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ORIGINAL PAPER

Climate impact on vegetation and animal husbandry on the Mongolian plateau: a comparative analysis

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Abstract International research has focused more attention on arid and semiarid regions in recent years, as climate change has already had adverse impacts on grasslands and local households in the Mongolian plateau. Based on meteorological data, GIMMS AVHRR NDVI3g data, and livestock records, through statistical analysis, a significantly strong warming trend and a slightly decreasing trend in precipitation were ascertained in this region. Precipitation patterns are shifting, and intensifying, extreme events, such as droughts and *dzud* (extremely harsh winters characterized by heavy snow and low temperature), are a major threat to vegetation growth and animal husbandry development. Following a comparative analysis approach, we explored how the vegetation and animal husbandry response to climate change and extreme weather differ between Inner Mongolia and Mongolia. We found that vegetation growth generally decreased after the mid-1990s, but began to recover from 2001 over the entire region. The agricultural intensification level is higher in Inner Mongolia than in Mongolia, and residents in Inner Mongolia have a greater awareness of unexpected disasters than those in Mongolia. To deal with these challenges, this region warrants further study on how climate extremes will impact on regional animal husbandry and local social economics on the arid and semiarid regions. This could have implications for the international community, local government, local residents, and future scientific activities in this space.

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1 Introduction

There has been a shift in the treatment of regional aspects of climate and land-use change in the latest Intergovernmental Panel on Climate Change (IPCC) AR5 report, especially in arid and semiarid areas (IPCC 2014a). This has resulted in a more systematic coverage of regional issues at continental and subcontinental scales. The Mongolian Plateau (MP), known for its ample mineral resources and peculiar landscape, is one of the largest grassland regions in the world. Grassland covers approximately 50 % of its land, and livestock husbandry is the most important source of income for pastoral livelihoods (Martin et al. 2014).

As a relatively closed and arid/semiarid inland plateau with a temperate continental climate in Central Asia, the MP, with a total area of approximately 2.6 million square kilometers and an average elevation of 1580 m, is the primary source region of sandstorms for China. It includes Republic of Mongolia (Mongolia), Inner Mongolia from China, and a very small part of Russia (Angerer et al. 2008). Mongolia and Inner Mongolia experience quite different political and economic conditions, vegetation dynamics and climate variations (Miao et al. 2013, 2014), herder knowledge and perceptions of ecosystem conditions, and consumption of resources (Zhen et al. 2010). As a consequence, they have different local institutions and rural livelihood adaptations to climate (Wang et al. 2013a). Olson's World Wildlife Fund biome boundaries divide the MP into three biomes: forest in the eastern, grassland in the middle, and desert in the western part (Olson et al. 2001). Meadow steppe, typical steppe, and temperate deserts can be found moving from east to

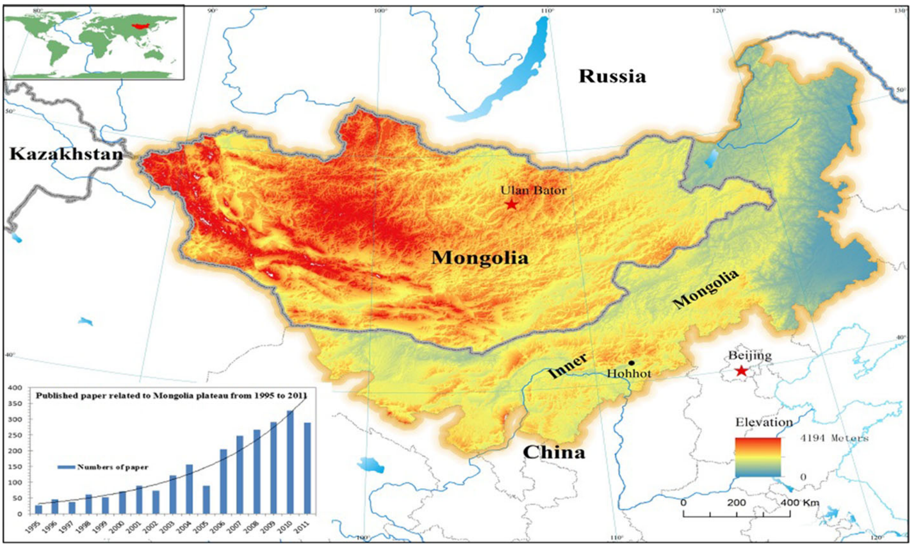

Fig. 1 Geographic location of the Mongolian Plateau. The number of published papers was counted from the ISI Web site in the fields of geology, environmental sciences, ecology, and social sciences

