EFFECTS OF LAND-USE CHANGE ON FIRE, VEGETATION AND SAIGA ANTELOPE IN ARID GRASSLANDS OF SOUTHERN RUSSIA

A dissertation proposal submitted by

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ABSTRACT

Human land use profoundly affects land cover, ecosystem processes, and biodiversity. Political changes may offer unique possibilities to study how these parts of the ecosystem are related. After the breakdown of the USSR, land use changed significantly, and exhibited strong decreases in livestock numbers. The overarching goal of this study is to quantify changes in burning, land cover and wildlife under the conditions of socioeconomic changes from 1985 to 2007. The project will focus on Kalmykia, a republic in southern Russia, where land-cover changes are widespread, and where the last European population of saiga antelopes is at risk of extinction. The main goal of this project is to understand how changes in land cover induced by the breakdown of the USSR affected the dynamics and interactions of fire, land cover and wildlife in the arid grasslands of southern Russia. Specific research questions are: how much, and why have land cover and fire regimes changed and what are the interactions between land use, fire, vegetation, climate, and saiga habitat selection. The analysis will largely be based on satellite data (Landsat TM/ETM+, AVHRR, MODIS NDVI) which are well suited to monitor land-cover changes. Preliminary results are promising and show, for example, a substantial increase in burned area, and a decrease in shrub cover likely due to the recovery of grassy fuels following decrease in livestock numbers. Ultimately, this research will contribute to an increased understanding of coupled human-natural systems.

OVERVIEW

The main goal of this project is to understand how changes in land cover induced by the breakdown of the USSR affected the dynamics and interactions of fire, land cover and wildlife in the arid grasslands of southern Russia (Fig. 1.). Key questions to be addressed are:

1. ***How and why have fire dynamics changed and how is annual burned area related to changes in livestock, vegetation and climate?***
2. ***How and why has land cover changed?***
3. ***Which human and natural factors affect saiga antelope habitat selection at three scales, and how can changes in land cover affect habitat selection?***

The Republic of Kalmykia represents a unique natural experiment to study environmental change in relation to institutional breakdown. In the **first chapter** I will use remote sensing data to quantify the change in burned area from 1985 to 2007. Change in burning is one of the most prominent regional changes, and related to socioeconomic changes, which affected land use. I will collect and analyze AVHRR, MODIS and Landsat data to reconstruct historical patters of burning, and will relate them to the dynamics of other factors like livestock densities, vegetation conditions and climate.

Land-cover change is another consequence of changing socioeconomic conditions affecting land-use. My major goal for the **second chapter** is to quantify the patterns of the land-cover change from 1985 to 2007. My first objective for this chapter is to quantify changes in bare ground, and fractions of green and non-photosynthetic vegetation using historical Landsat data. Because grassland vegetation is tightly connected to burning, it is important to understand how burning affects vegetation communities. This will form my second objective for this chapter – quantification of changes in the distribution of vegetation communities. To address this question, I will use MODIS time series data for 2001 and 2007, which will be classified based on phenological differences between the main vegetation associations. To understand how change in land cover is related to burning I will use the burned areas maps created in the first chapter.

Quantification of land-cover changes is an important and challenging task, but it is especially critical to apply the obtained information to practical local questions, such as conservation and resource management. In the **third chapter,** I will use different human and environmental variables, as well as results obtained in chapters 1 and 2, in a multivariate statistical analysis and apply resource selection function approach to understand habitat selection of a species of conservation concern – saiga antelope. The analysis will be focused on the locations of calving grounds, which will be studied at three scales: broad-scale, by comparing saiga summer-ranges in Russia and Kazakhstan with unoccupied areas, intermediate-scale, focused on the selection of a calving ground within a summer range, and fine-scale, by examining calving locations within a calving ground.

To summarize, my research will provide solid data on burned area and land-cover change in arid grasslands from 1985 to 2007. I will quantify the major trends and examine their interactions with other environmental and human factors. The results of this study will inform conservation by better understanding saiga antelope habitat selection, as it relates to these changes. Given that the studied ecosystem is representative of arid ecosystems and processes worldwide this study is reproducible and has potentially of globally significance.

INTRODUCTION

The Millennium Ecosystem Assessment has identified land-cover change and overexploitation as two of the major drivers of biodiversity loss and sources of concern for human well-being (MA 2005). Understanding how these processes operate and interact and how they might be mitigated are among the most pressing questions facing humanity. The emergent research community of the new interdisciplinary field of land change (or land system) science (LCS) seeks to improve a) observation and monitoring of land changes underway throughout the world and b) understanding of these changes as a coupled human-environmental system (Turner et al. 2007).

Grassland ecosystems represent an excellent example of coupled human-natural systems in which human and natural components interact (Liu et al. 2007b). The main drivers of grasslands change throughout the world are grazing, burning and climate change. Interactions of these factors with land use ultimately lead to changes in vegetation structure and composition and affect the wildlife species that inhabit grasslands. Interactions between components of ecosystem and the resulting feedback mechanisms require a comprehensive analysis to understand these coupled human and natural systems (Liu et al. 2007a, Bennett and McGinnis 2008). However, it is often argued that it is not possible to study interactions without decomposing the whole into its parts (Horgan, 1995).

Arid grasslands are undergoing significant change throughout the world, mainly as a result of ill-planned management and change in the disturbance regime, which often leads to overexploitation (Akiyama and Kawamura 2007, Zhang et al. 2007). One of the main disturbance agents in arid grasslands is fire. Grasslands, woody savannahs and savannahs account for more than 60% of burned areas globally (Tansey et al. 2004, Chuvieco et al. 2008). In Central Asia grasslands alone account for 80% of all active fire counts (Csiszar et al. 2005).

Fire is a highly interactive factor related to vegetation and climate conditions as well as other disturbances, like grazing (Skarpe 1992).

Another main direction of changes in grassland ecosystem is woody plant encroachment (Archer et al. 1995). Expansion of native shrubs is reported, for example, in the southwestern United States (Auken 2000), and in arid and semiarid regions of Africa (Roques et al. 2001), India (Sharma and Dakshini 1991), South America (Cabral et al. 2003), and Australia (Brown and Carter 1998). Multiple theories for the causes of woody plants encroachment exist and are debated, including climate change, chronic high levels of herbivory, change in fire frequency, change in small mammals populations, elevated CO_2 and combinations of these processes (Auken 2000).Woody plants encroachment is usually attributed to relatively recent (usually pre and post-European settlements) fire suppression both in temperate prairies (Briggs et al. 2002) and arid grasslands, often concomitant with an increase in grazing pressure. However, there is debate whether the increase in woody plants actually is persistent and connected to change in burning patterns for example since aboriginal times in Australia (Fensham, 2008).

Compared to studies of forest cover change, changes in grasslands biomes have received considerably less attention, though land-cover change in this biome are as likely to significantly alter biodiversity, carbon cycling and thus climate change. Furthermore, considerable knowledge gaps exist in certain geographic areas, one of which is arid grasslands of Eastern Europe and Central Asia. Due to specific institutional framework, dynamic processes of change happening in arid ecosystems of Russia and Kazakhstan are often opposite to processes that are currently under focus of research community and their study can offer interesting new perspective on the possible direction of grassland change.

Land-cover change in arid grasslands is affected by both environmental and socioeconomic factors. Together with natural disturbances (e.g. fire, drought, flooding) human disturbances play an important role in shaping ecosystem structure and function (Pickett and White 1985) through changes in grazing patterns and interactions with burning regime. The breakdown of the USSR in early 1990s offers a unique ‘unplanned natural experiment’ (Diamond 2001) to test hypotheses on the interactions between land-cover change (LCC) and its human and natural determinants and consequences. Unplanned natural experiments, albeit not driven by well-defined hypotheses and not controlled, provide opportunities at a scale that can rarely be studied in a classic experimental setting. After the breakdown of the Soviet Union, more than half of the agricultural land underwent significant changes (Lerman et al. 2004). In southern Russia's arid grasslands, livestock numbers plummeted (up to 80% between 1992 and 2000). These fragile ecosystems, which were previously overexploited by grazing, are now free from that pressure and vegetative cover is changing rapidly in response. This project will use remote sensing data to quantify LCC in southern Russia before and after the breakdown of the USSR and will relate it to wildlife habitat selection.

Biodiversity decline and species endangerment are major consequences of land-cover change through habitat loss and alteration (Hansen et al. 2001, Ceballos and Ehrlich 2002). The decline in habitat and wildlife populations in arid grasslands is highly dependent on country specific social and environmental conditions. In the Serengeti-Mara region of East Africa, for example, major changes in land cover and hence in the populations of dominant grazers were mainly driven by socioeconomic reasons, such as private landowners' response to market opportunities for mechanized agriculture and also by cattle numbers and population growth (Homewood et al. 2001). Similarly, cessation of pasture grazing and increased reforestation were found to be responsible for disappearance or decline of several pasture-dependent bird species in Italy (Falcucci et al. 2007).

