Grassland Ecosystems and Societal Adaptations under Changing Grazing Intensity and Climate on the Mongolian Plateau

Annual Report

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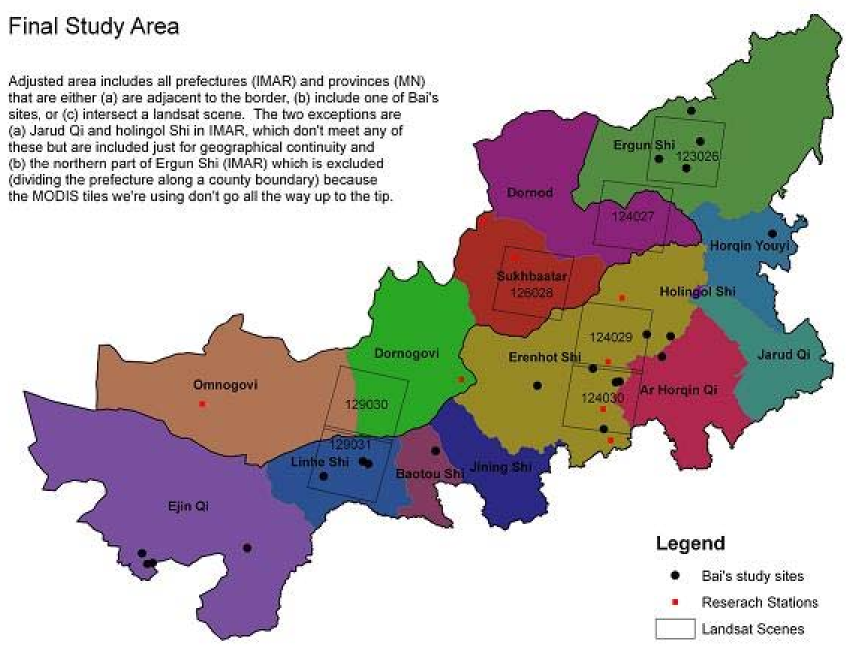
Summary and Project Status

In the second year of the project, we have made significant progress in the collection, compilation and processing of data required to meet our primary objectives. Significantly, we have completed one field season (July-August 2010) for collection of data on both the social and natural system aspects of the project. Because of the location of project and nature of the team, this has required significant coordination with our in-country partners and amongst the various team members. In addition to the specific activities undertaken pursuant to our three key objectives (outlined below), we have spent more time planning publications that we expect to result from the project. We refer below only to those that are either completed or in near-finished form.

Since the previous year's report, we have modified our study area definition and focused site selections somewhat. The figure at right illustrates our study area, which focuses on the prefectures and provinces adjacent to the national border between China and Mongolia.



The status of the project relative to each of the three research objectives is as follows:

(1) *Analyze and map grassland productivity over time (1975-2005) at three nested spatial scales/resolutions based on field, remotely sensed and climate data.*

Coarse Resolution

We have been working on applying geostatistical approaches to integrate 8-km GIMMS AVHRR-NDVI (1981 - 1999) with 1-km Terra MODIS-NDVI (2000 - present) and to build a high quality spatially consistent and temporally continuous NDVI data series. A first paper that implements and tests geostatistical inversion models with spatially stationary covariance functions for integrating these data sets with a constant 1-km resolution is completed and will be submitted soon. We are working on a second paper that uses process-convolution in the geostatical inverse modeling framework with spatially non-stationary covariance functions to model spatial variability of remote sensing images. As a result of the work presented in these papers, we will be able to produce a continuous NDVI data set for the Mongolian plateau at 1-km resolution from 1981-present. These data will then be input to a light-use efficiency model, calibrated with field data from Dr. Yongfei Bai (our collaboration at the Chinese Academy of Sciences, Institute of Botany). These data were collected at the sites identified in the figure above. The model has been coded and tested in ArcGIS-Python.