west, corresponding to a decreasing precipitation gradient (Xia et al. 2014). There is some evidence to suggest that climate change in the MP is also occurring at a more rapid speed; natural disasters such as drought and *dzud* increasingly threaten pastoralist and herd's survival (Chen and Tang 2005; Johnson et al. 2006; Onda et al. 2007). A recent study provided new evidence on the impact of one severe *dzud* weather shock on child height in Mongolia (Groppo and Schindler 2014). The impact of dzud on grassland productivity is quite different from drought. Drought would impact the vegetation in a more direct way, while the impact of dzud is indirect. According to Hirano's research, an improvement in grassland productivity is speculatively caused by the reduction in plant-eating animals during the dzud (a Mongolia-specific winter disaster which undermines the welfare and food security of the herding community through large-scale death and debilitation of livestock) (Hirano et al. 2006).

The MP has received considerable attention from the international community demonstrated in the substantial amount of the literature produced since the 1990s (Fig. 1, left corner). In recent years, grassland deterioration has occurred on the MP followed by declining grassland productivity and soil quality degradation as a result of the accelerated stresses from climate warming, rapidly growing population, and economic development-induced overgrazing (Miao et al. 2014; Ranjeet et al. 2013; Sneath 1998, 1999). It is not surprising to observe substantial growth in the number of goats as a result of a favorable global cashmere market, and rapid economic and population growth has certainly impacted the grasslands in a number of significant ways (Angerer et al. 2008). Decreased mobility caused by the shift from nomadic to sedentary grazing practices is likely to increase the level of damage to grasslands because of the reduced recovery time for impacted vegetation. Nomadic mobility is extremely lower in IM as pasture lands have been allocated to individual households; in Mongolia, the movement speed, distances, and frequencies have also decreased as a result of the purchase and storage of forage and changing residence patterns to better suit regional centers (Humphrey and Sneath 1999).

Since the 1980s, the improvement of advanced technologies, such as remote sensing and high-performance computing, has made it possible to timely and accurately monitor the inter-annual variations in vegetation from a regional to global scale (Gong 2012; Sneath 1998). Thus, it is interesting to explore climate trends and vegetation in order to assess

Table 1 Drought and *Dzud* records in the MP from 1998 to 2010

Year	Type of disaster	Location	References
1998	*Dzud*	Mongolia	A9
1999–2001	Drought + *Dzud*[a]	Mongolian Plateau	A3, A5, A6, A7, A11
2002	Drought + *Dzud*	Mongolia	A3
2005	Drought	Mongolian Plateau	A7, A1
2006	Drought	Mongolian Plateau	A1, A2, A5
2008	Drought	Inner Mongolia	A5
2009	Drought + *Dzud*	Mongolian Plateau	A3, A4, A7
2010	Drought + *Dzud*[a]	Mongolia	A3, A12

Data resources are from A1 (Sternberg et al. 2009), A2 (Sternberg et al. 2011), A3 (Fernández-Giménez et al. 2012), A4 (Chen et al. 2010), A5 (Zhou et al. 2013b), A6 (Zhang 2012), A7 (Ranjeet et al. 2013), A8 (Jiang and Qian 2003), A9 (Woo 2014), A11 (Wang et al. 2012), A12 (Vernooy 2011)

[a] Most extreme and damaging events

their associated impact on animal husbandry and thereby help to make the Inner Asia grassland more sustainable for pastoral development. The key objective of this study was to present a comparative perspective under two different national policies, underpinning land-use and animal husbandry adaption to the climate extremes between Mongolia and Inner Mongolia.