Assessments of the habitat of umbrella species of biodiversity can serve as important indicators for ecological assessments and monitoring. This project will focus on saiga antelope (*Saiga tatarica ssp. tatarica*) as an umbrella species and will study temporal and spatial components of its 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. Saiga populations are currently threatened throughout saiga's range (e.g., 90% population decline in Kalmykia since 1980 (Milner-Gulland et al. 2001).

Study of change over broad scales and long time periods requires specific set of instruments. Remote sensing is a key tool for studying land-cover changes, changes in ecosystem structure and function, potential cascading effects on vegetation and wildlife, and unintended consequences of management practices (Gutman 2004). Satellite imagery is also one of the primary data sources to measure habitat availability, its fragmentation and loss (Hansen et al. 2001, Liu et al. 2001). Remote sensing can also facilitate mapping biodiversity (Turner et al. 2003) most effectively by mapping quantity and quality of species habitats (Nagendra 2001).

Analyses of remote sensing data can add significantly to the understanding of coupled human-natural systems that exhibit both rapid and long-lasting changes in land cover. 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. This study proposes to monitor different aspects of driving forces and results of land-cover change in Southern Russia from 1985 to 2007 using Landsat TM/ETM+ and AVHRR data, and from 2001 to 2008 using MODIS data.

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, local observations of configuration and composition change are not sufficient to make well-informed conclusions about causal relationships over broad regions (Fig. 1). It is thus important to study the dynamics of land-cover change and its drivers to help develop appropriate policies that promote sustainable land management and counteract negative impact of undesirable land-use changes.

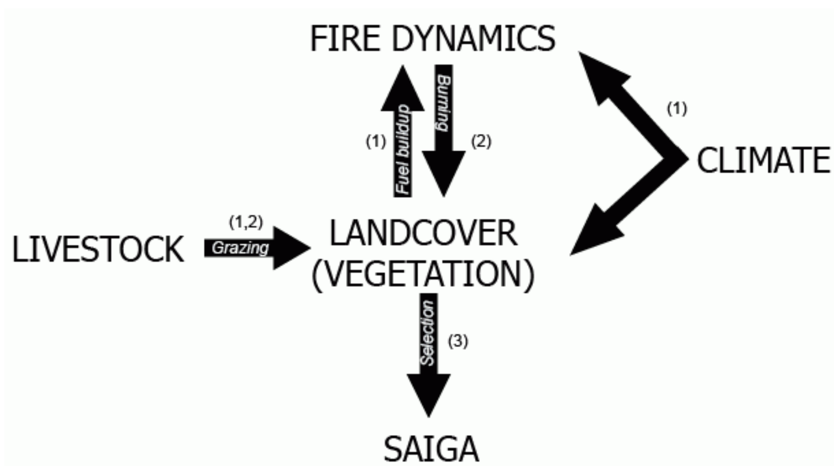


Figure 1. Land-cover change centered interactions; research questions numbers are given in parenthesis.

STUDY AREA

The study area is located in the grassland ecosystems of Southern European Russia and occupies ~30,000 km^2 (approx. 1 Landsat scene) of the Republic of Kalmykia and Astrakhan Region (Fig.

2). The area is sparsely populated with a density of 0.8-1.4 persons/km^2 (CIESIN and CIAT 2005) and no expectations for population growth (2015 expected population density 0.6-0.8 persons/km^2 (CIESIN et al. 2005)).

The climate of the study area is arid, with hot dry summers (mean daily temperature of +24°C in July; max +44°C common, average number of sunny days per year - 280), cold winters (mean daily temperature is -7°C in January; min -35°C not uncommon), with little snow (local name of the region Chernye Zemli = black lands/earth in Russian). Yearly temperature amplitude is 80-90°C. Annual precipitation is 150-350 mm (mean 281 mm for 1981 to 2006 period). Summer droughts are common, with most of the precipitation falling in spring (43% of all precipitation), coinciding with the period of the most active vegetation growth.

The terrain of the study area is characterized by the predominantly flat, and sometimes rolling terrain with a mean of 15 m elevation below sea level. The area was flooded by the Caspian Sea several times during quaternary period, which influenced parent rocks and consequent soil development. This caused a gradient from sands and sandy loams in the SE corner of the study area to clay loam in NW corner. The Sea itself is located 60 km to the East from the study area and its effect on the climate and vegetation is negligible.

The study area is occupied by poorly developed soils with aridic moisture regime (no water available for plants for more than half the cumulative time that the soil temperature at 50 cm below the surface is more than 5°C). Low amounts of precipitation and high temperatures lead to quick humus decomposition and fast mineralization, which results in relatively poor soils with undeveloped humus horizons. According to the FAO classification, the soils of study area are Calcisols, Cambisols, Luvisols characterized by argic (natric) horizon within 100 cm from soil surface soils, and loamy sand texture (FAO et al. 1998) analogous to USA soil taxonomy's Aridisols order, Argids and Cambids suborders (USDA 1999).

Vegetation associations are typical for northern Precaspian Plains and represent combinations of steppe and desert types. The main vegetation associations are shortgrass steppe (*Stipa sp., Festuca sp., Argopyron sp., Anizantha tectorum* and other graminoids) and sage scrub (*Artemisia sp., Kochia prostrata*). Shortgrass steppe is characterized by a short growing season from April-May and rapid senescence in dry summer, fall and winter. The grasses exhibit very high fire adaptiveness due dense bunches, which protect seeds and generate abundant fuels for burning. Highly productive, dense bunch grasslands (analogous to tall-grass praries) are more natural for the northern steppes (not present at the study area), which are more humid and which are almost entirely cultivated for crops today. Sage (*Artemisia sp.*) dominated shrublands have less biomass, but a longer growing season, and sometimes exhibit a secondary vegetation peak in the fall or even early winter. *Artemisia sp.* is more susceptible to fire because the points of growth are situated above ground and can be killed or damaged by fires, which leads to substitution by *Stipa sp.* and other graminoids. *Artemisia sp.* dominated communities provide very important winter forage for Saiga antelope.

The primary human use of the grasslands in the study area is as rangelands to support grazing for domestic livestock, mainly sheep and to a lesser extent cows and goats (see Historical background for more details).

Saiga ranges located on the study area are protected by two nature reserves: federal level Chernye Zemli ("Black Lands") Nature Reserve, created in June, 1990 and nominated as a UNESCO Biosphere Reserve in Dec, 1993 and the regional level Stepnoi Nature Preserve, created in Nov, 2001. For parts of the analysis of saiga habitats (chapter 3), we will compare Kalmykia with saiga ranges of Kazakhstan and Uzbekistan.

Figure 2. Study area and remaining saiga ranges in Russia, Kazakhstan and Uzbekistan (Milner-Gulland et al. 2001, Bartalev et al. 2003).

HISTORICAL BACKGROUND

1. **Period of seasonal stock-breeding (before 1930)**. Starting from their initial settlement of the lands of the Caspian plains in 1630, Kalmyks lived mainly a nomadic way of life with seasonal movements of stocks between pastures. Pastures of Kalmykia were mainly used during

winter, because of the small amounts of snow (Zonn 1995). Because grazing was restricted to the winter months, the pastures of northwestern Caspian plains remained relatively undisturbed by human land use before 1930 despite complex and highly variable environmental conditions (Shperck 1895). Signs of local degradation in that period were rare and restricted to certain places, such as the surroundings of waterholes, herder camps, and livestock trails (Krasnov 1886). As a result, Shperk (1895) counted only 52 sites of open sands in steppes of Kalmykia, and in the central parts of the republic, big areas of barren sands were uncommon. During that period, practices of local population were sustainable and caused serious degradation only in very rare and local cases. However, Kalmyk's way of life changed substantially after civil war in 1917-1920, and this caused considerable changes in the natural ecosystems.

2. **Period of collectivization (1931-1941)**. By the beginning of the 1930s, most of the Kalmyks were settled, livestock production was aggregated into state enterprises, and the size of sheep herds increased to about 1,000 heads and more. Prior wool-meat sheep production was substituted with wool producing merinos and karakul sheep breeds, as well as the cessation of herding of horses and camels. Some of the grasslands were plowed and farmed, though even the strongest crops could not resist the harsh winds and lack of precipitation. Degradation soon followed and by 1941, the area of degraded pastures on loamy sands increased by 40-50% (Zonn 1995).

3. **Period of decline of livestock industry and its restoration (1942-1960)**. Increasing degradation was slowed by the World War II and the deportation of Kalmyks to Siberia and Kazakhstan in 1943. Agriculture in Kalmykia greatly declined and the remaining population had little influence on pastures. Restoration of the natural vegetation and wildlife populations continued up to the early 1950s. Two governmental bills tightly connected with Kalmykia were adopted, the "Decree of restoration of livestock industry by creation of large agricultural enterprises" in 1946, and Stalin's plan of modification of steppe and deserts nature to combat droughts of 1948. Planned migrations of people from other regions of the Soviet Union began, and they started to restore the livestock industry in the region. During this period, pastures of Kalmykia were also used by the enterprises of surrounding Dagestan, Stavropol, Astrakhan and Volgograd regions. In 1957, Kalmyk Autonomous Region was restored and winter pastures were again held by enterprises located in Kalmykia itself.

