Effects of land use change on fire, vegetation and wildlife dynamics in arid grasslands of Southern Russia

ABSTRACT

Human land use profoundly affects land cover, ecosystem processes, and biodiversity. After the breakdown of the USSR, land use changed significantly, and exhibited strong decreases in livestock numbers, and the area of plowed lands. The overarching goal of this study is to identify the effects of recent socioeconomic changes on vegetation and wildlife. The project will focus on Kalmykia, a republic in southern Russia, where land use changes are widespread, and where the last European population of saiga antelopes is at risk of extinction. Specific research questions are: how much (and why) has land cover and fire regimes changed and what are the interactions between land use, fire, vegetation, climate and saiga behavior. The analysis will largely be based on TM/ETM+, MODIS, AVHRR satellite data. This research will contribute to NASA's goal of reliable forecasts of changes in living systems that link fundamental components of Earth system change.

RESEARCH PLAN

1. INTRODUCTION

Natural and human disturbances play an important role in shaping ecosystem structure and function (Pickett and White 1985). Disturbances also play a significant role in global change, especially through land use and land cover change (LULCC, Turner et al. 1995). LULCC depends on both the environment and socioeconomics. The breakdown of the USSR in 1990 offers a unique 'natural experiment' (Diamond 2001) to test hypotheses on the interactions between LULCC and its human and natural determinants. After the breakdown of the USSR, more than half of the agricultural land is undergoing succession to shrublands and forests, especially in northern Russia. For some regions in southern Russia, livestock numbers plummeted (about 80% between 1992 and 2000) in arid grasslands. These fragile ecosystems, which were previously overexploited for grazing, are now free from that pressure and vegetative cover is changing rapidly in response. This project will use remote sensing data to quantify LULCC in southern Russia after the breakdown of the USSR.

Biodiversity decline and species endangerment are major consequences of land cover change (Hansen et al. 2001), and remote sensing can play an important role in mapping biodiversity (Turner et al. articles in Trends in Ecology and Evolution) either by mapping species rich ecosystems, or by focusing on umbrella species of biodiversity (Schiller et al. 2001). This project will focus on saiga antelope (*Saiga tatarica*) as an umbrella species and examine its population trends and habitat selection in response to changes in vegetation and fire regimes. Saiga antelope is the unique remnant of the Pleistocene fauna, and one of the few remaining large herbivores that exhibit long-distance migrations, but saiga populations are currently threatened (e.g., 90% population decline in Kalmykia since 1980 (Milner-Gulland et al. 2001).

The complex interactions and feedbacks between fire, vegetation dynamics, wildlife, and climate make it difficult to evaluate trends and management options through short-term field studies. Although field research often provides invaluable information, snapshot observations of composition change are not sufficient to make well-informed conclusions about future scenarios over broad regions. Remote sensing can be an important complementary tool for studying LULCC, mechanisms of change in ecosystem structure and function, potential cascading effects on vegetation and wildlife, and unintended consequences of management practices. Remote sensing thus can add significantly to the understanding of coupled human-natural systems that exhibit both rapid and long-lasting changes in land cover.

2. STUDY AREA

My study area is the arid grassland ecosystems of Southern European Russia in the Republic of Kalmykia and surrounding regions (Fig. 1). Typical vegetation is feathergrass (*Stipa sp.*) and sage (*Artemisia sp.*) dominated arid grasslands. Summers are hot and dry, winters cold with little snow. Annual precipitation is less than 210-340 mm, summer draughts are common. Important nature reserves are Chernye Zemli ("Black Lands") Nature Reserve and Bogdinsko-Baskunchaksky Nature Reserve. The study area covers ~100,000 km^2 (approx. 5 Landsat scenes). For parts of the analysis of saiga habitats, we will compare Kalmykia with saiga ranges of Kazakhstan and Uzbekistan selected as controls, in areas where saiga can still conduct long-distance migrations.

Figure 1. Study area and remaining saiga ranges in Russia, Kazakhstan and Uzbekistan (Milner-Gulland et al. 2001).