Moderate Resolution

We searched the GLOVIS archive for useful TM5 and ETM+7 images within the seven Landsat scene footprints (identified in the above figure) that serve as the project detailed study area. Sixty-six images were identified, downloaded, and are in various stages of processing. The most recent cloud-free or nearly cloud-free images were selected for each of the seven scene footprints, and processed using unsupervised classification with preliminary land-cover/use labels applied to the clusters for use during the summer 2010 field data collection effort. All downloaded images are undergoing atmospheric and terrain correction.

A ground reference (ground truth) data collection campaign was developed and implemented during summer 2010. Land Cover/Use classification schema were developed based on the UN Land Cover Classification System (LCCS), operationalized into field forms and with a corresponding spreadsheet database, and implemented by American, Chinese, and Mongolian field teams between July and August 2010. Reference data points included coding of observed vegetation and land cover/use conditions collected within cropland/pasture, forest, grassland, water, urban, and other lands, with each general class having several sub-types. Data collection teams were instructed to selected representative locations of each sub-type with large enough area to correspond to roughly a 90m by 90m extent. Preliminary classifications of Landsat imagery were provided to the field teams to aid in the reference data site selection and collection process. Systematic digital photography was collected for each site, in correspondence with the completion of field forms. All field sites and photos were georeferenced using GPS. Compilation and cleaning of these data is ongoing.

Expectations are that this dataset will be used extensively in the Landsat image classification calibration and validation process. We are discussing publication goals that could include assessment of the LCCS-based field data relative to Landsat classifications, to determine if estimates of grassland vegetation condition and change can be accurately mapped from Landsat at a level that will help understand household-level pastoral behaviors and the outcome of land use decisions, and if there are detectable differences in vegetation condition and change between Inner Mongolia and Mongolia proper. We are considering a publication relating to the use of the LCCS, but still need to determine how well the field teams were able to implement the LCCS method, which is somewhat more complex than traditional hard class-based systems.

Local Study, Fine Spectral Resolution

Five years ago, the Chinese Academy of Science, Institute of Botany established long-term grazing experiment control plots in the vicinity of the Inner Mongolia Grassland Ecosystem Research Station. These grazing control plots represent a unique opportunity for the project. Experimental control consists of: flat versus sloped land; traditional versus mixed grazing practices; and use intensities ranging from un-grazed to 12 sheep per hectare. Plots ranged in size from 2 to 5 hectares, and contained permanent exclosures as additional control. Access to the study area was granted in summer 2010 in order to facilitate the calibration of multispectral and hyperspectral satellite imagery for the purpose of land-cover classification. An ASD FieldSpec Pro spectroradiometer was used to collect in-situ spectral signatures for 39 control plots, based on a stratified-random sampling protocol implemented for each individual plot. A second spectral dataset was collected for 27 of the permanent exclosures. Field photography and GPS control were collected concurrently. Spectral signatures, corresponding GPS coordinates, digital photos, and scanned field forms were compiled into a database. Processing of the spectral signatures is ongoing at present, and we expect that the results of analysis of the processed signatures in relation to ecological and grazing control data will lead to a publication. The processed signatures will also be used to help calibrate classification of Hyperion and Landsat imagery.

The Hyperion sensor onboard EO-1 was tasked for three acquisitions during the 2010 growing season. The sensor was targeted centered upon IMGERS and the nearby grazing experiment control plot farm. Unfortunately, two of three acquisitions failed to collect useful imagery due to complete cloud cover. A single image was acquired, but it had scattered cumulus clouds, including over the control plots where concurrent ground reference spectra were being measured. This partially clear Hyperion image is currently being processed, with results pending. The sensor has been re-tasked for the 2011 growing season over IMGERS and the control plots, again with the goal of hopefully obtaining useful multi-temporal images. We will also be expanding the acquisition requests to all of the other Inner Mongolian and Mongolian Landsat scene areas that comprise the project study area. In spite of partial clouds in the existing Hyperion image, we are proceeding with the research goal of scaling up field data to hyperspectral to Landsat imagery, but will need to work around the problem that the pixels where the concurrent field spectra for grazing control plots are obscured by clouds. Fortunately, there is also a substantial amount of additional grassland ecology data collected by our Chinese collaborators existing for cloud-free Hyperion pixels, so we expect to be able to complete and publish valid research by the end of April 2011.