Table 2 Vegetation growth on the Mongolian Plateau from multiple studies

Code	Study area	Time series	Vegetation trends	Data	Reasons	References
B1	MP	1982–2012	Enhanced before 1994 Decreased before 2001 Recovery after 2001	AVHRR MODIS SPOT		Miao et al. (2013)
B2	MP	1982–2006	Little variation	AVHRR		Zhang et al. (2009)
B3	MP	1982–2006	Increased from the early 1980s to the mid-1990s Decreased after the mid-1990s	AVHRR		Shinoda and Nandintsetseg (2011)
B4	MP	1982–2003	12.4 % of the total area increased 73.5 % of the total area had no obvious change	AVHRR		Hu et al. (2008)
B5	MP	1998–2012	1998–2001 decreased 2002–2012 increased	SPOT	Precipitation Ecological engineering	Miao et al. (2014)
B6	MP	2001–2010	The decreasing area and increasing area are equal	MODIS	Precipitation	Bao et al. (2013a)
B7	MP	1982–2006	Increasing rate in Mongolia is higher than Inner Mongolia	AVHRR		Bao et al. (2013bb)
B8	IM	2000–2010	The vegetation in 2010 grew better than that in 2000	MODIS		Zhang et al. (2012)
B9	IM	2001–2010	Increased	MODIS	Precipitation	Mu et al. (2013)
B10	IM	1982–2006	A large portion (17 %) experienced a significant vegetation increase	AVHRR	Precipitation and human activities	Li et al. (2011)
B11	IM	1982–2006	Decreased from the 1980s to 2000. Reversed between 2000 and 2006	AVHRR	Human activity livestock grazing	Li et al. (2012)
B12	IM	1998–2012	A gradually decreasing trend from the northeast to southwest	SPOT	Temperature followed by precipitation	Yang et al. (2011)
B13	IM	1982–2000	A slightly increasing trend	AVHRR	Precipitation	Sun et al. (2010)
B14	IM	1982–2003	(1982–1992) increased (1988–1998) equal trend (1993–2003) decreased	AVHRR	Precipitation	Chen and Wang (2009)
B15	M	2001–2010	Stable trend with a slight increase	MODIS		Wang and Li (2011)

2 Data and analysis method

The documented information used in this study listed in Tables 1 and 2 includes all of the available climate and vegetation studies covering the past three decades, from the 1980s to the 2010s, in the MP including IM and M, collected from published papers. Temperature (daily average value) and precipitation data (total annual value) were derived from Climatic Research Union (CRU: http://www.cru.uea.ac.uk/) data and GIMMS AVHRR Vegetation NDVI (Normalized Difference Vegetation Index) to separately represent the spatiotemporal distribution of climate and vegetation change. The livestock numbers are from the National Statistical Office (NSO) of Mongolia and the China Animal Industry Yearbook. The number of animals constitutes large animals (camels, horses, and cattle), sheep, and goats, all of which primarily graze on grassland.

As livestock activities are the main source of income for the people who live in the Mongolia Plateau, it is important to characterize the differences in climate impact and the adaption of animal husbandry on this area. This paper will use the comparative method to show the differences between climate change, vegetation dynamics, and how climatic extremes impact the vegetation and livestock for the Republic of Mongolia and Inner Mongolia, China. The qualitative comparative analysis (QCA), systemically introduced by Ragin (1989) in the seminal book "The Comparative Method," is a relatively novel yet simple method that is particularly suitable for the social sciences. The QCA is a comparative case-oriented approach, combining some of the strengths of qualitative and quantitative research methods (Marx et al. 2014).