3. RESEARCH QUESTIONS AND WORKING HYPOTHESES

The main goal of this project is to understand how LULCC induced by the breakdown of the USSR affected the dynamics and interactions of vegetation, fire and wildlife in the arid grasslands of southern Russia (fig. 2.). Key questions to be addressed are:

1. ***How much has land cover changed in southern Russia?***
2. ***What are the main driving forces for LULCC in southern Russia?***
3. ***How have fire dynamics changed and what are the effects of fire on vegetation?***
4. ***How does vegetation affect saiga habitat selection, and how has habitat selection changed due to LULCC?***
5. ***How do temporal and spatial patterns of vegetation affect saiga calving time and location?***

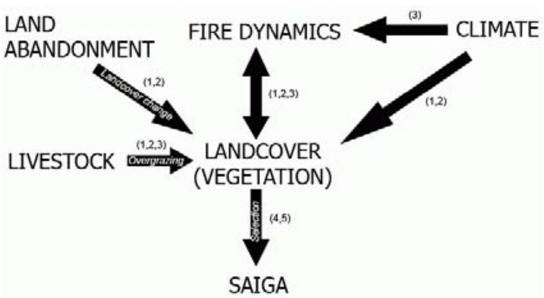

Figure 2. – Landcover change centered interactions; research questions numbers are given in parenthesis

1. How much has land cover changed?

According to agricultural statistics, substantial decreases in livestock and declines in area of plowed and irrigated land, occurred since 1990. However, there is little concrete information on how much and where land cover changed in the study area. Estimating LULCC in agricultural - grassland ecosystems is an important methodological challenge in remote sensing because change are often hard to track and quantify. From an environmental point of view, changes in grassland ecosystems are particularly important, because these ecosystems often lack resilience to human disturbance, and globally threatened.

Hypothesis: Vegetation fraction increased while areas of arable and irrigated lands decreased and these changes can be quantified using satellite data.

2. What are the main driving forces for the land cover changes in southern Russia?

The postwar restoration of the area's economy after the 1960s was boosted by a massive immigration, and new state-owned collective farms which mostly focused on sheep. In just one decade, sheep population reached 3 million, this level was kept until the breakdown of USSR in 1991, after which sheep numbers plummeted (Fig. 3). Overgrazing was common prior to 1991, and prompted efforts to "improve" pastures by turning them into hay fields, most of which were destroyed by wind erosion to the point of having no vegetation at all (Neronov 1998, Lushchekina and Struchkov 2001).

Hypothesis: The main driving force for land cover change is decline in livestock numbers.

3. How have fire dynamics changed and what are the effects of fire on vegetation?

A rapid decrease in sheep numbers reduced grazing pressure and consequently increased the amount of fuels. Preliminary analysis shows an increase in MODIS active fires (Fig. 4), but we can not rule out that this is due to weather conditions. The analysis of historic data (including satellite data) is

needed to complete the trend and test the hypothesis. Effect of fire on Kalmykia's grasslands is largely unknown and vegetation response captured by MODIS NDVI allows estimating both short (the same year) and long-term (consequent years) effects of fire on different vegetation types.
Hypothesis: Fire occurrence increased significantly since 1990 and effects of fire on vegetation is different for different vegetation types.

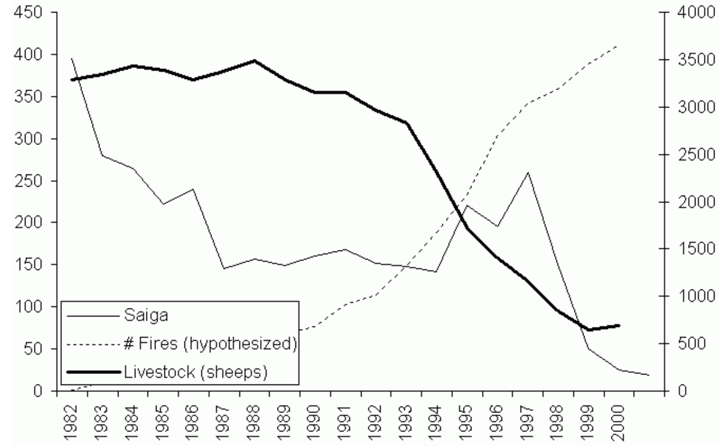

Figure 3. Change in hypothesized fire frequency, livestock and saiga populations in Kalmykia, right axis – livestock, left – saiga (Sokolov and Zhirnov 1998)

