Eurasian Land Use Impacts on Rangeland Productivity

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Dramatic changes have occurred in pastoral systems of East and Central Asia covering the steppe ecosystems of Mongolia, China, Kazakhstan, and Russia over the past several decades. The socio-economic changes over the past decades have markedly shaped the land use patterns in the region. Evaluation of these pastoral systems is the focus of this paper. These pastoral systems have existed for thousands of years; however, in recent decades a decline in nomadic movements has led to greater vulnerability of the pastoralists. The nomadic pastoral systems developed to cope with arid or semi-arid climate variability. Interactions between ecosystems and nomadic land use systems co-shaped them in mutually adaptive ways for hundreds of years, thus making both the Mongolian rangeland ecosystem and nomadic pastoral system resilient and sustainable. The pervasive role of demographic, political and economic driving forces during the past 50 years has greatly altered the pastoral systems. The general trend involves greater intensification of resource exploitation at the expense of traditional patterns of range utilization. This set of drivers is orthogonal to the described climate drivers. Thus we expect climate–land use interactions to be modified by socio-economic forces. Nevertheless, the complex relationship between climate variability and pastoral exploitation patterns will still form the environmental framework for overall patterns of land use change. Integration of knowledge and delivery of this knowledge to scientists, policy makers and land users is critical for regionally sustainable development.

INTRODUCTION

In the semi-arid regions of the Eurasian steppe, nomadic pastoralism has been the dominant agronomic activity for thousands of years. Recent changes in cultural, demographic, political and economic factors have caused changes in how the pastoral systems operate within the region. These changes have altered grazing patterns, including frequency and intensity of grazing, and have incorporated livestock breeds not indigenous to the region. In many parts of the region, modernization of livestock management has led to reduced movement of livestock and more concentrated livestock around villages. These changes have increased the vulnerability of the pastoral systems in the region to climate stress (e.g., drought or harsh winter storms).

These pastoral systems of the Eurasian steppe developed under these highly variable semi-arid climate systems [*Ellis and Lee*, 1999; *Ellis and Chuluun*, 1994]. Thus, in many ways, the historical pastoral livestock systems are intimately adapted to climatic variability of the region. There is a direct relationship between climate variability and the spatial scale of pastoral exploitation. Extensive nomadic systems are found in the most variable regions throughout the world; less exten-

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sive, more intensive modes of livestock management occur in less variable climate regions. Land use and climate interactions have critical implications for Eurasian people and their ability to utilize these valuable resources.

Throughout the region, large changes in demographic, political and economic driving forces have also occurred over the past 50 years. The general trend involves greater intensification of resource exploitation at the expense of traditional patterns of extensive range utilization. This set of social factors tended to override the climate drivers during periods of economic change. Thus, climate relationships to land use/land cover have been modified by these socioeconomic changes. These changes have resulted in a more sedentary livestock management system, to more intensive stocking rates in localized areas, especially around water facilities and villages, and change in animal breeds used. During the past decade, political changes and opening of economic constraints have led to modifications in pastoral management due to relaxation of central government controls, privatization of livestock, and access to "free-enterprise" and open market systems. What will result from these recent changes is unclear, and the effect on human and natural resources of these arid and semi-arid regions needs to be determined.

The focus of this paper is to discuss the interaction of the social-economic changes of the past 50 years with pastoral land management of the Eurasian steppe, to better understand the challenges pastoralists face today as they attempt to cope with climatic and economic changes in the region.

Regional Land Use and Cover Pattern

The Eurasian steppe ecosystems, from the Black Sea to the Mongolian Plateau (Plate 1), constitute the most extensive grassland region of the temperate world and these steppe ecosystems have relatively fertile soils, mountain-fed rivers, and productive rangelands. Land cover of east and central Asia is dominated by rangelands, comprised of grasslands, steppe, and desert systems (Plate 1 and Table 1). The rangeland extends from the Mongolian Plateau of Mongolia and Inner Mongolia to the steppe of Central Asia. These systems are characterized by arid to semi-arid climate with a mean annual temperature of 4°C and a mean average annual precipitation of approximately 250 mm. Land use distribution in the arid and semi-arid regions of Eurasia is summarized in Table 1 [*FAOSTAT* data, 2003; *Loveland et al.,* 2000]. More than two-thirds of the land in Central Asia (i.e., Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan and Tajikistan) is rangeland, amounting to some 2.35 million km^2 [*Kharin*, 1996]. Arable lands are rather small in comparison, accounting for approximately 0.3 million km^2.