3 Results

3.1 Climate change and extreme events

Extreme climatic events seriously threaten pastoralists' livestock and the stability of their daily lives, and pastoralists, without comprehensive winter fodder provisions, are predominantly reliant on maintaining a mobile system (Sneath 1998). Over the past decade, anthropological studies have increasingly turned their attention to the subject of the adaptation of animal husbandry to climate variability and extreme climatic events. Adaptation to climatic variability is important for local sustainable development (Wang et al. 2013a, b; Zhen et al. 2008). Several papers report on significant and severe warming trends and slightly decreasing trends in precipitation across the Mongolian Plateau (Batima et al. 2005; Miao et al. 2014; Pei and Hao 2009; Wang et al. 2013a; Xia et al. 2014). Between the years 1880 and 2012, the MP experienced a substantial increase of 0.36 °C/10a in overall average temperature, which is 4.24 times the global average (0.085 °C/10a) according to IPCC AR5 (IPCC5th 2014b; Miao et al. 2014). Furthermore, a consistent increase in temperature is projected for the following 100 years (Zhang and Xu 2011), but models show no increase in annual precipitation for the next 30 years across the entire plateau (Tang et al. 2009). Not only have the average climatic conditions changed since the 1990s, but also frequent extreme events (drought and *dzud*) occurred on the MP from 1998 to 2010, as shown in Table 1. Climate change has caused more frequent extreme droughts on the Mongolian Plateau during the last decade. Both IM and M experienced the most severe drought and *dzud* events between 1999 and 2002 because of their adjacent climate systems, a disaster covered to a great extent in the literature.

3.2 Vegetation growth under climate change

Climate variability and pasture degradation have increased pastoralists' livelihood and ecosystem vulnerability (Wang et al. 2013a). Vegetation growth is a good intermediate index for the impact of climate change on animal husbandry (Thornton et al. 2009; Wang et al. 2013a, b). NDVI is a widely used vegetation index that monitors the spatial–temporal variation in vegetation growth (Anyamba and Tucker 2005; Miao et al. 2013; Mu et al. 2012). Table 2 shows that vegetation growth varies among different studies on the MP and is even contradictory in certain periods. Vegetation coverage in Inner Mongolia was consistently higher than in Mongolia for all the years reported (Cao et al. 2013; Miao et al. 2013, 2014). Most studies agree that the vegetation decreased across the Mongolian Plateau after the mid-1990s (B1, B3), but improved after the year 2001 based on three global datasets (MODIS, SPOT, and AVHRR) (B1, B5, B9, B11, B15). Addison et al. (2012) suggested that the assessments of pastureland degradation were exaggerated for the Mongolian Plateau Gobi Desert area (Addison et al. 2012). When considering the longer period of 1982–2006, the vegetation coverage shows insignificant changes (B2, B4) with Mongolia experiencing a higher greening rate than the changes observed in Inner Mongolia (B7).

To examine whether the inconsistencies of changes in the NDVI from various studies result from different periods and different satellite data, we examined the vegetation growth and climate change trends (temperature and precipitation) and their relationship (Fig. 2) by combining the longest records of satellite data from the GIMMS NDVI datasets and the meteorological data from CRU. We found that although there was a linear trend at a rate of 0.77 % per year for temperature anomaly in IM from 1982 to 2011 ($P < 0.01$), a linear trend is found for the enhanced temperature anomaly in M at a rate of 0.0755 per year ($R^2 = 0.35$, $P < 0.01$). Moreover, the NDVI anomaly shows a significant correlation with the precipitation anomaly variation in both Inner Mongolia ($R = 0.41$, $P = 0.03$) and Mongolia ($R = 0.51$, $P < 0.01$) from 1982 to 2012. Furthermore, the extreme events (drought from 1999 to 2001) match well to the decline in vegetation NDVI dynamics as shown in Fig. 2.

3.3 Climate extremes and livestock

Climate change has shown to have increasingly adverse impacts upon the ecosystem and livelihoods of local residents on the MP (Ju et al. 2013; Li et al. 2013; Zhen et al. 2008).

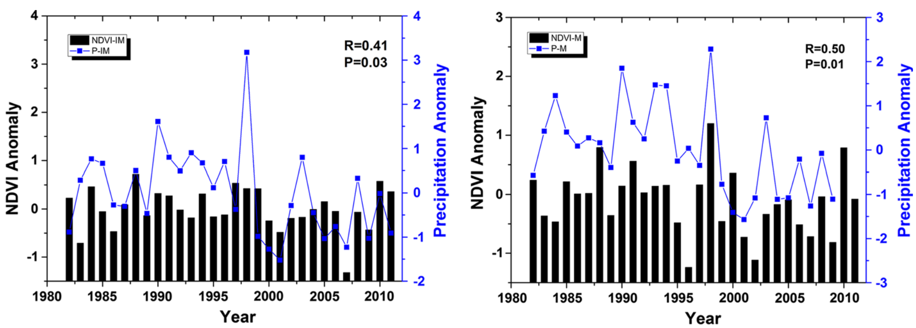

Fig. 2 Relationship between annual precipitation and NDVI in Inner Mongolia (IM) and Mongolia (M)