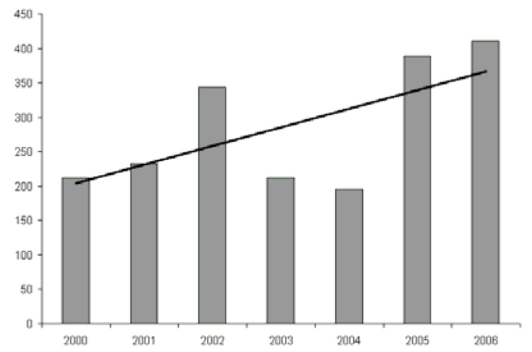

Figure 4. Recent changes in fire frequency for Republic of Kalmykia (MOD14 data, preliminary results)

4. How does vegetation affect saiga habitat selection, and how has habitat selection changed due to LULCC?
The saiga population of Kalmykia is constrained due to human development and does no longer exhibit long-distance migrations. The question is how this range contraction affected saiga population. In regions of variable climate (summer draughts), migration is a crucial adaptation. Preliminary results show interesting differences between saiga summer ground in Kazakhstan, where saiga still conduct long range migrates, and Kalmykia, where it is confined to short distance movement. Cumulative MODIS NDVI in Kazakh summer grounds exceeded those of Kalmykia summer grounds, suggesting that saiga in Kazakhstan can select optimal habitats, while Kalmykian saiga is limited in this (Dubinin et al. 2006).
Hypothesis: Saiga habitat selection is determined by vegetative cover as measured by NDVI.

5. What is the relation between vegetation and calving time and location?
Both the timing and the location of calving is crucial for saiga populations. According to the plant phenology hypothesis, the timing of births affects offspring growth rate and ultimately, survival (Rutberg 1987), but calving dates have never been analyzed in relation to NDVI pattern. Saiga calving is highly synchronized both in time and space (Sokolov and Zhirnov 1998), and that allows to identify spatiotemporal patterns of calving in relation to vegetation. Preliminary analysis shows that calving dates coincide strongly with peaks in MODIS NDVI. Calving occurs earlier when greenup is early, and later when NDVI peaks later and is generally lower (Fig. 5).

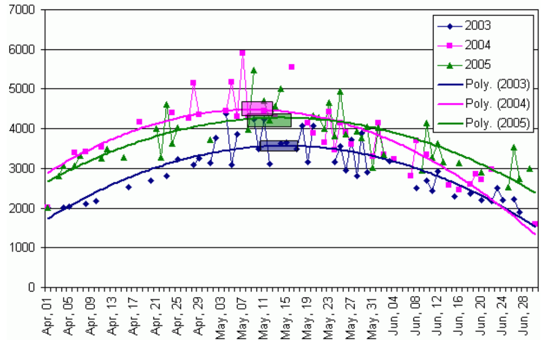

Figure 5. 2004-2006 calving periods (boxes) and mean MODIS NDVI in Kalmykia.

Hypothesis: There is a significant dependence of the location and timing of calving for Saiga antelope on vegetation especially in years with low vegetative cover, and greenup acts as a trigger for calving.

4. APPROACH

Remote sensing is playing a key role in monitoring land cover change (Gutman 2004). This project will use remote sensing data as an unbiased, operational and reproducible source of information on LULCC. Satellite data will be used to assess vegetation and biophysical parameters which will be related to human and environmental factors. Satellite imagery is also one of the primary data sources to measure habitat availability and its fragmentation and loss (Hansen et al. 2001, Liu et al. 2001). This study proposes to monitor land use and land cover change in Southern Russia from 1985 to 2002 using Landsat TM/ETM+ and AVHRR data, and from 2002 to 2006 using MODIS data.

