeper soil layers and subjects them to wind and water erosion.

5. Institutional responses to environmental change

The increasing frequency of dust and sand storms within and across the DEA region has become a major government concern of China. In response, a series of new policies, including the ‘Three-North Shelterbelt Forest Program’, initiated in 1978, and the ‘Sloping Land Conversion Program (a.k.a. ‘Grain for Green’ Program’), initiated in 1999, after the major flood in 1998, were rapidly implemented at the national level on the west side of China. The effectiveness of these programs has been evaluated to be positive at the national level (e.g., Ojima and Chuluun 2008, Xu et al 2010, Liu et al 2008). Yet, at some local levels, the responses have been less effective as the livelihoods for some herders and farmers have been altered (Liu et al 2008). Given the
need to balance environmental conservation and economic development, the government of China has taken further steps to limit the ecological degradation of grasslands in western China. For example, on 15 June 2011 the State Council of China introduced eight policy measures for the development of the Inner Mongolia Autonomous Region, the first of which was ‘to promote the ecological construction and environmental protection’ (Yin and Yin 2010). At the same time, the Inner Mongolia government officially launched ‘the Inner Mongolia grassland ecological protection subsidiary incentives program’, where herdsmen who have completed the mission of ‘no-grazing and pasture-animal balance’ will receive compensation from the local government. These efforts are made at the national level, but their societal consequences are far-reaching. Unfortunately, there are no corresponding efforts to assess substantive intended and unintended consequences. A monitoring and evaluation (M&E) process should be effectively implemented.

6. Knowledge gaps remain

To address the complex issues of environmental conflicts with socioeconomic development in the region under increasing climate variability, the existing knowledge is insufficient to understand the interactive nature of the coupled grassland and human systems. Some ongoing programs and projects exist, such as those of NEESPI (North Eurasia Earth System Partnership Initiative) and MAIRS (Monsoon Asia Integrated Regional Studies), with aims of understanding the hydrological processes, regional climate variability and future scenarios, land use and land cover changes, and associated carbon cycles in the region. These two programs address little concerning the social consequences of the climate impacts. Some research projects in the region attempt to examine social and policy issues; however, they are more about understanding the historical aspects of social events and societal consequences of climate change and economic developments. Therefore, there still remain major gaps and challenges, as identified during the workshop, which are summarized below.

(1) Insufficient data in the DEA region to holistically assess climate impacts on both grassland ecosystems and societal impacts.

- Water is probably the most important issue in the region. However, there are very limited hydrological stations to understand the water balance and water resources. Groundwater table data are too sparse to capture its spatial variability in the region and thus it is impossible to holistically assess precipitation impacts on grassland and agricultural productivity. The large-scale afforestation in the DEA region is the primary driver for land conversion from grassland to poplar plantations. Yet, little is known about their impact on the regional groundwater reservation or the climate. Similarly, historical meteorological observations, particularly in Mongolia, are lacking and there is a need to develop and strengthen national and international meteorological station networks. It is also recognized that data quality control is another challenging issue that needs to be addressed.

- There are no (or very limited) data on the social dimensions of the climate change and thus it is difficult and/or impossible to assess the societal impacts of climate change including, but not limited to, human health, gender disparity, age structure, education, cultural beliefs and other social demographic aspects of the region.

(2) There are large knowledge gaps in our understanding of the socio-physical processes, drivers and societal consequences.

- The nature of the future climate change is not clear. There is a consensus that the DEA region became warmer and precipitation varied little over the past century; however, the spatial and temporal climate variability in the future is unclear as the simulations are significantly biased in the current GCMs used by the IPCC, especially in western China and Mongolia.

- The regional hydrological processes are not well understood. The role of regional glaciers needs to be analyzed because the fate of the glaciers is unclear under current and future climate change (e.g., Immerzeel et al 2010). Glaciers are exceptionally important in providing water recharges in the rivers and groundwater of the DEA region. Further, little is known about the water resources in the region as they are constantly altered by human activities such as dam construction, reforestation, irrigation, and inter-basin transfer. There is little knowledge on international water rights within the DEA region and its total human consumption demands.

- Land cover and land use change information, particularly on urbanization, is needed. It was recognized that the total urban area within DEA may not be significantly large compared with the total other land area. However, urban expansion and development has played a key role in change of the livelihoods of farmers and ranchers in the past. The majority of the younger generations from rural areas have migrated to urban cities, leaving behind vacant or abandoned land. How the shift in demography, particularly in the age distribution, has affected the grassland ecosystems needs to be further studied.

- Societal impacts of climate change have not been fully assessed and are not understood. Little is known about how climate change has impacted the livelihoods of the rural communities of DEA: food, health, and water security.

- There is a lack of research on adaptation solutions for climate change. There is very limited knowledge or even research on the adaptation to future climate change in order to maintain and improve the human well-being in the region. The needed research requires the quantification of key drivers of land degradation, including social, economic and biophysical drivers such
as overgrazing, mining and poor agricultural practices (irrigation). One particular issue is the impact of the mining industry on the grassland ecosystem’s goods, services and human livelihoods.

(3) Coordination and communication among programs and projects in the region is important but lacking.
- Improved coordination is needed in order to effectively address the environmental issues in the region. There are many ongoing projects in Mongolia funded by the US, the European Union and Japan, and there are many national projects in China. However, the coordination and collaboration is limited. Some efforts are duplicative, although many are complementary.
- There are still barriers to sharing the results, methods and data among different parties and researchers in the region. Meetings and workshops are seldom held to specifically address the regional issues.
- The engagement of stakeholders and decision makers in the climate adaptation research process should be enhanced. The research results need to be in a format that is easily understood and applied by the local decision makers.

7. Conclusions

The workshop successfully enabled the identification of the current state of grassland ecosystems in Dryland East Asia as well as gaps in the data and knowledge required to fully understand the interacting nature of the coupled human and grassland ecosystems. It further identified the need for future research. It concluded that climate change, especially the frequency of extreme climate events, is occurring and has had significant impacts on the grassland ecosystems and, consequently, the lives of the ranchers and farmers in the DEA region. Sufficient evidence showed that grassland ecosystems have been degraded and the drivers of degradation include both increased climate variability and intensified human activities such as overgrazing and land use conversion. However, the lack of key in situ measurements of both biophysical and socioeconomic variables and factors undermines the possibilities to holistically diagnose the root causes of ecosystem degradation or develop plausible adaptation strategies to cope with both climate change and socioeconomic disturbances. The institutional responses to ecosystem degradation have been generally positive in restoring or preserving grassland ecosystems through national policy and regulations; however, the societal implications of these national programs have been not been fully assessed. Future research should focus on a systematic approach that includes all of the key components of the coupled human and grassland ecosystems in order to develop sustainable management practices for climate adaptation and economic development.

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