4. **Period of pastoral sheep industry (1961-1972)**. During the 1960, pasture lands were divided between agricultural enterprises (Trofimov 1995). At this point a forage deficit emerged, which could not satisfy the ever-growing numbers of livestock. Increasing forage deficits led to the attempt to increase volume of forage by plowing 150,000 ha of steppe (Vinogradov and Kulik 1987). However, these efforts failed, and by the beginning of the 1970s, wind erosion turned these fields and adjoined areas into aeolian dune complexes, completely bare and hard to restore.

5. **Period of continuous growth of sheep industry and unsystematic pasturing (1973-1990)**. In 1973 stationary sheep herding enterprises were created in Kalmykia. The transition to completely stationary land use led to further increase in livestock numbers and intensification (up to year-round) of pasture's exploitation. Continuing pressure reached critical numbers. About 500,000 hectares were in the last stage of degradation and needed to be excluded from grazing for at least 2 years (Filonenko et al. 1976). In the Black Lands, by 1975 overgrazed area represented 60% of the region and after 10 more years the entire Black Lands were classified as overgrazed (Zasoba 1993). At this point, aeolian sands occupied about 380,000 ha.

6. **Period of transition to a market economy (1991 – now)**. Despite some measures taken in 1987 (e.g., the 1986 adoption of the "General scheme to fight desertification of Black Lands and Kizlyar pastures"), the situation did not change significantly until the beginning of 1990s. Political changes in the country and the transition to a market economy led to substantial declines in livestock numbers in state and collective farms, which were no longer profitable. According to governmental statistics and interviews, livestock population dropped 8 to 10 times, and the number of herders' camps decreased 4 to 5 times. The same decline was observed in privately owned herds. However, an improving economic situation since 2000 has led to partial recovery of livestock populations, which will possibly reach Soviet times numbers in the near future.

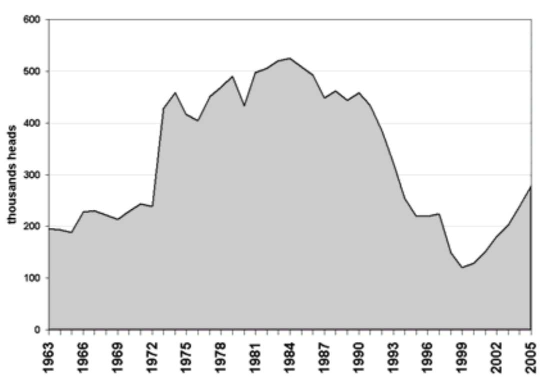


Figure 3. Livestock population in 1963-2005 (ROSSTAT 2003, 2007).

CHAPTER 1

Research question:

Q1. How and why has fire dynamics changed?

Fire is a prominent disturbance process and an agent of environmental change with local to regional impacts on land use, productivity, and biodiversity, and regional to global impacts on hydrologic, biogeochemical, and atmospheric processes (Csiszar et al. 2004). Fire also greatly affects vegetation structure and composition (Johnson and Miyanishi 1997) and in many land-use systems fire is a proximate cause or indicator of land-cover change (Bucini and Lambin 2002, Cochrane 2003). Indirectly, through habitat alteration, burning influences animals of many taxa, from small mammals (Yarnell et al. 2007) to megafauna. The extinction of the latter in Australia is sometimes attributed to the changes in fire regime, introduced by arrival of early humans (Merrilees 1968, Archer 1984).

Burning is responsible for a significant portion of greenhouse gas emissions to the atmosphere (van der Werf et al. 2006). The amount of CO_2 emissions from biomass burning in Latin America, for example, where 63% of fires occur in grasslands and savannahs, is eight times larger that Latin America's fossil fuel emissions (Liousse et al. 2004). And according to the Seiler and Crutzen equation (Seiler and Crutzen 1980), burned area is one of the parameters that introduces the greatest uncertainty calculations of the amount of burned biomass and emitted gases (Scholes et al. 1996).

The frequency, intensity, seasonality, and type of fire that prevails in an area are collectively referred to as the fire regime. Two spatially explicit fire estimates are most often used to characterize fire regime: number of active fires and burned areas. Active fires are areas of actively burned fuels, so called "hotspots". Burned areas represent the cumulative total of all active fires in a particular area over a given period of time. In this chapter my objective is to reconstruct local fire regime by quantifying temporal and spatial distribution of burned areas for the period from 1985 to 2007.

The fire season in the study area starts with the onset of the dry season in June and ends in the fall when precipitation increases in late August and early September. Considerable amount of anecdotal evidence indicates that annual burned area increased drastically after the breakdown of Soviet Union. However, broad-scale quantification of burned areas in Kalmykia's grasslands is so far lacking. Unfortunately, while government agencies of some countries keep records of fires (Brown et al. 2002), this is not the case in Russia. Some global datasets of burned areas exist (Simon et al. 2004, Tansey et al. 2004), but they do not provide sufficient temporal resolution to reconstruct long-term burning trends for specific areas, and are often not validated. A comprehensive database of burned areas in Russia does exist (Sukhinin et al. 2004), but focus mainly on forested ecosystems in Siberia and the Far East. Decrease in the effectiveness of fire suppression is one of the consequences of the country's continuing transition from a centrally planned economy to free markets and consequent general lack of funds for fire protection (Shvidenko and Goldammer 2001). Based on this background and preliminary analysis I hypothesize, that ***Annual burned area increased substantially since the breakdown of the USSR in 1990 and shows different dynamics before and after institutional collapse (H1.1).***

Besides mere quantification of burning, information on the reasons for potential trends is critical for both scientific and management communities. The combustion of vegetation is influenced by a range of factors, including flammability, phenology (proportion of living and dead material), vegetation structure, and the location of fuels within vegetation, weather conditions (humidity, wind speed, temperature) and fuel moisture levels. Amount and contiguity of fuels are major factors related to frequency of fires. Normalized difference vegetation index (NDVI) is an effective and widely used measure that is highly correlated with broad-scale vegetation abundance and hence the abundance of fuels. Amount of burning in a particular year is highly dependent not only on conditions in the same year before the onset of the fire season, but also on the antecedent year, as the prior year may determine how much fuel will be available (Knapp 1998). Together with rainfall data, NDVI allows estimating relationships between fire, vegetation and climate both intra- and inter-annually. I hypothesize, that: ***Annual burned area is positively correlated with broad-scale estimates of vegetation vigor represented by NDVI during the growing season and negatively correlated with NDVI during plant senescence (H1.2).***

Grazing is another agent affecting fire-vegetation interaction and a good indicator of institutional collapse leading to the temporary absence of large herds, formerly managed by state enterprises. Changes in grazing patterns are also the result of institutional changes and the transition to market economy that resulted in a 5 to 7 fold decrease in livestock density (Fig. 3). Initial numbers were considered disastrous by researchers and proved to be ecologically inappropriate for fragile arid ecosystems and ultimately led to increasing desertification from the 1960s until the 1980s (Saiko and Zonn 1997). Grazing influences the rate of vegetation recovery and directly reduces both amount and contiguity of fuels by consumption, wallowing, and trampling of vegetation. Given the rapid decrease in sheep numbers in the beginning of 1990s accompanied by favorable climatic conditions of the same time I hypothesize that: ***Burned area is negatively correlated with livestock population trends (H1.3).***

Satellite remote sensing provides the only means to monitor burned areas at a regional scale. Both active fires and burned areas can me monitored, though methodologies for detecting the two differ substantially. We focus here on burned area, because active fire measures do not reliably measure the entire fire-affected area (Fig. 4). Active fires underestimate fire area because the satellites do not overpass a given area sufficiently frequently to capture the whole extent of the fire scar, especially if a fire spreads fast across a grassland area, and because clouds and smoke may preclude active fire detection (Robinson 1991). The type of the derived fire estimate (active or burned) is also highly dependent on the type of remote sensing data and depends on the band arrangement of the particular sensor. Mid-range infrared bands are used for active biomass burning detection through calculation of brightness temperature (3.55-3.93 μm range of band 3 AVHRR and 3.93-3.99 μm range of band 22 MODIS). The detection of burned areas focus usually on changes in reflectance in red and infrared bands, or in the NDVI (0.62-0.67 μm band 1, 0.73-1.1 μm band 2 AVHRR and 0.62-0.67 μm band 1, 0.84-0.88 μm band 2 MODIS). Use of other bands sensitive to temperature can greatly increase detection accuracy. Using active fire and burned area measurement together can validate each other. For example, active burned areas detected with MODIS data can be used to validate burned areas detected with AVHRR, which has a longer time series.

Technical plan

General approach

I will use remote sensing data to reconstruct historical burned areas for 1985 to 2007 and validate it using independent datasets. I will further relate reconstructed record with environmental and human factors such livestock population, vegetation condition and climate to explain the trends that were observed.

Data Sources and analysis

I will use AVHRR large area coverage (LAC) data with 1-km resolution to estimate burned areas for each year starting from 1985 until 2007. I will also use MODIS calibrated radiances data (MOD02) and MODIS active fire product (MOD14) for 2000 to 2007 to create an independent validation dataset. Analysis will be limited to the season when fires are most abundant, i.e., from the beginning of April to the end of September. Higher resolution Landsat 4, 5 MSS, TM and Landsat 7 ETM+ data will be used to validate burned areas estimates, especially for the 1980s and 1990s.