Total area of China is 9.6 million km^2, of which an estimated 4.0 million km^2 is classified as grassland. However, useable grasslands are only slightly more than half this area, 2.2 million km^2 [*NRC*, 1992]. Covering nearly 1.20 million km^2, Inner Mongolia accounts for 12.3% of China's total area. In 1989, Inner Mongolia had 0.87 million km^2 of grassland, of which 0.19 million km^2 were deemed "unusable" and another 0.30 million km^2 were considered "deteriorated" or "seriously deteriorated," leaving only 0.38 million km^2 both usable and in good condition. Currently, Inner Mongolia has about 0.08 million km^2 of croplands and 0.63 million km^2 of usable rangeland [*Enkhee,* 2000]. In comparison, over 80% of land in Mongolia (1.29 million km^2) is rangelands [*Tserendash,* 2000]. Arable lands occupy only less than 1% of total agricultural lands (0.012 million km^2) in Mongolia.

Humphrey and Sneath [1999] found that pasture degradation in Inner Mongolia was associated with loss of mobility in pastoral systems. In Russian rangelands, pasture degradation was most severe at research sites from Buyatia and Chita Oblast' (Russia), where the sedentarization level was the highest, compared to other sites from Mongolia, Tuva (Russia), Inner Mongolia and Xinjiang (China). Thus, they concluded that mobile pastoralism still remains a viable and useful technique in the modern age.

From 1990 to 2001, dramatic changes in livestock systems have been observed throughout Eurasia. In Kazakhstan, livestock densities have dropped dramatically since 1990 and have changed from 10 ha per unit livestock to more than 25 ha per unit livestock [Table 2, *FAOSTAT*, 2003]. In other countries of Central Asia, declines in livestock density have been observed, though not to the degree of livestock declines in Kazakhstan. In Mongolia, this decadal trend was reversed with privatization of livestock in the post-Soviet period. Livestock numbers, especially cashmere goats, increased markedly in 1995 and 2000 census data. Drought and dzud (the Mongolian term for "severe" winter storms condition which causes livestock losses) caused large livestock losses during 2000 through 2002.

The rangeland vegetation has moderate biomass with aboveground and belowground components totaling about 3000 kg/ha [simulated values from Century ecosystem model, *Parton et al.,* 1994]. Total net primary production is about 1000 kg/ha. Despite low productivity the soils tend to store large amounts of soil organic matter due to higher proportion of root productions (Table 3). Century simulations [*Chuluun and Ojima,* 1996; *Ojima et al.,* 1998; *Chuluun and Ojima,* 1999] confirm that the Mongolian grasslands could lose significant amounts of carbon under continuous annual or summer heavy grazing systems. The effect of different seasonal and annual grazing treatments on soil carbon lev-