Climate extremes particularly threaten the livestock husbandry industry and the welfare of local households. For example, 8700 herder families in Mongolia lost all their animals as a result of the *dzud* in 2009–2010, and 1400 families were forced to migrate to urban areas according to the annual report of the Swiss Cooperation Office in Mongolia. Abrupt extreme climate conditions can lead to livestock death as a result of coldness (extreme cold during a *dzud*) or starvation (low grass production caused by drought) directly or indirectly. In IM, the number of livestock and their rate of increase were much higher than that in Mongolia during the period 1986–2010. In IM, the number of livestock increased from 32.5 million in 1986 to 61.6 million in 2010, at a rate of 0.92 million per year ($P < 0.01$). In Mongolia, the number of livestock increased from 22.6 million in 1986 to 32.7 million in 2010, at a rate of 0.75 million per year ($P < 0.01$). Figure 3 demonstrates a high correlation between the number of livestock and extreme climate conditions, both in IM and M. In particular, it is clear that the continuous drought and *dzud* from 1999 to 2002 and 2010 were large threats to the survival of animals. The 2006 drought also caused a decline in the number of animals in Inner Mongolia. In terms of some years, for example, the 2006 drought did not cause a decline in the number of animals in Mongolia, and the 2009 drought did not cause a decline in the number of animals in Inner Mongolia; this phenomenon could not be explained by the statistical data, and it warrants further study on how climate extremes will impact on regional animal husbandry and local social economics over the MP.

Concerns have been raised over the excessive consumption of natural resources in the MP, which has already threatened the sustainable development of the economy and the utilization of land resources (Sheng et al. 2000). Several natural science researchers have postulated that perhaps desertification and land degradation is not as severe as once thought. Sternberg analyzed the NDVI and *situ* data and suggested that although vegetation cover had declined, desertification (permanent reduction in capacity) has not occurred

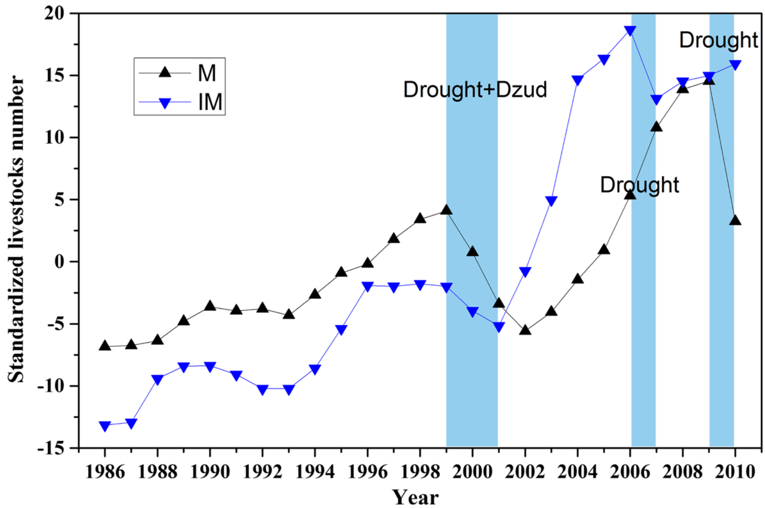

Fig. 3 Livestock numbers and extreme events in IM and M. The livestock numbers are from the National Statistical Office (NSO) of Mongolia and the China Animal Industry yearbook. The category of animals constitutes substantial animals (camels, horses, and cattle), sheep, and goats that rely on grasslands for grazing

because the fluctuation in vegetation cover over the Mongolian steppe remained high from 1998 to 2006 (Sternberg et al. 2010). However, according to several other researchers, the deserted area in Mongolia expanded quickly after 1990, and especially in 2007, with approximately 72 % of the land experiencing desertification (mild desertification: 23 %; moderate desertification: 26 %; severe desertification: 5 %) (Buren 2011).