AVHRR data has been obtained from the NOAA Comprehensive Large Array-data Stewardship System (CLASS). The AVHRR data will be radiometrically and geometrically corrected. Images will be radiometrically normalized based on pseudo-invariant objects (Collins and Woodcock 1996). Clouds and bad pixels will be masked. From each year, the two best images for two seasons will be chosen. The first image will represent peak-vegetation period (around late April – May) and the second the end of the fire season (late August – September). These two images will be combined (layer stacked) and classified jointly to produce a burned area map for each year.

Before the classification, band composites will be visually inspected to locate recently burned areas and non-burned areas, which will serve as a training and validation dataset. Besides the bands themselves, a number of other spectral and texture measures will be generated, namely: NDVI, 3x3 mean of each band, 3x3 standard deviation, 5x5 mean and 5x5 standard deviation, as well as band differences between each pair bands (i.e. BAND1 of image 1 minus BAND1 of image 2, etc.). For the locations of the training data I will extract pixel information from the layer stack. Extracted information will then be used to parameterize a decision tree. I will use bagging to make our sampling more robust (Breiman 1996). Fifty percent of the training dataset will be sampled 30 times and a decision tree will be created for each subsample. Trained trees collection will be examined and metrics which did not improve class separation based on deviance decrease criteria (De Fries et al. 1998) will be rejected. After revision, trained trees will be used to classify the whole layer stack into burned (class 1) and non-burned (class 0) areas.

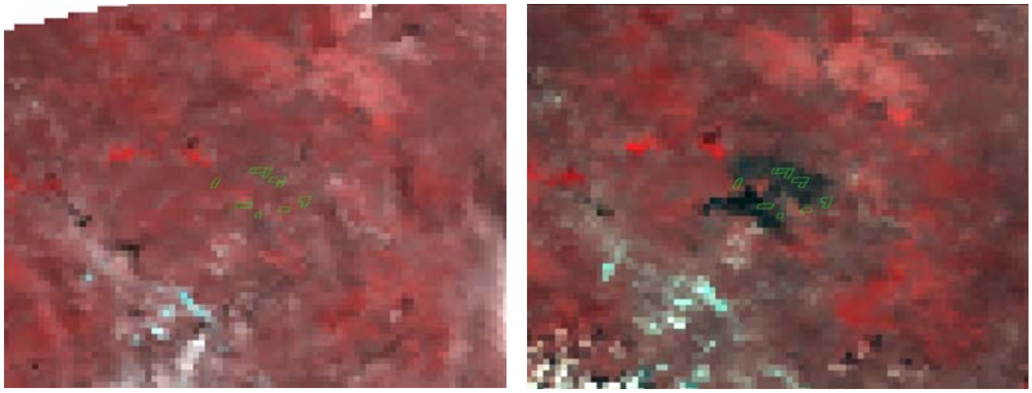


Figure 4. Before and after burning as visible on AVHRR image (bands 2-1-1). May 23-26, 2002. Green polygons indicate active fires of May, 26 extracted from MODIS thermal anomalies (MOD14Q1) dataset. The approximate area burned is 14,500 ha.

In the second step, I will create a validation dataset using historical (Landsat) and current imagery (MODIS). The data will be screened for fire scars which will be manually digitized. Visual analysis has been widely used for discriminating burned areas, since burned areas have a distinct color and shape (Roy et al. 2005). The resulting dataset will be generalized to the scale of AVHRR (1-km pixels). I will select points both from inside and outside the digitized polygons to represent both burned and non-burned areas, and use these to estimate user's and producer's accuracy as well as the kappa coefficient (Congalton and Green 1998). The results will also be compared to two worldwide burned areas mapping projects: the GBA2000 (Tansey et al. 2004) and GLOBSCAR (Simon et al. 2004) which provide data of comparable spatial resolution, though only for 2000.

For the explanatory part of the analysis, I will extract vegetation trends using GIMMS NDVI data (Tucker et al. 2005) and relate the observed change in burned area with change in mean monthly NDVI. GIMMS NDVI data is currently available bi-monthly from 1981 to 2006 with 8-km resolution. I will also use climate data from the National Center for Environmental Prediction (NCEP) Reanalysis Project (Kalnay et al. 1996) and local weather station data, including minimum, mean, maximum temperatures and precipitation data to check how climate has changed in the region and if weather and climate changes correlate with burned area. Meteorological data, including monthly temperature and precipitation since 1990, are already in hand; data for the 1980s will be obtained from the Meteorological Service and Chernye Zemli Nature Reserve meteorological station.

Relationships between burned area and potential predictor variables will be evaluated using multivariate linear regression models. As response variables I will use burned area itself, average burned area in different moving windows, and variability in burned areas over 3 and 5 years windows. Potential predictors will include vegetation, climate, and livestock data, as well as their variability, both lagged by one year and simultaneous. Consistently with the response, the predictor variables will also be averaged over a window. Residuals will be examined for possible temporal autocorrelation and if present, a temporal autoregressive term will be included in the regression models. I will also examine the influence of stratifying the data into two periods (before and after the institutional breakdown of early 1990s) and examine how temporal stratification affects the set of important variables influencing burned areas.

Univariate relationships between variables, as well as potential collinearity, will be estimated using linear correlations. Statistical significance will be established using bootstrapping. Multiple surrogate time series sharing the same power spectrum and amplitude of the original time series will be created for each variable. Linear correlation of each other variable will be computed for each bootstrapped time series. The statistical significance of the relationship, i.e. two-tailed *P* value, will be computed by comparing correlation between observed variables and bootstrapped ones (Beckage et al. 2003).

Preliminary results

Preliminary AVHRR decision tree classifications have been carried out for the years 1985 through 2007 and showed a considerable increase of burning starting around 1997 and 1998 (Fig. 5). This was confirmed by visual interpretation of Landsat TM/ETM+ data that showed considerably smaller number of fire scars in the 1980s compared with 2000. These results suggest that there was a several years lag the after the institutional change, during which vegetation and fuels accumulated up to a threshold beyond which fires increased fairly abruptly. The process is self-maintaining and once started, exhibited rather constant dynamics with large areas burned every second year or two years in a row.

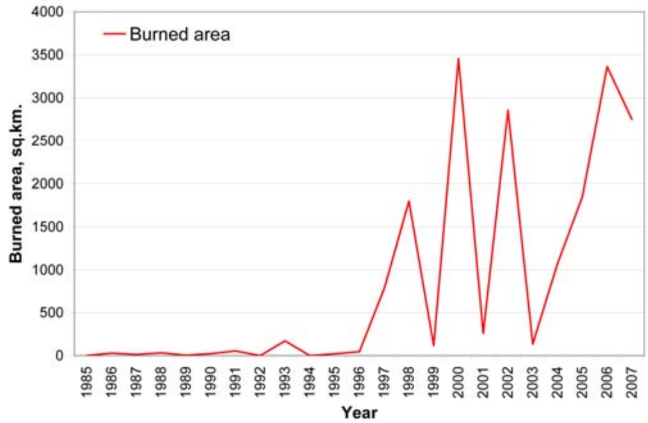


Figure 5. Changes in burned area for 1985-2007

Expected outcomes

Findings of this chapter will be summarized in a manuscript planned for submission to either the *International Journal of Wildland Fire* or *Remote Sensing of Environment.* The paper will include following points, addressed in this chapter:

- Reconstruction of burned area dynamics from 1985 to 2007;
- Maps of burned areas from 1985 to 2007;
- Reconstruction of the concurrent trends in livestock, climate and vegetation using independent data sources;
- Statistical and qualitative analysis of interrelations between burned areas and vegetation, climate, and livestock numbers.

CHAPTER 2

Research question:

Q2. How and why has land cover changed?

Arid grasslands can undergo considerable land-cover change in response to disturbances. This is of management concern because grasslands are important for soil conservation and the livestock industry. Changes in grassland ecosystems are particularly worrisome, because grassland ecosystems often lack resilience to human disturbance, they are globally threatened (Hannah et al. 1995), and they provide important habitat for keystone species, in our case – saiga antelopes. Opportunistic livestock grazing on arid pastures have been the most important form of land use in Kalmykia for several centuries and until recently acted as a broad scale disturbance agent. However quantitative measures of pasture conditions and their change in space and time have not been reported for Kalmykia and our knowledge about these pastures is poor. Our study area has a complex history of environmental changes that is tightly linked to the history of land use and we aim to study their intended and unintended consequences.

Land-cover changes can include the increase of bare ground, and the decrease of green vegetation and non-photosynthetically active vegetation (e.g. litter), as well as compositional changes Though vegetation cover changes depend partly on weather conditions, over long periods (20+ years) they can serve as good indicators of the effects of changing disturbance regimes.

According to agricultural statistics, substantial decreases in livestock and declines in the area of plowed and irrigated land have occurred since 1990 (Fig. 3). Though this process did not miss the eye of scientists (Neronov V.V. et al, 1998 see historical outlook), there is little concrete spatial and quantitative information on the patterns of land-cover change in Kalmykia.