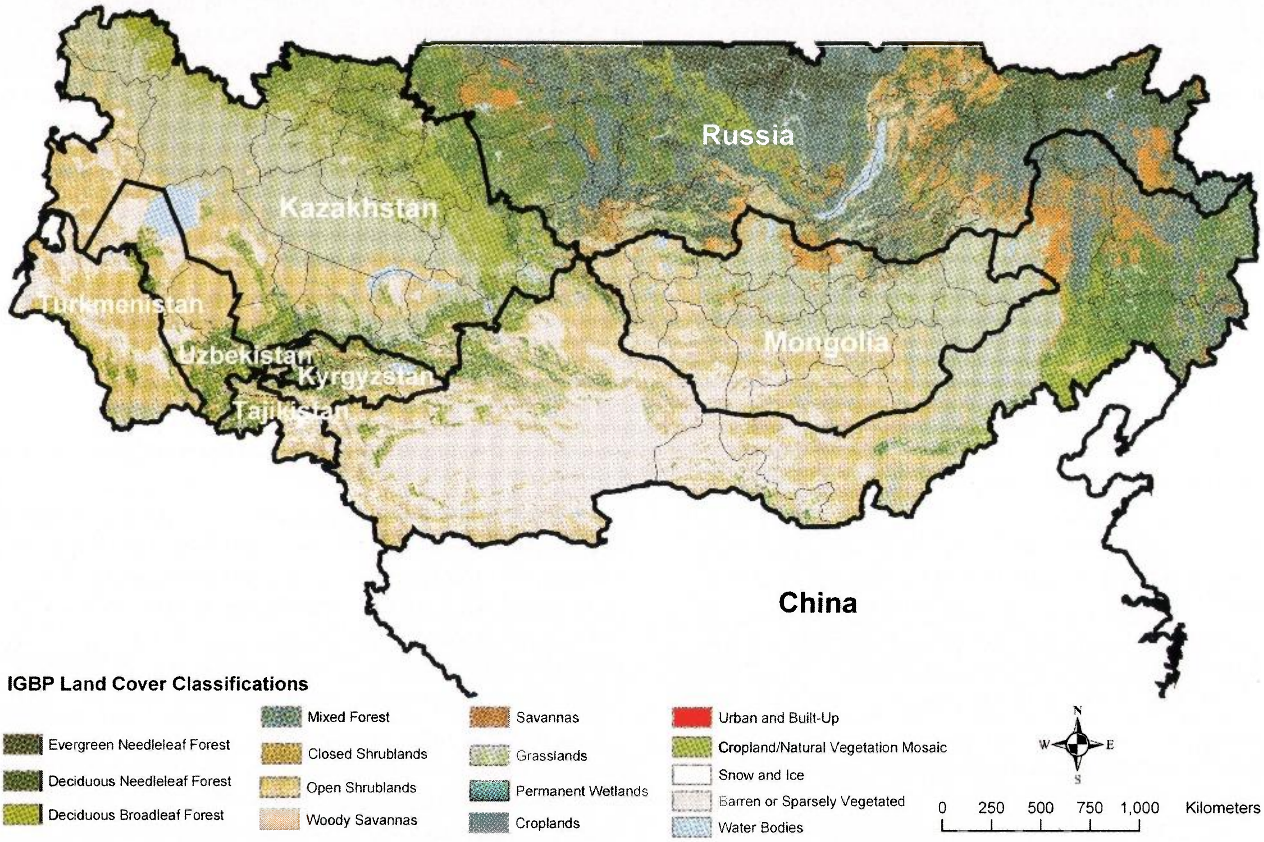

Plate 1. Land cover across Eurasian steppe region. Based on the 1-km resolution AVHRR IGBP DisCover data set [Loveland et al., 2000].

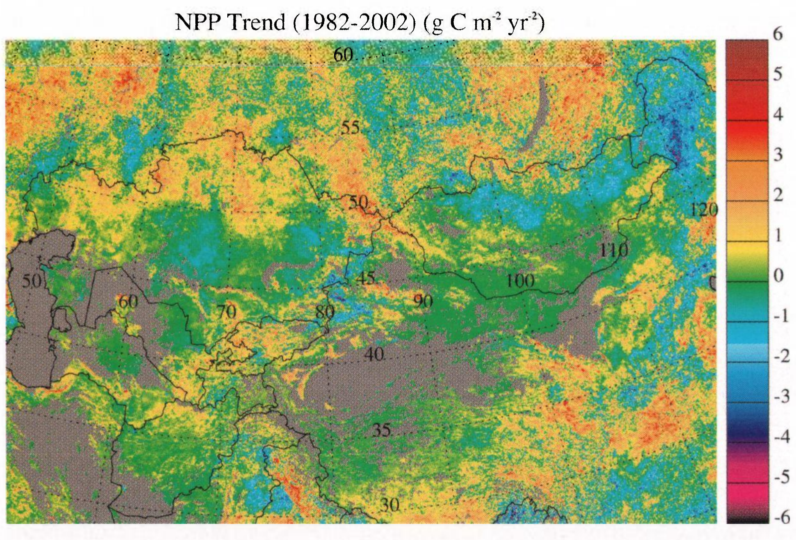

Plate 2. NPP trends for Eurasia from 1982 to 2002. Based on Global Area Coverage AVHRR data set [Tucker et al., 2001]. Dashed lines are latitude and longitude reference lines. Solid lines indicate the major biomes of each region. Yellow to red regions indicate areas of increasing NPP trends ($gm^{-2}y^{-1}$) and blue to purple regions indicate declines in NPP trends.

els was simulated for 50 years. Summer or annual heavy grazing for 50 years resulted in the largest loss of total soil carbon relative to other seasonal grazing scenarios. Heavy summer grazing resulted in a 15% soil carbon loss. The influence of spring grazing on soil organic carbon levels was slightly greater than winter and fall grazing. Observed total soil organic carbon levels decreased by about 25% in the heavily grazed Xilingole research site treatments compared to the controls. However, a decrease in soil organic carbon was not observed in the heavily or overgrazed grassland sites in Mongolia relative to control sites. Thus, the grazing histories and vegetation response in different Mongolian steppe regions are important considerations in understanding impacts on soil organic matter responses.