(2) *Develop a conceptual and quantitative understanding of societal responses to variability in climate and grasslands productivity at the household and village scales.*

A household social survey has been designed, tested, modified, and implemented in IMAR, China. We are planning to implement the survey in Mongolian villages later in 2011. The survey design for Inner Mongolia involved interviews with at least 30 households in each of four villages, selected from within the geographic footprints of the Landsat scenes. Villages are selected to represented villages that have both high and low average income and high and low distance from city centers. Although the intent was to have all surveys in China complete by November 2010, delays related to both scientific (required instrument revisions and translations) and logistical challenges (delayed payments from the US to Chinese collaborators), necessitated a late start. The current progress of the household social survey in IMAR is summarized by the administrative county (or city).

- In Ulazhongqi (乌拉特中旗) dessert steppe (荒漠草), the survey was completed in Village E13, and E28, and E31. Thirty surveys were collected each village with a total of

90 households. Based on the communication from IMAR Institute, the survey at a fourth village was also completed, but was not reported back yet.

- In Xilinhot (锡林浩特) typical steppe (典型草) the survey was completed in Village X4, and X8, and X15 (30 surveys each village with a total of 90 households). Village X17 is in a remote area and the weather is getting cold and snowing, the survey of 60 households in X17 will be conducted in the 2011 spring.

- In Ewengeqi (鄂温克旗) meadow steppe (草甸草), the survey was completed in Village W25 and W20 with a total of 90 households. An additional survey of 45 households should have been finished but has not reported back yet. About 60% of the household surveys have been completed so far. Through the lessons learnt and the experiences obtained in the first phase, we are confident that the second phase survey in the remaining villages in Spring 2011 will be much smoother and faster.

We are discussing several paper possibilities using this set of empirical data, though what we actually do will be constrained by the quality of the data, which we have not yet been able to assess, but will in the coming months. Our focus will be on the livelihood adaptation choices of herders under climate variability and institutional change (IMAR and Mongolia), and how these are related to the characteristics and endowments of various households. We also plan to combine the dataset with remote sensing data to study socio-ecological performances of various policies (“grain to green”) over the past ten years. Finally, this survey dataset will inform an agent-based modeling of spontaneous institutional change;

(3) *Analyze regional-scale relationships between ecosystem productivity and human adaptation, over time, across ecological gradients and between the IMAR and Mongolia.*

We have processed all available daily climate data, county-level socioeconomic census data, and GIMMS NDVI and organized them in the panel data format (only for IMAR). We have coded and tested a spatial panel model with spatial lags on both dependent and independent variables in the software package MATLAB. These two models will be used for estimating and analyzing grassland productivity dynamics at the spatial resolution of counties and temporal resolution of years since the middle of 1980s. Additionally, we have been collecting literature to organize and write the review paper. In this paper, we will focus on analyzing dynamics of grassland socio-ecological systems (i.e., livelihoods and grassland quality) on the Mongolian Plateau under changes in climate, institutions, and policies over the past 50 years. Our expectation is to submit this chapter for a book that is part of the synthesis activities on-going within the NEESPI project.

PhD Student Jun Wang have been designing and coding the agent-based model as part of his dissertation research. This model will be used to explore under what conditions cooperative use of grassland resources will emerge and socio-ecological performances of grassland use under alternative institutional arrangements.

Publications and Presentations (Summaries in Appendix)

Xie, Y., Sha, Z., and Bai Y., 2010. Classifying historical remotely sensed imagery using a tempo-spatial feature evolution (T-SFE) model. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65: 182-190.

Sha, Z. and Xie, Y. 2010. A Supervised Spectral Substratum Classifier To Classify Images With Fuzzy Memberships. In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS Proceedings, IAPRS, Vol. XXXVIII, Part 7A, Vienna, Austria, July 5–7, 2010.