1. How much has land cover changed?

LULCC will be analyzed based on Landsat 4,5 MSS, TM and Landsat 7 ETM+, MODIS reflectance (MOD09) and vegetation indices (MOD13). Landsat data of 9/2000, 6/2001 (ETM+), 9/1988 (TM), 9/1986 and 8/1977 (MSS) is in hand and additional spring images will be purchased. Data will be imported, taking data quality (QA flags) into consideration when available. Images will be co-registered using ERDAS AutoSync (Leica Geosystems 2005), and atmospherically corrected using 6S (Vermote et al. 1997).

Image classification will be implemented using Maximum Likelihood supervised classification algorithms for Landsat data, and phenology based classification after TIMESAT analysis for MODIS data (Jonsson and Eklundh 2004). Change detection methods, including change-vector analysis, and layer-stack classification will help to determine areas which are no longer plowed, lands which are no longer irrigated, and other land cover class changes. Supplementary thematic maps data from Pastures of Kalmykia map of 1983, Land cover map of Chernye Zemli Nature Reserve of 2000, and Geobotanic maps of GIPROZEM of 1990, and field data will be used for classifier training and accuracy assessment.

Land cover classifications may miss subtle changes in sparse vegetation and I will use spectral mixture analysis to capture these (Hostert et al. 2003, Brandt and Townsend 2006). Image endmembers will be selected using Pixel Purity Index (RSI 2004) for photosynthetically active vegetation, non-photosynthetically active vegetation, several soil types, and shade. In addition, soil and vegetation samples will be collected in the field to derive reference spectra using a FieldSpec II spectrometer available at collaborators at Humboldt University, Germany. Regression models and trend analysis will be used to determine significance of the recent changes in land cover. Result of the data classification and mapping will be verified using stratified random accuracy assessment in the field seasons of 2008 and 2009. Some field data on vegetation has already been collected by the authors in 2006 and further collection is planned in 2007.

2. What are the main driving forces for LULCC in southern Russia?

Agricultural statistics data will be collected in state archives of the respective regions. Variables include livestock populations, amount of plowed lands, human population density, and road density. Data will be obtained from the State Statistical Committee for 15 administrative regions of the Republic of Kalmykia from 1950 to the present. Road density and infrastructure will be derived from topographic maps of 1:500.000 - 1:200.000 scale of 1920-30 to 1990 (Military Topography Corpses – Korpus Voennykh Topographov, State Military Mapping Agency) and Landsat imagery.

Multiple regression models will be used to analyze the effect of the selected explanatory variables on LULCC (response variable). A correlation matrix will be used to identify collinearity. The best model will be selected using a stepwise procedure (Chatterjee et al. 2000). Models will be evaluated with the AIC criterion (Burnham and Anderson 2002). Hierarchical partitioning analysis will be used to determine the most influential variables in the model (Mac Nally 2002). Model residuals will be checked for spatial autocorrelation with Moran's I index. If errors are autocorrelated, a spatial autoregressive model will be fit (Fortin and Dale 2005).

3. How have fire dynamics changed and what are the effects of fire on vegetation?

I will use Landsat 4, 5 MSS, TM and Landsat 7 ETM+ data to derive burned areas and MODIS fire product (MOD14), AVHRR LAC to establish a trend of fire occurrences since the 1980s and spatial distribution of burned areas. Preliminary image interpretation of Landsat TM/ETM+ data shows considerably smaller amounts of fire scars on the images from the 80s compared with 2000.

I will also use NCEP/NCAR data and weather station data to check how weather has changed in the region and if these changes correspond with vegetation change. Meteorological data, including monthly temperature and precipitation since 1990, are already in hand; data for 1980 and 1990 will be collected from the Meteorological Service and Chernye Zemli Nature Reserve meteorological station.