Regional Climate Trends

The Eurasian steppe region has a highly continental climate, with cold harsh winters and hot summers. The short summer rainy season provides adequate precipitation for good forage production. In the last 60 years, the mean annual air temperature increased by 1.56^{0}C, due to winter warming [*Batjargal et al.*, 2000; *NCDC,* 2002]. Changes in warming are more pronounced in the high mountains and mountain valley, and less in the Gobi desert and steppe. There has been a slight increase in annual precipitation in the last 60 years [*Natsagdorj,* 2000]. During 1940–1998, the annual precipitation increased by 6%, while summer precipitation increased by 11% and spring precipitation decreased by 17%, with the main spring dry period occurring in May.

The frequency of extreme events such as drought, flood, dust storm, thunderstorm, heavy snow, and flash flooding has increased over the past 30 years [*Natsagdorj,* 2000]. In addition, forest and steppe fire frequency is increasing because of extremely dry springs. The economic losses during 1999 and 2000 have been estimated to be 90 billion Togrog (approximately 90 million US$) per year. Livestock losses from 1999–2000 *zud* (the Mongolian term for 'severe' winter conditions) were 2.4 million, and over 1.3 million for the winter of 2001 (lost by February 25, 2001).

It is likely that the boundary zone between the Gobi desert and steppe is already affected by global warming and land use impact. Analysis of onset of green-up, an indicator of spring thaw and the initiation of the growing season, during the 1982 to 1991 time period indicates that large portions of eastern Mongolia and Inner Mongolia are experiencing earlier green-up [*Yu et al.*, 1999]. The authors suggest that this is associated with warmer winter and spring temperatures during this decade. This region of advanced green-up is dominated by meadow steppe and relatively mesic areas of typical steppe. There are also large portions of desert steppe and dry areas of typical steppe where there is a strong trend towards delayed green-up. Old herders from central regions of Mongolia also complained that plant productivity decreased from one-third to one-half during their lifetime [*Ellis and Chuluun,* 1993].

According to general circulation model (GCM) scenarios, the annual mean temperature in Mongolia is projected to increase by about 1.8 – 2.8^{0}C in the first quarter of the 21st century [*Batjargal et al.,* 2000]. This increase is projected to double during 2025–2050. An increase in total precipitation by 20 – 40% was projected in the first half of the new century, but precipitation is expected to decline from 2040 to 2070. Consequently, increased plant productivity is expected until the 2040s, with a projected decline in the subsequent decades.

Table 1. Major land use categories and change events in arid and semi-arid regions of east and central Asia in 2000 based on FAOSTAT data [*FAOSTAT,* 2003] and IGBP DIScover data base [*Loveland et al.*, 2000].

Location	Rangelands million km^2	Croplands million km^2	Collectivization	Privatization
Mongolia	1.293	.0.012	Late 1950s	Early 1990s
Inner Mongolia[1]	1.433	0.548	In 1950s	Early 1980s
Central Asia	2.514	0.308	In 1930s	Mid 1990s
Kazakhstan	1.851	0.217	In 1930s	Mid 1990s
Kyrgyzstan	0.093	0.014	In 1930s	Mid 1990s
Tajikistan	0.035	0.011	In 1930s	Mid 1990s
Turkmenistan	0.307	0.018	In 1930s	Mid 1990s
Uzbekistan	0.228	0.048	In 1930s	Mid 1990s

[1]Inner Mongolia and semi-arid regions of Northern China is estimated using IGBP DIScover database. Rangelands include grasslands, shrublands, and savannas classes; croplands include croplands and cropland plus cropland/natural vegetation mosaic classes.

Regional Socio-Economic Changes

Modifications of the socio-economic situation in the region have been a primary agent of change of land use systems during the past century, and especially during the past 50 years. Large scale intensification efforts took place during the Soviet era: large tracts of land were converted to cropland, livestock production became more sedentary, and collectives for agricultural production were organized throughout the region. During the past decade, most of the land use management in these countries is adjusting to new situations and transitional economies. These countries are among the most vulnerable in terms of their economic, political and environmental systems. Interactions between and among policies, human responses, and Earth system function cannot be decoupled. Transition economies are characterized by a combination of: a) volatile markets, b) policy reforms, and c) unclear and uncertain land tenure systems. It is not any single one of the factors, but rather the combination of all three, that makes these systems and peoples vulnerable in a number of different capacities.