The first chapter of my dissertation examines the relationship of grazing and fires. In this second chapter my aim is to study changes in land cover (with vegetation a part of it). My objective for this chapter is to quantify the changes in different land cover classes from 1985 to 2007. Preliminary evidence shows different trends of vegetation with a gradual increase over time in spring NDVI values, but a decrease in early fall NDVI (Fig. 6.). Increase of spring NDVI may suggest vegetation restoration, but may also indicate compositional vegetation change. It is unknown if trends in spring and fall NDVI can be accounted for by burning and resulting compositional vegetation change.

Livestock can significantly change plant cover by trampling and grazing. Change in edaphic and microclimatic conditions can trigger a positive feedback mechanism further reducing plant cover by decreasing rainwater infiltration and increasing surface runoff. These conditions favor woody species, which form typically less dense communities, with considerable bare interstitial space. My first hypothesis for this chapter is: ***Overall vegetation fraction increased and the proportion of bare ground decreased (H2.1).***

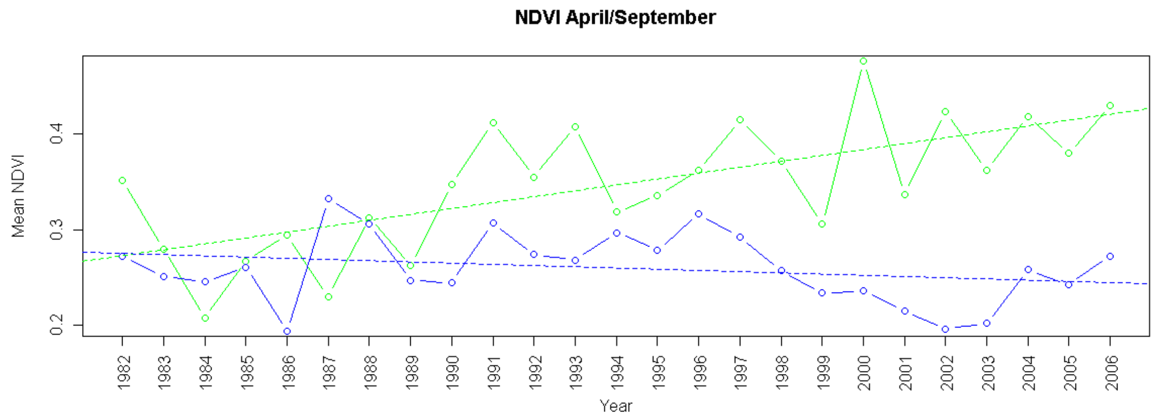


Figure 6. Change in mean NDVI and linear trends over the period of 1982-2006 (green line – April, blue line – September).

In addition to change in the abundance and the structure of vegetation, changing disturbance regimes can also lead to gradual or abrupt changes of the vegetation composition. Directions and scale of vegetation composition changes depend on the initial conditions of the vegetation, the type of the disturbance and its intensity. The lack of strong general trends in precipitation and temperature since the 1980s and high resistance of infertile grasslands to climate shifts (Grime et al. 2008), suggests that the effect of climate on vegetation change can be ruled out. My second objective for this chapter is to quantify recent changes of the vegetation communities themselves. I am interested in broad-scale patterns of compositional vegetation change and their relationship with the increase in burned areas hypothesized in Chapter 1. I will focus my investigation of changes in vegetation communities on the years 2001 to 2007 because preliminary results on burning trend suggested that fires increased only recently and because I will use MODIS satellite imagery which is not available for the 1990s.

Generally speaking, the main short-term impact of fires on vegetation composition is to prevent the replacement of herbaceous strata by woody vegetation and to enhance the growth of some graminoids. Grasslands that lack consistent burning usually undergo woody encroachment (Archer et al. 1995). Given the decrease in livestock abundance and the possible resulting increase in burning (Chapter 1), I hypothesize that change in vegetation composition trend of my study area should be in direct opposition to the common change in the other parts of the world, where fire is excluded or suppressed (Auken 2000), i.e.: ***Shrub-dominated communities in the study area decreased (H2.2).***

Estimating vegetation change in agricultural-grassland ecosystems using remote sensing is a methodological challenge due to the highly dynamic nature of grassland ecosystems. Remote sensing has been widely used to monitor vegetation on continental scales using AVHRR data (Tucker et al. 1985, Justice and Hiernaux 1986), but routine techniques available to estimate parameters of plant canopies are limited. However, coarse resolution imagery can provide valuable information about climatic and anthropogenic influence on vegetation dynamics (Reed et al. 1994, de Beurs and Henebry 2004). The advantages of coarse-resolution data are very frequent, usually daily acquisitions, which capture phenological trends. However, AVHRR data has such limited spatial and spectral resolution that it is very difficult to derive vegetation classifications or distinguish between green and senescent vegetation using only low resolution data (Oleson et al. 1995). More modern sensors, like MODIS, provide much better spectral and improved spatial resolution, but the drawback of these data is that they only available since 2001. This makes it hard to classify long-term vegetation changes accordingly using only coarse resolution data. Medium resolution Landsat MSS/TM/ETM+ data provide more precise spatial and spectral estimates of land-cover types, making it possible to distinguish between different types of vegetation. Numerous studies report possibility to quantify grassland cover and its change over years using such data (Sohn and McCoy 1997, Hostert et al. 2003, Brandt and Townsend 2006, Numata et al. 2007). However, the major limitation of Landsat data is its low temporal resolution, although this can be partially overcome by recent changes in data distribution policies (Woodcock et al. 2008).

Technical plan

General approach

To address my research questions for this chapter I will use remote sensing imagery to quantify changes in three land-cover components: bare ground, green and non-photosynthetically active vegetation since 1980s. I will also discriminate between the two main vegetation types (*Stipa* grasslands and *Artemisia* shrublands) to better understand changes in their distribution since 2001.

Data Sources and analysis

Changes in bare ground, green and non-photosynthetic vegetation will be analyzed based on Landsat 4,5/MSS, TM and Landsat 7/ETM+ data. Landsat data from 9/2000, 6/2001 (ETM+), 9/1988 (TM), 9/1986 and 8/1977 (MSS) is already in hand and additional spring images will be purchased. Images will be co-registered using ERDAS AutoSync (Leica Geosystems 2005), and regression using pseudo-invariant targets approach will be used to match images together radiometrically (Collins and Woodcock 1996).

Vegetation cover in semi-arid landscapes varies at scales that are often finer than the pixel size. Since satellite observations integrate the radiance of all elements within a pixel, techniques to invert fractional coverage of components such as spectral unmixing may provide more reliable estimates of land-cover attributes than hard-class classifications (Adams et al. 1995). Spectral unmixing is particularly efficient in arid ecosystems and will be utilized to estimate bare ground, green and non-photosynthetic vegetation fraction (Hostert et al. 2003). One advantage of SMA is that it uncouples information from external factors such as soil brightness and color, thus minimizing their influence. Image endmembers will be selected using Pixel Purity Index (RSI 2004) for photosynthetically active vegetation, non-photosynthetically active vegetation, several soil types, and shade.

As Landsat images are often not recorded at the peak of the vegetation period, additional correction is needed to compare the resulting fractions over time. To account for the effect of image acquisition date and consequent changes in amounts of green vegetation, I propose a novel approach of “phenological optimization”, which corrects reflectance of source Landsat pixels of particular date by establishing relationship between then and corresponding MODIS data of the same date and MODIS data that corresponds to peak vegetation condition. This correction can help to derive vegetation fractions that are better comparable.

The analysis of Landsat data will provide high-resolution information on changes in green, non-photosynthetic vegetation and bare ground for several time slices that can be further analyzed as a trend. For accuracy assessment of resulting fractions I will use field data (described below) that includes ground estimates of different components of vegetation cover. As no data exist to validate analysis results back to the 1980s, the output of the unmixing model will be also evaluated empirically. Different measures will be used: the spectral unmixing process provided images of root-mean-square errors, as well as band-wise residuals. Both will be taken into account to identify potential shortcomings in the mixing model (Hostert et al. 2003).

To test the second hypothesis of this chapter and discriminate between two main types of vegetation, I propose to use a phenology-based classification of MODIS time-series data. I will use already collected field data of vegetation communities dominated by *Artemisia sp.* and by grasses (both annual and perennial). Based on this ground truth, I will classify a time-series of twenty three 16-day composite MODIS images from 2001 and another time series from 2007 into these two classes. The output of classification will represent areas with phenological trajectories similar to shrub-dominated or grass-dominated communities. The results of the two classifications will be compared to estimate transitions between the two vegetation communities. For classification, I will use a similar as for burned areas (i.e., multiple decision trees, 50% sampling of the training dataset, multiple classifications with continuous output, see previous chapter for details).

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 will be used to assist the classification and accuracy assessment.

