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

Sinkyu Kang[1,2], Keunchang Jang[1,3], Bolorerdene Lkhamsuren[4]

[1]Department of Environmental Science, Kangwon National University, Korea
[2]<kangsk@kangwon.ac.kr>
[3]<xjvmguy@kangwon.ac.kr>
[4]Institute of Meteorology, Hydrology, and Environment, Mongolia
<boogie@kangwon.ac.kr>

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.

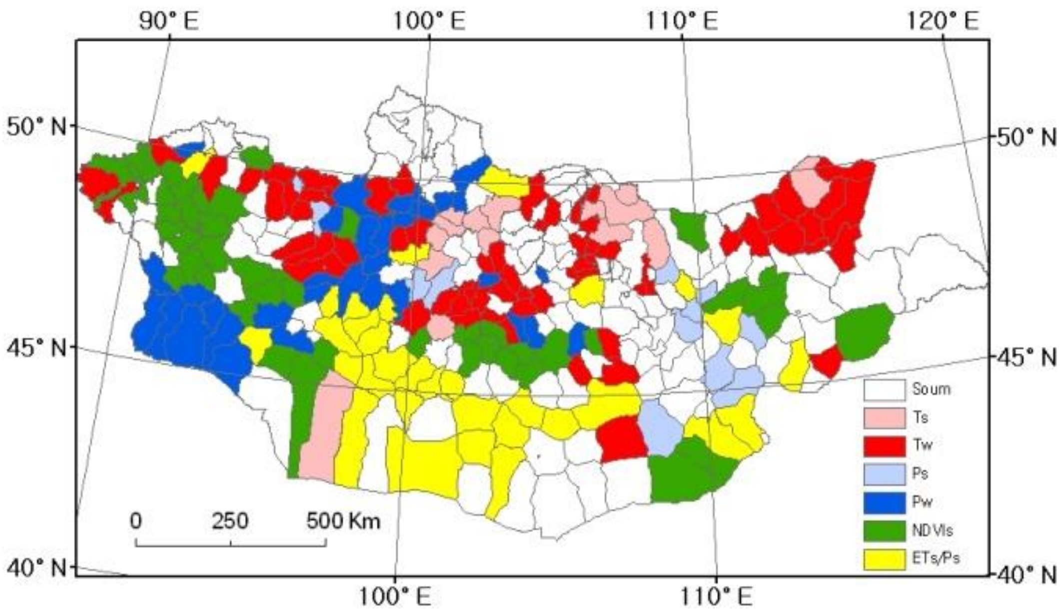

Figure 1. Biophysical variables of determining inter-annual livestock change for the period of 2003-2010: primary independent variables included in *soum*-level regression models. Ts and Tw, summer (JJA) and winter (DJF) mean temperature, Ps and Pw; summer (JJA) and winter (DJF) total precipitation; 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).

REFERENCES

Fernandez-Gimenez ME, Gatkhishig B, Batbuyan B. (2012). Cross-boundary and cross-level dynamics increase vulnerability to severe winter disasters (*dzud*) in Mongolia. *Global Environmental Change*, 22, 836-851.

Huete A, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment,* 83, 195-213.

Jang K, Kang S, Lim YJ, Jeong S, Kim J, Kimall JS, Hong SY. (2013). Monitoring daily evapotranspiration in Northeast Asia using MODIS and a regional Land Data Assimilation System. *Journal of Geophysical Research,* 118, 12927-12940.

Jang K, Kang S, Kimall JS, Hong SY. (2014). Retrievals of all-weather daily air temperature using MODIS and AMSR-E data. *Remote Sensing,* 6, 8387-8404.

Middleton NJ, Sternberg T. (2013). Climate hazards in drylands: a review. *Earth-Science Reviews,* 126, 48-57.

Sternberg T. (2010). Unravelling Mongolia's extreme winter disaster of 2010. *Nomadic Peoples,* 14, 72-86.

Tachiiri K, Shinoda M, Klinkenberg B, Morinaga Y. (2008). Assessing Mongolian snow disaster risk using livestock and satellite data. *Journal of Arid Environments,* 72, 2251-2263.

United Nations and Government of Mongolia. (2001). Mongolia winter disaster *Dzud*: appeal for international assistance (February-May, 2001).

Zhang XY, Gong SL, Zhao TL, Arimoto R, Wang YQ, Zhou ZJ. (2003). Sources of Asian dust and role of climate change versus desertification in Asian dust emission. *Geophysical Research Letters*, 30, DOI:10.1029/2003GL018206.