The recent changes in social-economic factors (i.e., transition of the political-economic state following the dissolution of the USSR) affecting land use decisions in the region has led to cropland abandonment, de-stocking of certain rangelands and increased stocking of others, degradation of soils, and desertification. Despite these changes the agricultural, grassland and non-forest ecosystems constitute a significant portion of total land area in Northern Eurasia and still are seen as important food-producing regions. These changes to the political and economic situation in the region have resulted in reduction of the numerous basic social services. Rural infrastructure supporting health care, education, drought reduction mechanisms, and water resource maintenance have all been reduced in much of the region. Resulting impacts have increased rural poverty and abandonment of agriculture in many of these rural areas where these effects have been most detrimental.

Not all land use changes were negative for grassland health and carbon storage. The crop sector has been collapsing in Mongolia since the 1990 transition to a market economy. In 1995, sown areas have decreased by half, and crop production has decreased by about one third from 1990 levels. The growing of plant fodder and cereals other than wheat was practically eliminated by 1995. This agricultural failure decreased food security of the country. Livestock reduction in Central Asia and cropping industry failure in Mongolia could potentially contribute to degraded pastures and eroded arable lands. Restoration would have the added benefit of serving as potential sinks for atmospheric carbon.

Regional Political Changes

The most influential factor of land use change in this region was political, especially during the past century. Communist governments in China, the Soviet Union and Mongolia forced grassland conversion into cropland and collectivization programs, during different periods of time and with different intensity. In the 1950s, a push to increase wheat production in central and east Asia, including Mongolia, was promoted by the Soviet Government. In Russia, central Asian republics, China and Mongolia agricultural policies have converted the most productive grasslands into farm croplands (often irrigated) and improved pastures (usually a monoculture) [*Zhang*, 1992]. These policies not only reduced the rangeland available for livestock production, but they also increased grazing intensity, often on less fertile rangelands.

The policies of the Maoist era (1949–1976) were marked by the belief that people are China's greatest resource and that human will, organization, and labor can overcome all obstacles, including the limitations of the natural environment. Given this view, it was logical to move large numbers of peasants into marginal frontier areas, many of which had been devoted to animal husbandry, so that the resources could be "reclaimed" for more productive and efficient uses such as growing grain. For example, two million hectares of grasslands were converted into cropland in Inner Mongolia during 1958–1976 [*Enkhee*, 2000].

While human population growth and agricultural expansion impinged upon and reduced grasslands, the number of ani-

Table 2. Pasture usage (ha) per unit livestock unit (LU) based on small livestock mass. Data source is *FAOSTAT*, 2003.

Location	1990	1995	2000
Kazakhstan	10.1	12.4	26.8
Kyrgyzstan	2.6	4.1	4.5
Mongolia	14.2	12.2	12.2
Tajikistan	NA	1.9	2.3
Turkmenistan	NA	12.3	14.9
Uzbekistan	NA	3.0	3.2

mals that depend on this shrinking resource increased exponentially. During the first 40 years of the People's Republic of China (1949 to 1989), the total number of grazing animals more than tripled, from slightly more than 100 million to nearly 340 million [*NRC,* 1992].

During the 1930s the Soviet government introduced collective farming systems. At the same time, nomadic cultures were viewed as "primitive," so sedentarization of nomads was perceived as the main idea for rural development. Livestock mobility was reduced and dependence upon cultivated feed over the cold winters was increased with the collectivization of pastoralists into state farms. Livestock populations increased steadily in the central Asian states during the collective period, and by the close of the Soviet period, they had over 63 million sheep or goats, 18 million cattle and 2 million horses, as well as several hundred thousand camels and yaks [*Kerven and Lunch,* 1999].

Land use practices with higher mobility and diversity of coping mechanisms, and traditional pastoral networks were strong in Mongolia before collectivization, until the late 1950s. Mongolian herders privately owned diverse livestock: horse, cattle, camel, yak, goat and sheep. The collectivization of livestock started in Mongolia during the 1930s; however, it only reached many parts of the country in the late 1950s. Many villages were developed and about half of the rural population started to concentrate in these small towns, where medical, educational and postal services were developed. These collectives made all decisions over allocations of animals, and specialization in tasks and species [*Mearns,* 1993]. Although the collectives may have subsumed the customary institutions, the latter did not disappear altogether. A general herding strategy relevant to particular climatic, ecological and landscape conditions didn't change much, although frequency of movement decreased and moving distance increased during the collective period.