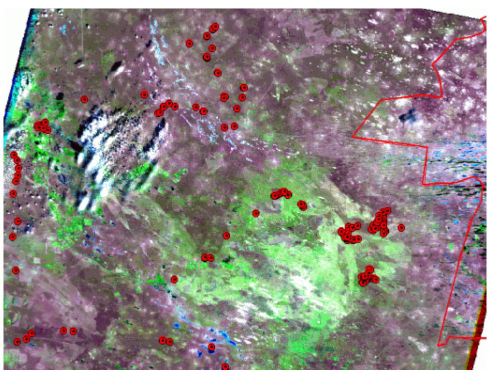


Figure 7. Locations of the field plots.

To further support and validate the classification and validation, field data on vegetation has been collected in 2006, 2007, and 2008. Vegetation data was collected along 90 m transects along which percent cover of plants, bare soil and litter were estimated. Transect locations were chosen based on preliminary image interpretation to represent main vegetation communities, considering logistical constrains (Fig. 7). Each transect was split into three 30-m sections, and in each section, 100 observations were made at 30 cm interval, 300 observation total per transect (Elmore et al. 2000) (Fig. 8). At each observation the tallest cover type was noted and classified as bare ground, litter, or plants (classified by species). In addition, a visual description of vegetation was conducted for a 5 m wide strip along each side of the transect (900 m^2). In this broader transect, I registered all plant species, estimated the height and cover of each species, and noted signs of disturbance by fire and grazing. Besides that, 6 breast height nadir digital pictures were taken along the transect starting at 7.5 m at 15 m interval. Data from 238 transects were collected during the summers of 2007 and 2008. A supplementary dataset of 200 points were collected where only class cover of dominant species, bare ground and litter were measured. Both transect and supplementary points were georeferenced using handheld GPS.

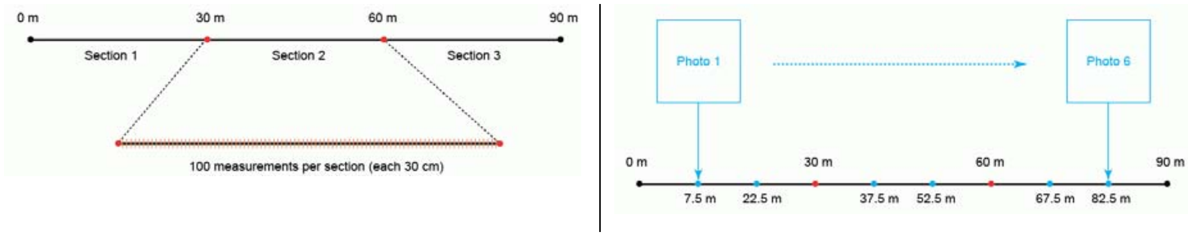


Figure 8. Field data collection protocol schematics.

Preliminary results

Preliminary analysis of changes in shrub-dominated vegetation communities was carried out for test site of ~10,000 km^2 area, located in the center of study area. Results suggest that changes in communities are widespread (Fig. 9). Decision trees classification of phenological multi-date stacks showed a 20% decrease of shrub cover. Areas of shrub cover loss were highly coincident with burned areas: 65% of the areas where grasses replaced shrubs occurred within burned areas from 2001 to 2007. At the same time, not all shrubs in the burned area were converted to grasslands. Mismatch can be explained by different burn severity due to different fuel types, amount and moisture as well as weather conditions. There is some evidence that areas that burn several times are more likely to change to a degree that phenological difference becomes detectable. Interestingly, there is also considerable proportion of shrubland conversion outside the burned areas. This suggests that under the conditions of reduced livestock pressure grasses can are expand even without fires, but grassland expansion can be greatly facilitated by burning. The phenomenon of grassland expansion is consistent with results of plot-level succession studies reported elsewhere (Neronov 1998).

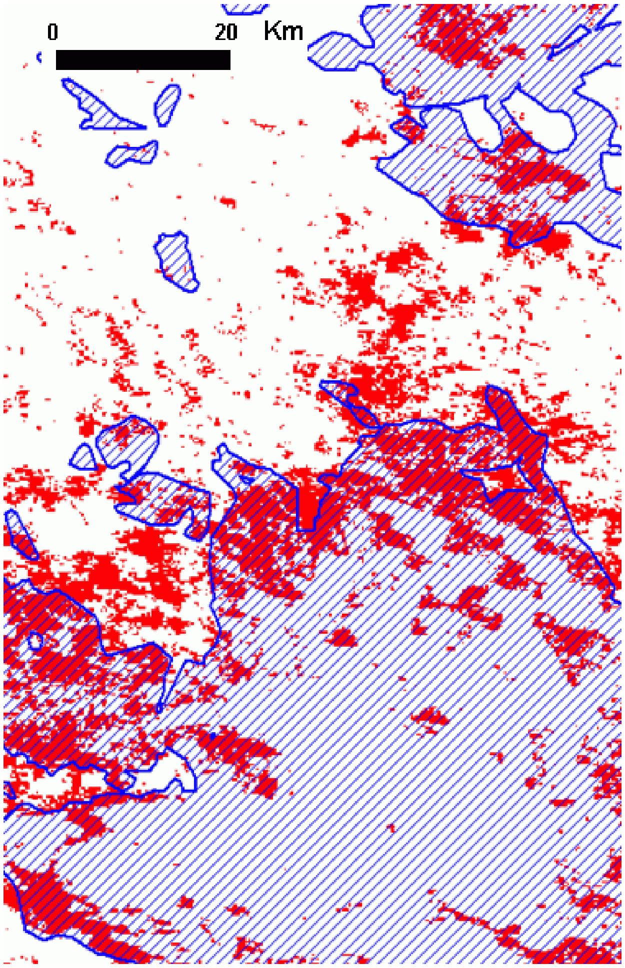


Figure 9. Shrub-dominated vegetation communities in 2001 that are converted to grassland by 2007 (red). Blue polygons – burned areas from 2001 to 2007.

Expected outcomes

Findings of this chapter will be summarized in a manuscript planned for submission to *Remote Sensing of Environment* or *Ecosystems*. The paper will include:

- Reconstruction of bare ground, GV and NPV dynamics using Landsat data for the period from 1985 to 2007;
- Results from phenological change analysis in main vegetation associations using MODIS data for the period from 2001 to 2007;
- Validation of the Landsat and the MODIS derived classification using existing field data and other sources.

CHAPTER 3

Research question:

Q3. Which human and natural factors affect saiga antelope habitat selection at three scales?

Kalmykia hosts a set of wildlife species that are adapted to the local vegetation types and disturbance regimes. Maybe the most characteristic species for the Kalmykian steppe, an umbrella species for biodiversity and a possible indicator of land-cover change, is the Saiga antelope (*Saiga tatarica sp. tatarica,* saiga – hereafter) (Bannikov et al. 1967). Saiga is one of the few remnants of the Pleistocene megafauna, the last free-roaming antelope in Europe, and one of the few remaining large herbivores that exhibit long-distance migrations worldwide. Saiga used to occupy major portions of Central Asia, but is now limited to few disjunct population ranges in Russia (Republic of Kalmykia, 26,000 heads), Kazakhstan (Betpak-dala 15,000, Ural 17,000, Usturt 116,000) and Mongolia (Shargyn Gobi, Mankhan, 3,000 total) (Milner-Gulland et al. 2001). Saiga inhabits short-grass steppes and usually has separate winter and summer pasture, rutting takes place in late December and calving in May (Bekenov et al. 1998).

Saiga are threatened throughout their range and have suffered a 90% population decline in Kalmykia since the late 1980s (Milner-Gulland et al. 2001) mainly due to poaching for meat and horns. The saiga population of Kalmykia is also constrained by human development and no longer exhibits long-distance migrations. Saiga is using pastures in the study area as both winter and summer ground, which distinguished it from the migratory populations of Kazakhstan that still have distinct winter and summer pastures.

The reasons that Kalmykian saiga are able to persist without migrating, are first the relatively small population size, second the vegetation composition of pastures, and third, weather conditions (i.e., little snow). In terms of the vegetation composition, *Artemisia sp.* dominated grasslands are of key importance because the provide a secondary vegetation peak late in the year, which together with practically snowless winters provide animals enough forage to persist on the same territory throughout the year.

Many migratory ungulates have experienced population collapses after the disruption of their migration routes and loss of key habitats (Bolger et al. 2008). This chapter aims at studying spatio-temporal patterns of selection for areas important for calving. Lack of critical basic information on habitat needs makes saiga conservation ineffective. Due to the migratory behavior of saiga, and complex human and environmental conditions, habitat selection by saiga operates at different scales that ultimately increase their reproductive success (Baker 1978). This research will contribute to integrative understanding necessary for conservation of saiga species (Bolger et al. 2008).

As in many other ungulate species (Anderson et al. 2005) saiga habitat selection process is multi-scale. I propose to study selection of key areas for calving at several spatial scales: regional (spring-summer pastures), local (calving grounds) and fine (calving locations) (Figure 10). My hypotheses are that regionally saiga selects pre-calving spring pastures in the areas remote from human disturbances, such as densely populated regions and areas with high road density. At the local scale both disturbance and forage quality are ultimately determining where saiga populations establish their calving grounds. And at the fine scale, the calving location selection process is driven mainly by vegetation conditions and saiga behavior. At the regional scale units of study are spring-summer pastures, even though in the case of Kalmykia they are identical the winter pastures because the population is constrained. Local scale is represented by actual calving grounds, which are typically selected within spring-summer pastures. Only one calving ground and spring-summer range exists in Russia, but several exist in Kazakhstan. At the fine scale, locations represent individual calving sites nested within the calving ground. On each scale different parameters influence the selection process, such as vegetation attributes, human disturbance, topography and burning.