Trend analysis will be used to determine significance of the recent changes in climatic and vegetation parameters derived from MODIS data versus changes in frequency of fires (de Beurs and Henebry 2004, Jonsson and Eklundh 2004). MODIS vegetation index products (MOD13) data will be used to quantify changes in vegetation both intra and inter-annually for different vegetation types.

4. How does vegetation affect saiga habitat selection, and how has habitat selection changed due to LULCC?

Saiga location data and range data have been collected by collaborators from Severtsev's Institute of Ecology and Evolution and Imperial College of London during 2003-2006 and will be collected by myself in 2007-2009. Saiga data will be combined with the results of the LULCC analyses (land cover classifications, vegetation fractions from spectral mixture analysis) and direct measures of vegetation by MOD13 to extract point and zonal statistics and processed using resources function selection methodology (Manly et al. 1993). Actual ranges will be compared to random ranges. Literature sources and expert knowledge will be used to estimate historic and current distribution of saiga both in Kalmykia, and in control areas in Kazakhstan and Uzbekistan.

5. How do temporal and spatial patterns of vegetation affect saiga calving time and location?

Calving ground survey data of previous and future years collected by collaborators and myself in 2003-2008 will be analyzed using logistic regression and resource selection function to understand how location and timing of calving relates to vegetation dynamics and conditions. For timing analysis daily MODIS reflectance product (MOD09GHK) will be used to calculate NDVI calculations for each date and construct phenology curves for each year where ground data is available. Important phenology parameters (e.g., vegetation onset, peak of greenness), derived from MODIS data will be related with calving dates using regression to estimate significance of association.

5. EXPECTED RESULTS

After the completion of the project, the following results are expected to be archived:

- Map of main land cover changes for the area of study
- Map of spatial and temporal distribution of fires occurrences and burned areas;

I plan to publish at least 4 papers on the following topics:

- LULCC in southern Russia, including details about the remote sensing methodology and accuracy assessment. Proposed Journal: *Remote Sensing of Environment*
- Statistical and descriptive analysis of the driving forces of LULCC, including the climate and agricultural statistics; Proposed Journal: *Land Use Science*
- Remote sensing data, and statistical analysis on fire regimes and their effect on the vegetation in short (intra-annual) and long (inter-annual) terms; Proposed Journal: *International Journal of Wildland Fire* or *Remote Sensing of Environment*
- Saiga antelope ranges, habitat selection and calving behavior in relation to vegetation parameters; Proposed Journal: *Ecological Applications* or *Conservation Biology*

Processed data, developed ancillary software, created maps, algorithms along with detailed descriptions of methodology will be made available via Internet. Results of the research and findings are also going to be presented at several conferences and distributed among local collaborators and conservation groups in the region to help continue this work in future.

6. SIGNIFICANCE

Results of this research are expected to contribute to NASA's goal of reliable forecasts of changes in living systems that link fundamental components of Earth system change under the fundamental question of *How is the Earth changing and what are the consequences for life on Earth*. Though much attention is being paid to human-wildlife or vegetation-wildlife interactions, such studies are rarely supported by remote sensing data. The case study proposed her will provide important information both globally and locally. On a broader level, this research will add to the knowledge of coupled systems of humans, wildlife, and vegetation from a LULCC perspective, showing the applicability of space-based observational measurements. The results will also inform research in other regions where fire, land cover change and management of endangered species are important issues (e.g. many arid grassland ecosystems around the world). Based on the understanding gained, it will become possible to examine the critical interactions and feedback processes that emerge from the co-evolution of anthropogenic and natural disturbance, thus reflecting the complex behavior of real life. Results will also help target areas for protection of endangered species inhabiting comparable ecosystems, and can be used to evaluate the consequences of land cover change, and help focus field-based observations and experiments. Last but not least, the information gained from this research will help to advise nature reserve's personnel and local conservationists about how to protect saiga better, and thus help to sustain this magnificent species.

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