According to the rural household survey in the MP conducted by Zhen et al. (2008), in which 150 families from Mongolia and 64 families from Inner Mongolia were asked to list the greatest factors threatening their livelihoods, drought was the most common factor affecting IM and M's animal husbandry. Sandstorms and technology are the other two key factors affecting the ranches of Mongolian families, whereas poverty and a lack of money are important factors affecting Inner Mongolia (Jin et al. 2014; Zhen et al. 2008; Zhou et al. 2013a). Climate-related factors were perceived as being the main prevailing factors affecting animal husbandry in the MP. Comparing the differences between IM and M, not only is the agricultural intensification level in IM higher than in M, but the IM respondents also reported having overall higher levels of concern about unexpected disasters than those in M(Zhen et al. 2008).

4 Discussion

Important cultural, economic, and ecological ties that transcend international borders have long characterized the Mongolian plateau region. These include a common steppe environment, a long history of mobile pastoralism, and comparable experiences of socialist and post-socialist transformation. Climate warming is a big concern, especially the trend toward desertification projected between 2020 and 2100. The warming areas include the middle and northern parts of Inner Asia, northwestern China, and the Mongolian Plateau based on the IPCC (Independent Police Complaints Commission) RCP85 scenario (Miao et al. 2015). Based on our analysis, we believe that comparative and interdisciplinary investigation offers the best prospect for the evaluation of the differing trajectories currently being followed by each Inner Asian state, and the anticipation of the likely effects on the societies and environment of the region in the future.

Faced with the vast challenges from climate change, the suitability of nomadic culture is of major concern for local people and policy makers. From a local perspective, mobility can reduce the risk of land degradation caused by overgrazing, as increased mobility and diversified income allow the limits of ecological tolerance (the ability to withstand damage from an environmental infection) to be shifted from a narrow to a wider extent (Martin et al. 2014; Sneath 1998). There are major differences between IM and M to respond to climate extremes in order to protect animal husbandry. Mongolia still has a much greater level of general pastoral mobility, including the use of mobile dwellings and draft and riding animals, unlike IM's nomadic animal husbandry activities, which are more sedentary and within the new economic and policy environment of China's rapid growth. Mobility and communal pooling were the two main adaptation strategies implemented by local institutions in Mongolia, whereas storage, livelihood diversification, and market exchange were the three key categories of adaptation strategies in Inner Mongolia (Wang et al. 2013a).

Usually, farmers' decisions to manage persistent drought were contingent on a complex web of natural, economic, structural, and cognitive factors (Keshavarz and Karami 2014). Climate extremes often occur over a very short and unexpected period (i.e., strong storms or sandstorms) during the winter time; however, these extreme events can affect a relatively large area. In these cases, adaption measures such as mobility will not work effectively for households or local groups (Easterling et al. 2000). Thus, traditional adaption measures by the household or local groups need to be coordinated with a disaster relief campaign offered by the government or relevant organizations. Advance preparations to increase adaptation capacity are extremely important.

In terms of the policy influence, in Mongolia, the privatization of livestock, reduced government support, and more immediate livelihood needs have affected Mongolian herding practices, resulting in the transformation to a market economy, leading to land degradation and an end to cooperative herding decision making and implementation (Janzen and Bazargur 2003; Sternberg 2008). More seriously, Mongolian herders now need to pay new livestock taxes per animal in the new 2015 budget. Governmental institutions were much less influential in Mongolia than in Inner Mongolia (Sneath 2012; Wang et al. 2013a). The Chinese government has initiated a series of large-scale ecological restoration programs to protect the grassland and nomadic Mongolian culture. One of the most notable is the "Grain For Green Project (GFG)," which is designed to tackle the increasingly aggravated situation of soil erosion by paying farmers subsidies to convert their cropland to grassland or forest (Liu et al. 2008). In total, the GFG project budget has reached 41.2 billion RMB (US$6.59 billion), most of which is spent on pasture subsidies, house subsidies, and labor training subsidies. In IM, grazing bans are enforced in ecologically sensitive and fragile areas. Studies have shown that such measures have at least partial impact, with some degraded grasslands recovering after 5 years without grazing (Wang et al. 1997).