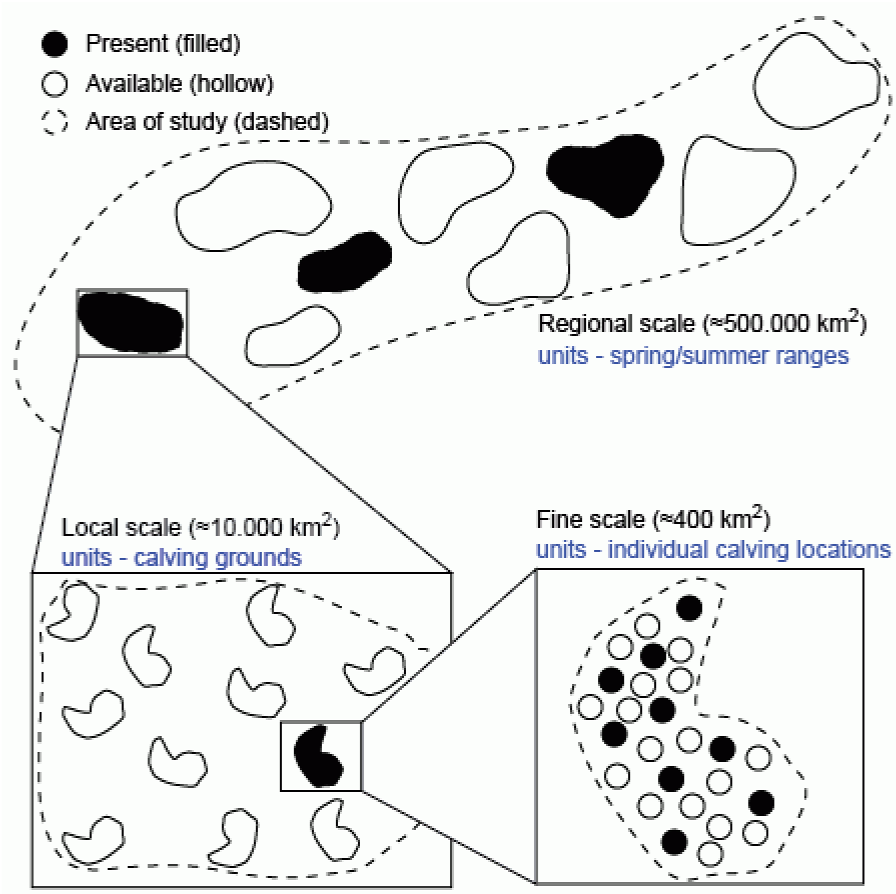


Figure 10. Conceptual diagram of the saiga resource selection process at three different scales.

Both the timing and the location of calving are crucial for saiga populations and calving events are highly synchronized and concentrated in space (Sokolov and Zhirnov 1998). Birth synchrony has been attributed to two causes, a short growing period and predator avoidance. Predator avoidance is no longer a major issue in the study area because the wolf population (the only saiga predator in the region) is very low. However, females during calving need to have good access to nutritious forage needed for lactation. Since the vegetation period is short, this requires high synchrony in timing of birth which will ultimately affect offspring growth rate and survival (Rutberg 1987).

I propose to use NDVI as a measure of vegetation productivity and a proxy for forage quality. NDVI is a useful indicator of ungulate habitat quality, and good predictor of ungulate diversity (Baird 2001), habitat use (Verlinden and Masogo 1997, Leimgruber et al. 2001), and distribution (van Bommel et al. 2006). In arid environments, continuous vegetation measurement such as NDVI are strongly correlated with aboveground net primary productivity and serve as a measure of habitat quality for both migrating (Leimgruber et al. 2001, Mueller et al. 2008) and non-migrating ungulates (Pettorelli et al. 2006). A strong advantage of using NDVI for habitat assessments is that it can be analyzed for specific times during the year, and across the growing season.

I propose to use both phenological and static measures of vegetation conditions as well as estimates of vegetation change from Chapter 2 and hypothesize that: ***Vegetation condition is the main factor of the selection at local and fine scales and relatively less important at the regional scale (H3.1).***

Topography is another potentially important parameter of saiga habitat. More rugged terrain can provide shelter against predation, wind, and human disturbance, and is especially valuable for animals inhabiting open ecosystems (Grace and Easterbee 1979, Pryke and Samways 2003). Topography may be related with saiga habitat selection in two ways. Saiga may select for slightly rugged, hilly terrain to avoid harassment by humans, or vice versa, saiga may select for large areas of flat space to be alert of incoming humans and vehicles (Bekenov et al. 1998). I will test both alternative processes and hypothesize that: ***Topography is more significant at the local and fine scales and less at the regional scale (H3.2).***

Human disturbance is considered one of the most important factors that drive the selection of the habitats by ungulates especially at broad scales (Nicholson et al. 1997, Rowland et al. 2000). Saiga calving grounds are generally found at least 10 to 20 km apart from lakes, rivers, and major roads. The reason for this may be to avoid disturbance, as people, domestic animals and motor vehicles are concentrated along rivers and roads (Bekenov et al. 1998). ***At regional and local scales, selection of calving grounds is driven by human disturbance (roads and settlements). At the fine scale, human disturbance is less significant then vegetation parameters (H3.3).***

Burning can also represent a human disturbance, but this is more typical for period after calving, when poaching is common and fires are set to draw saiga to recent burns sites that have abundant fresh vegetation (Archibald and Bond 2004). Burning of antecedent years can interact with habitat selection in two ways. Firstly, it can alter current year vegetation forage quality, removing extra non-palatable litter. Secondly, the removal of vegetation enhances visibility, which is highly favored by saigas during calving (Erdnenov, Lushchekina, pers. comm). I plan to use the results of Chapter 1 as estimates of burning and hypothesize that: ***Burning is an important parameter for saiga habitat selection at regional and local scales, and not important at the fine scale (H3.4).***

Technical plan

General approach

I will use a set of environmental and human related variables to parameterize resource selection functions at regional, local and fine scales in order to determine factors important for saiga habitat selection. I will also use NMS ordination to study calving locations at the local scale.

Data Sources and Analysis

Resource selection functions, defined as the relative probability of use of a resource unit (Manly et al. 1993) are now the common method to study habitat use in ungulates and have been used extensively for the study of scale-dependent habitat selection of, for example, East Caucasian tur (Gavashelishvili 2004), elk (Anderson et al. 2005) and caribou (Apps et al. 2001). For local and fine scales analysis I will analyze saiga range and calving location data that have been collected by collaborators from the Severtsev's Institute of Ecology and Evolution and the Imperial College of London from 2003 to 2007. Literature sources (see for example Bekenov et al. 1998) and expert knowledge will be used to delineate historic and current distribution of saiga calving ranges in Kalmykia, Kazakhstan, and Uzbekistan for the regional-scale assessment.

For the fine-scale analysis, used and available locations will be generated for the entire calving ground, and on a per-transect basis (Fig. 11). I will define presence points as "used" locations and compare them with randomly generated "available" locations, while excluding "available" locations in "used" map units. Minimum mapping unit at this scale will be represented by 250 x 250 m grid cells equal to the resolution of the remote sensing data. Calving locations will be used to extract the set of potentially important variables (Table 1). Logistic regression models with AIC-based model selection will be used to determine habitat variables associated with sites selection.

The individual calving location data that was collected may ultimately not be useful for logistic regression analysis because the random locations selected as "available" may suffer from high level of contamination with "used" (Pearce and Boyce 2006). I will thus also use aggregated numbers of calving locations in each MODIS pixel along each transects as a response variable for a Poisson regression. The data will be collected along each transects. Each transect will be approximated as a linear sequence of pixels, and pixels with calves will be either represented by number of these locations or aggregated "used" parameter. Pixels that do not have calving sites will be assigned zero or "available" (Fig. 11). This second approach makes less stringent assumptions of absence and suffer less from contamination (Lancaster and Imbens 1996).

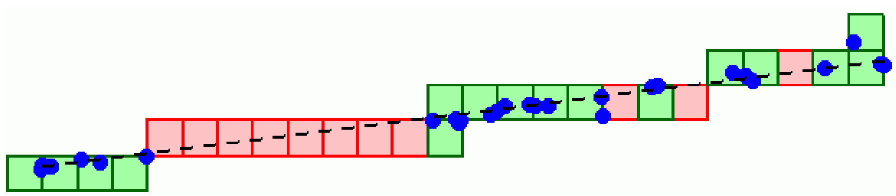


Figure 11. Transect data. Dashed line – transect, blue dots – presence points, green cells – aggregated use cells, red cells – absence cells.