Shestakovich, N. Spatial Variation of Dzud Events in Mongolia 1993-2003. M.S. Thesis, School of Natural Resources and Environment, University of Michigan, anticipated completion March 2011 (Advisors: Daniel Brown, Kathleen Bergen)

Staffing

Staffing for this project has been met through employment of existing students and post-docs at the University of Michigan and Eastern Michigan University. The staff members are listed below in alphabetical order:

Ninel Shestakovitch (MS student, UM) – a research assistant working on GIS and data compilation. Master's thesis (summary included) is on the response of cattle populations to Dzud events in Mongolia

Jun Wang (PhD student, UM) – he began his PhD program in Fall 2008 at the University of Michigan. He has two degrees in Geography, GIS/remote sensing, and resource management (from China). He is a key researcher on the project, focusing on remote sensing data integration and social processes of adaptation. His dissertation proposal focuses directly on the goals of the project.

Zhangbao Ma (Post-doc, EMU) – he assisted the project Co-PIs to identify best-available footprints from the USGS GloVis Landsat archive to represent the Meadow Steppe, Desert Steppe and Typical Steppe ecoregions in both Mongolia and Inner Mongolia grasslands.

Xining Yang (GIS master student, EMU) – he was responsible for cleaning-up the socioeconomic data at county level and collecting GIS vector data layers in Inner Mongolia. He also assisted in searching and reviewing Hyperion images from the USGS GloVis EO-1 Hyperion archive.

Hai Lan (PhD student, Wuhan University) – as a visiting scientist at Eastern Michigan University from Wuhan University, he is responsible for processing and organizing data he participated in collecting in the field, and helping with Landsat and Hyperion image processing.

In-Country Collaborations

The contracts and agreements with the partners in China and Mongolia were done through Eastern Michigan University (EMU). EMU entered the agreement for conducting the household social survey in IMAR with Institute of Rangeland Survey and Design, the Academy of Agricultural and Grazing Sciences of Inner Mongolia in March 2010, and entered the agreements of conducting the household survey in Mongolia and the field vegetation and soil sampling and laboratory testing with the Institute of Botany - Chinese Academy of Sciences and Mongolian Academy of Sciences in April, 2010.

The key project collaborating researchers and their affiliations are:

Dr. Yongfei Bai (白永飞), Institute of Botany, Chinese Academy of Sciences

Dr. Indree Tuvshintogtokh Mongolian Academy of Science), Institute of Botany

Dr. Xing Qi (邢旗）, Inner Mongolia Academy of Agriculture and Animal Husbandry, The Institute of Rangeland Survey and Design

Dr. Zongyao Sha (沙宗尧), Wuhan University

Appendix - Publication summaries

Xie, Y., Sha, Z., and Bai Y., 2010. Classifying historical remotely sensed imagery using a tempo-spatial feature evolution (T-SFE) model. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65: 182-190.

ABSTRACT: Large and growing archives of orbital imagery of the earth's surface collected over the past 40 years provide an important resource for documenting past and current land cover and environmental changes. However uses of these data are limited by the lack of coincident ground information with which either to establish discrete land cover classes or to assess the accuracy of their identification. Herein is proposed an easy-to-use model, the Tempo-Spatial Feature Evolution (T-SFE) model, designed to improve land cover classification using historical remotely sensed data and ground cover maps obtained at later times. This model intersects (1) a map of spectral classes (S-classes) of an initial time derived from the standard unsupervised ISODATA classifier with (2) a reference map of ground cover types (G-types) of a subsequent time to generate (3) a target map of overlaid patches of S-classes and G-types. This model employs the rules of Count Majority Evaluation, and Subtotal Area Evaluation that are formulated on the basis of spatial feature evolution over time to quantify spatial evolutions between the S-classes and G-types on the target map. This model then applies these quantities to assign G-types to S-classes to classify the historical images. The model is illustrated with the classification of grassland vegetation types for a basin in Inner Mongolia using 1985 Landsat TM data and 2004 vegetation map. The classification accuracy was assessed through two tests: a small set of ground sampling data in 1985, and an extracted vegetation map from the national vegetation cover data (NVCD) over the study area in 1988. Our results show that a 1985 image classification was achieved using this method with an overall accuracy of 80.6%. However, the classification accuracy depends on a proper calibration of several parameters used in the model.