5 Conclusions and pathway to sustainability

The analytical results of this paper suggest that climate on the MP has experienced warmer and drier trends in past decades. Precipitation is the primary influencing climate factor on vegetation growth, whereas temperature shows no significant impact on vegetation growth. The frequency of climate extremes has increased in recent decades, especially the persistent drought and winter *dzud* between 1999 and 2001 that caused lasting and enormous damage to livestock and, as a result, social and household welfare. Faced with the pressures of climate fluctuations, population fluctuations, and increasing livestock, grasslands are expected to encounter serious potential pressures and threats. The solutions to regional degradation and desertification, climate extremes, and regional policy disparity were the major determinants and challenges of the adaptation strategy for animal husbandry. Balancing socioeconomic development and environmental conservation is necessary for a sustainable future. To manage these challenges, we propose several specific suggestions on different levels, ranging from the international community and national governments to local institutions and individual households, as well as discuss future scientific efforts.

5.1 International society and the national government

Special agencies from multiple countries have been established in the Mongolian Plateau to help develop strategies for maintaining the livelihoods of locals and helping to sustain their culturally unique way of life, for example the "Swiss Agency for Development and Cooperation in Mongolia," "The University of Central Asia's Mountain Societies

Research Center," "Cambridge Mongolia Development Appeal," and "Mongolian Studies Center at the University of Inner Mongolia in China." There are still many barriers concerning the integration and sharing of data from social and ecological experiments. Therefore, a more open and integrated system based on multiple data sources, such as high-resolution remote sensing, climate data, and household surveys, is urgently needed to perform a more comprehensive and comparative analysis. National government affiliations are responsible for the unified leadership of the local administration. Problems such as the "Tragedy of the commons" must be identified and resolved. Government efforts should not only increase investment in training, education, and technical innovation, but farmers' mobility and income must also be improved.

5.2 Local institution and individual household management

Local institutions play important roles in shaping the impacts of climate change and facilitating the adaptation strategies that affect the livelihoods of herders (Wang et al. 2013a). Extensive livestock farming operations are gradually shifting in intensity, but the MP is still less productive than America and Japan because of lower operations and management ability (Zhen et al. 2008). The livelihood strategies of households in the past decade have changed the diversification and livestock management strategies to adapt to the changing climate (Brown et al. 2013). The awareness about protecting animals from drought and *dzud* is increasing after years of suffering losses (Zhen et al. 2008). *Dzud* is a complex social–ecological phenomenon; even communities and families who are well prepared for *dzud* may still be extremely vulnerable and suffer disproportionate losses caused by immigrating livestock (Fernández-Giménez et al. 2012). Therefore, local institutions and collective actions are necessary to cope with natural disasters such as *dzud*, although households and individuals are ultimately responsible for affecting natural resource utilization.

5.3 Scientific efforts

Vulnerability assessments and the investments of pastoralists are two widely used methods that provide a basis upon which decisions are made by the government concerning pastoral livestock management (Jin et al. 2014; Zhen et al. 2008; Zhou et al. 2013a). The ecological carrying capacity of an ecosystem is vital for monitoring the sustainability of a region. The concept of an ecological footprint was first proposed by Wackernagel et al. (1999), Wackernagel and Rees (2013). Romina posed the question as to how much climate change pastoral livelihoods can tolerate (Martin et al. 2014). Few would doubt the importance of this question for the future of the Mongolian Plateau, but to accurately answer the question requires more research on the nature of pastoral capacities and the patterns of human land use, the management of which is a powerful weapon in adapting to climate change.

Animal husbandry faces serious problems and enormous challenges from climate change in the Mongolia Plateau, but it is also an opportunity. The range of existing and historical pastoral techniques and methods of land-use management on the MP represent a rich and unique resource for future research and have potential for promoting economic growth in the future content of climate change. Effective implementation of China's ecological programs can relieve land degradation and also provide important lessons for the Mongolian example. In the future, we will conduct cross-boundary research in Inner Mongolia and Mongolia with face-to-face household interviews in representative communities, complemented by high-resolution remote sensing and climate data. A critical research question is how to disentangle and quantify the contribution of the internal and external effects of climate change and human activities on grassland dynamics under different situations in terms of diverse economic systems, state policies, and land-use management patterns.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest.

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