For the local scale analysis, a delineation of only one calving ground is available. I will compare the existing site with randomly located areas of the same size distributed within the entire saiga range in Kalmykia. To explore potential uniqueness of the current calving ground in the multi-dimensional space, representing interactions between variables, I will use Non-metric Multidimensional Scaling (NMDS) ordination because this approach is well suited to data that are non-normal or are on arbitrary, discontinuous, or otherwise questionable scales (Clarke 1993). Following the approach for the fine scale analysis, generated random and existing polygons will be used to extract zonal statistics (mean, sum and standard deviation) from a set of variables.

The regional-scale analysis will be conducted across the Caspian lowland desert (CLD), the Kazakh semi-desert (KSD), and the Central Asian northern desert (CAD) ecoregions (Olson et al. 2001) (Fig. 12). These ecoregions are characterized by comparable vegetation and climate conditions. As the results from the Chapter 1 are not available for the whole territory used for regional scale analysis, I will use sum of active fires counts (MOD14) as a substitute for

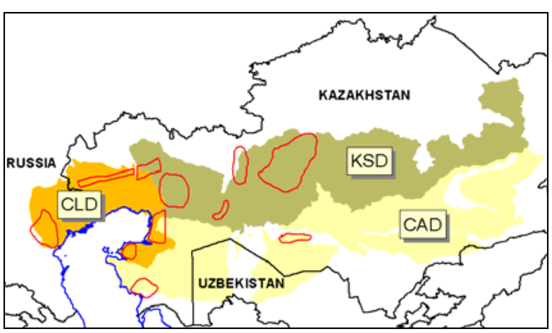


Figure 12. Ecoregions and spring-summer ranges (red).

burned areas to capture fire patterns. I will use randomization as in the analysis for local scale and generate equivalent amount of samples where saiga is absent. Locations will be used to extract statistics from the set of variables (Table 1) to extract zonal statistics. Logistic regression will be used to model relationships.

Variable category	**Source**	**Scale**
NDVI	MODIS	Regional, local, fine
Topography	SRTM, Topographic maps	Regional, local, fine
Human disturbance	Topographic maps	Topographic maps
Phenology	MODIS/TIMESAT	Regional, local, fine
Burning	Chapter 1	Regional, local, fine
Change in bare fraction	Chapter 2	Local, fine
Change in GV fraction	Chapter 2	Local, fine

Table 1. Groups of variables that will be used for analysis.

NDVI data (16-day composites at 250 m resolution, MOD13 product) will be downloaded from NASA's Earth Observing System Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome; for details see Huete et al. 2002). Based on the NDVI data, I will estimate phenological parameters for each pixel (for example onset of vegetation (START), length of the growing period (LENGTH), presence or absence of secondary vegetation peak, and other parameters). Fitted models for each growing season will be created using adaptive Savitzky-Golay using TIMESAT software, which uses local polynomial functions to model bi-modal vegetation phenology (Jönsson and Eklundh 2003).

Human disturbance variables will be derived from digitized topographic maps of 1:500.000 scale for the regional analysis and 1:200.000 for both local and fine-scale analyses. Estimates of the terrain ruggedness (Riley et al. 1999) will be derived from SRTM (regional scale) and contour lines from 1:200.000 topographic maps.

Preliminary results

Preliminary results show some differences between saiga summer grounds in Kazakhstan, where saiga still conduct long-distance migrations, and Kalmykia, where saiga are 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 can not (Dubinin et al. 2006).

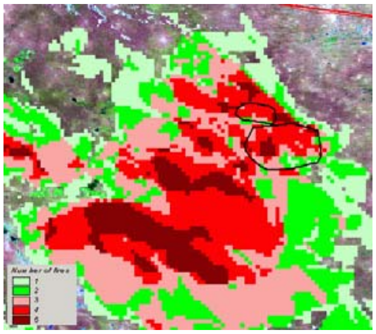


Figure 13. Spatial association of number of burning events and calving ground (black line – calving areas).

Interestingly, saiga calving grounds are located in the areas that experienced multiple fires from 2001 to 2007 (Fig. 13). Saiga selection of such areas potentially reflect better calving conditions related to improved visibility to avoid predation and disturbance or improved vegetation conditions because less litter remains after fires during the previous year.

Preliminary multi-year analysis results of fine scale selection showed inconsistent variables selection between years (Table 2). After removal of highly correlated variables (length of growing season – LENGTH, May, 9^{th} NDVI - NDVI129, crossed in the table), vegetation entered the model almost every year, but surprisingly changes sign occurred between years. Neither topography (terrain ruggedness index - TRI) nor phenological parameters (amplitude of growing season – AMP, start of growing season - START) were selected in the preliminary models, while there was some evidence that human disturbance variables (road density – RDENSITY and distance to roads – RDISTANCE). Inconsistency in the preliminary results may be attributable to model sensitivity to the absence point selection, and these preliminary results are only presented to showcase the type of results that are expected (Table 2).

	2003	2004	2005	2006
AMP	-			
DEM				-
~~LENGTH~~				
~~MAX~~				
NDVI113				
~~NDVI129~~				
NDVI145	+	-		-
RDENSITY	-			-
RDISTANCE			+	-
START				
TRI				

Table 2. Variables included in the annual logistic regression models.

Expected outcomes

Results from this chapter will be summarized in a manuscript planned for submission to *Ecological Applications* or *Conservation Biology*. The manuscript will discuss important variables for calving habitats selection by saiga antelope at three scales.

SIGNIFICANCE

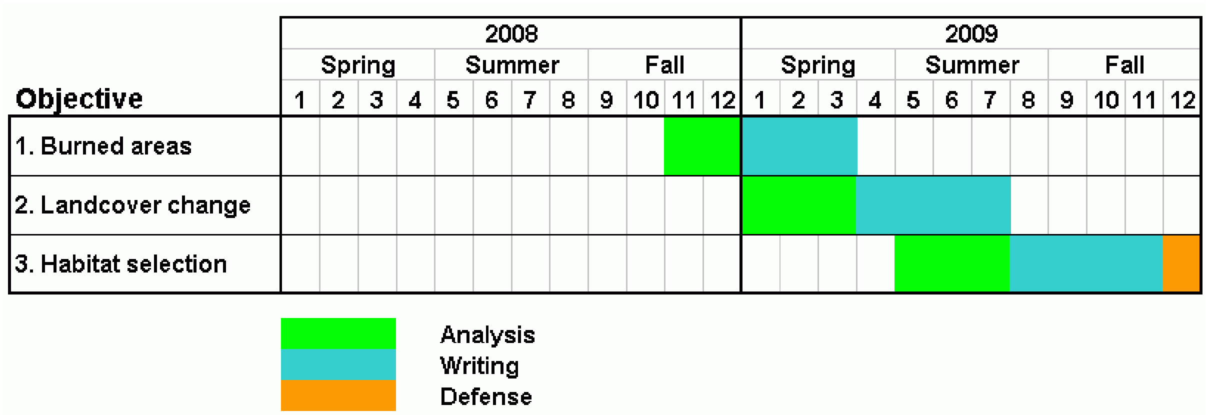
My research will add to the knowledge of coupled systems of humans, wildlife, and vegetation from a land-cover change perspective, showing the applicability of space-based observational measurements. The results will inform research in other regions where fire, land-cover change and management of endangered species are important issues (e.g. many arid grassland ecosystems around the world). Based on the understanding gained, I will examine the critical interactions and feedback processes that emerge from the co-evolution of human and natural disturbance, thus reflecting the complex behavior of coupled human-natural systems.

My research will contribute to science and practice in three ways. **Technical approaches** introduced by this research are novel and provide interesting opportunities in studying land-cover change using remote sensing in arid ecosystems. The developed techniques are especially promising for vegetation classification and change detection. Phenological optimization will improve spectral unmixing to provide less biased estimates of vegetation change over time. The use of decision trees is promising for the analysis of long time series from remote sensing data and allows reconstructing long-term times series of burned areas and vegetation community changed. All resulting data, developed ancillary software, maps and algorithms along with detailed documentation will be made available to local researchers to ensure widespread use and facilitate future research in this field.

Ecologically, my work addresses the general problem of interactions of different environmental factors and processes. My results will help to understand historical and modern dynamics of vegetation and fire and will provide statistical evidence of the drivers of these patterns. My approach will decouple the effects of climate and livestock populations on vegetation structure and composition. Estimates of vegetation cover and composition as well as fire disturbance will contribute to a better understanding of saiga biology. Furthermore, studying temporal and spatial distribution at different scales is interesting from the point of view of ungulates behavior in different conditions.

The results of this project will also have direct management implications. Ecosystem and species **conservation** will benefit from a better understanding of ecosystem structure and dynamics. Results will be used to inform the development of conservation strategies currently underway in the region and be valuable for the protection of endangered species inhabiting comparable ecosystems (such as Mongolian gazelle, Tibetan antelope, pronghorn, wildebeest and others). A better understanding of species-ecosystem relationships will help to establish a coarse-filter approach to conservation, where it is extended from single species being surrogates for the species assemblages to entire ecosystem (Groves 2003). 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.

TIMELINE



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