Sha, Z. and Xie, Y. 2010. A Supervised Spectral Substratum Classifier To Classify Images With Fuzzy Memberships. In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS Proceedings, IAPRS, Vol. XXXVIII, Part 7A, Vienna, Austria, July 5–7, 2010.

ABSTRACT: Remotely sensed images often display spectral variations over heterogeneous regions in the context of land cover classes (LCCs), which imposes challenges to information extraction from the images. In this paper, an easy-to-apply image classification model, supervised spectral substratum classifier, is proposed. The classifier first builds spectral LCCs (SLCCs) from a training dataset (*TD*). A SLCC comprises the spectral signals of a labeled LCC in *TD* based on the ground truth. This SLCC is further marked as homogeneous or heterogeneous according to the statistical properties of the mean value and the standard deviation of all spectral cases in this SLCC. When this SLCC is marked as heterogeneous, the spectral space of the SLCC will be disaggregated (or clustered) into substrata by applying statistical cluster analysis. A membership function is then defined for each substratum. To classify images, fuzzy membership functions are applied to measure similarities between corresponding spectral substrata and any new to-beclassified cases (pixels). The new cases are classified to the most comparable substrata as determined by the membership functions. As a case study, a vegetation cover classification over a typical grassland in Inner Mongolia from Landsat ETM+ is conducted. The result shows that the proposed classification model obtains an overall accuracy of 79.3% and kappa of 0.76. As comparison, a hybrid fuzzy classifier and a conventional and hard classification of maximum likelihood were applied as references.

Shestakovich, N. Spatial Variation of Dzud Events in Mongolia 1993-2003. M.S. Thesis, School of Natural Resources and Environment, University of Michigan, anticipated completion March 2011 (Advisors: Daniel Brown, Kathleen Bergen)

Rationale: Dzud is a winter disaster involving the mass debilitation, starvation and death of livestock, seriously damaging the livelihoods of the herder households who depend on them. Mostly ultimately driven by meteorological conditions, dzud can be caused by a single or any combination of the following environmental factors: heavy snowfall, extremely low temperatures, wind and lack of pasture vegetation. Mongolia, there seems to be a strong evidence to believe that there is regional variation in dzud dynamics that can be separated at the finer spatial scale of analysis. Furthermore, the contributing factors to dzud may be changing, reflecting changes in potential coupling of climate-induced summer drought with winter dzud conditions, the socio-economic system and in herding practices.

Goal: The overall goal of the study is to improve the understanding of dzud causality and to develop an appropriate methodology to accommodate its spatial dynamics. The individual objectives are 1) to characterize environmental conditions through assembling climate data on snow water equivalent (SWE) and temperature, data on vegetation including remotely sensed NDVI, topographic data, and data on livestock mortality; 2) to implement and test a methods to understand environmental, spatial and other variables influencing livestock mortality; and 3) to interpret results in terms of different environmental variables, geographic variation, livestock composition and other variables.

Study Area: the study area is the country of Mongolia, divided into soums (counties) and the study time period includes major dzud and drought events in 1992-1993 and 1999-2003.

Approach: All datasets were processed to generate consistent statistics across the selected years. All data were aggregated by county (N=329). The rate of livestock mortality is the response variable for the analysis. The approach focuses on understanding the relationships between environmental precursors to dzud (factors) and livestock mortality (response). Both aspatial and spatial regression analysis were tested as was a spatial recursive partitioning approach. The analysis was done using ArcGIS Spatial Statistics extension.

Results: spatial autoregressive models using recursive portioning provided best results. The second goal of the analysis is to isolate dzud variables in terms of livestock-dependent factors that may have an indirect effect on mortality but are not related to weather or climate conditions. Exploration of methods led to the conclusion that patterns of dzud mortality had non-linear and varying relationships with some factors that need to be better understood before building an effective *predictive* model and that OLS models performed poorly. However, for the years and datasets used, recursive partitioning successfully identified regions with clearly defined relationships and revealed locations where dzud mortality could be adequately explained with the available factors. SWE had the strongest effect on livestock mortality in 1992/1993. For areas of SWE < 30.4, NDVI was the next strongest predictive factor. The mortality is higher in the desert where temperature is below -7.3. In the semi-desert region, higher mortality is was associated with higher livestock density and lower NDVI. Explanatory power of the regression tree was moderate, $R^2 = 0.464$. By 2000, the first year of a multi-year dzud event in Mongolia, herds had reached their peak densities. In 2000 dzud outcome first split on NDVI and then by livestock composition (greater horse percent having greater mortality, followed by sheep and then goat having lowest mortality influence). The year 2001 had the highest dzud incidence throughout the country and percent horses in the herd was the first dividing factor (underscoring the vulnerability of horses to dzud). By 2003, herds had deteriorated to 1993 levels. Counties were split first on SWE and then on NDVI. Geographically, the affected counties grouped into two clusters: northeast and south Gobi. The most interesting characteristic of processes at work in 2003 is that mortality was driven primarily by environmental and livestock density factors. Herd composition plays played only a minor role. The final tree reached R^2=0.685, 0.687and 0.774, each higher explanatory powers than the 1993 data.

Some overall patterns along with their exceptions can be summarized. The expected relationship between temperature and mortality are was negative: the lower the temperature, the higher the mortality. Presence of snow determines the magnitude of mortality in the desert, which underscores vulnerability of this region to black dzud. SWE and mortality have had positive relationships with mortality characteristic of white dzud: high SWE results resulted in high mortality. However, 2000, 2001 and 2003 partitioning revealed that the opposite relationship is was also possible in some areas. In 2000 and 2003, the negative relationships between SWE and mortality were recorded in the south-eastern part of the Gobi desert where SWE values were below 1.14 mm in 2000 and 0.09 mm in 2003. Such low values of SWE and sub-zero temperatures create perfect conditions for black dzud, when all sources of surface water are inaccessible to livestock and people. Elevation is was another variable that has had positive relationships with mortality: mortality is was almost always higher in the mountainous regions. Among five types of livestock, goats are the most resilient to dzud and the higher percentage of goats in the herd is associated with lower mortality; the opposite was usually true for percentage of horses which were the most vulnerable. High previous previous-year mortality usually has had a lingering effect on the present present-year mortality because livestock physical condition is was undermined from the previous winter. However, in 2001 some counties observed the opposite relationship: counties that suffered from dzud of 2000, did not experienced dzud in 2001. The spatial pattern may reflect the movement of herders escaping from dzud affected counties in 2000. Geographic variation was a factor. In the north regions are susceptible to white dzud. The mechanism of dzud is reverse in the Gobi desert and adjacent areas. Lack of snow limits surface water sources available to livestock, and sub-zero temperatures may freeze streams and rivers that are used for livestock watering. Therefore, black dzud is endemic to the Gobi region. These appear to influence the factors in determining livestock mortality. More recently, policies may influence dzud impact. The spatial signature of 2000 partition shows a zone of impact is organized along the northwest-southeast diagonal axis, of which the Central Mongolia witnessed the highest mortality. Central Mongolia has witnessed influx of herders since the privatization period because of better access to central market, services and transportation throughways. This suggests that mortality of livestock in 2000, especially in this region, is not due to winter dzud but has more to do with a drought and/or overgrazing of pasture, precipitating a multi-seasonal dzud phenomenon. The other observed hard hit area was in the desert region where the scarcity of good grazing lands and dzud forces herders to move their herders at greater distances than in steppes and forested areas.