Transition from a centrally-governed to a free-market economy brought very different consequences for the livestock industry in countries of east and central Asia during later decades. Mongolia's collectives began to be dissolved during the summer of 1991. Almost 90% of livestock were privately owned by the end of 1993. The number of livestock grew from 25 million in 1993 to 33.5 million in 1999 in Mongolia.

China, as did Mongolia, made a rapid transition to a market economy in the livestock industry, privatizing animals in the early 1980s. Selling livestock at low prices influenced rangeland management system reforms in China [*Enkhee,* 2000]. This reform (1979–1989) stimulated herders to improve their livestock management; however, public lands were more deteriorated during this period. The government then enforced the second stage of a policy reform called "Two Rights and One System" (1989–1996) according to which land ownership is given to *Gatsaa* and lands were given to every household under a 30-year contract. A new sustainable development strategy called "Two Increase and Two Improvement" started to be implemented in late 1996. Goals of this new stage for sustainable development of livestock farming were to raise pasture productivity by large-scale construction of grasslands, maintain balance between grass and livestock, industrialize to improve economic benefits of livestock farming, and improve livestock quality using advanced technology.

While livestock privatization was relatively successful in China and Mongolia, it was disastrous for some central Asian states such as Kazakhstan, Tajikistan and Kyrgyzstan. According to Kerven and Lunch [1999] the livestock herd of Kazakhstan fell precipitously following the initiation of privatization in 1993–1994, with a loss of about 30% of the small stock population. This rapid decline continued through 1996 by another 33%, resulting in a total of 70% of the national small stock population being lost (from roughly 33 million in 1993

Table 3. Simulated value of total vegetation carbon, net primary production, and soil organic matter carbon. Simulations were conducted using the CENTURY ecosystem model [*Ojima et al.*, 1993; *Parton et al.*, 1994].

Location	Land area	Mean annual temp	Mean annual precip	Veg C	NPP	Soil C (top 20 cm)
	(km^2)	(°C)	(mm)	(g/m^2)	(g/m^2)	(g/m^2)
Tundra	2,455,450	–3	402	470	107	4,014
Desert	363,649	10	84	45	27	2,096
Grassland/ Steppe	7,969,480	4	250	300	100	2,677
Forest	4,792,650	–1	522	6,236	290	4,576
Total	15,581,229					

to about 10 million in 1998). Similar patterns of sudden destocking of small stock after de-collectivization were observed in Kyrgyzstan and Tajikistan. This collapse was caused by multiple interacting factors, including policy failures, withdrawal of subsidies, monetary collapse, and transition difficulties of salaried labor force into free-market economy [*Behnke,* 2001].

The ensuing crash in the small stock population, coupled with removal of state support, has left pastoralists in Kazakhstan mostly unable to continue seasonal movement of their livestock [*Kerven,* 2001]. As some herders accumulate more livestock, they are returning to the former long-distance migratory system practiced by their ancestors and during most of the Soviet period. In contrast, livestock numbers in Turkmenistan have remained the same, but as in Kazakhstan, pastoralists with more financial resources are able to hire additional labor to enable longer-distance livestock movements and escape from the over-used pastures around water points.

Regional Implications

Ellis and Lee [1999] analyzed rain use efficiency of different vegetation communities in the Lake Balkash basin in southeastern Kazakhstan, between 43^0 and 47^0 north latitude, using remotely-sensed AVHRR-NDVI data. Site NDVI data were compared to annual rainfall figures from the closest weather station. Improved rainfall use efficiency in typical steppe and shrub steppe vegetation communities (indication of grassland recovery) for the last decade has been observed, and this change has coincided with a shift from intensive year-long grazing to very light or no grazing pressure.

Net primary production (NPP) in Mongolia was estimated from satellite observations of the normalized difference vegetation index (NDVI) using the Carnegie-Ames-Stanford Approach (CASA) carbon cycle model [*Potter et al.,* 1993; and *Field et al.*, 1995]. CASA is a light-use efficiency model that calculates NPP at a monthly time step from solar radiation absorbed by plants with a light-use efficiency that converts this radiation to the amount of fixed carbon. The NDVI data set used had a spatial resolution of 8 km and covered the period 1982–2002 [*Tucker et al.*, 2001]. Four regions within Mongolia were analyzed to investigate the temporal behavior of NPP, including an area in the far west; a region around the capital, Ulaanbaatar; a region just north of Ulaanbaatar; and an area in the east. NPP pixels within each of these regions were aggregated based on the IGBP DISCover land cover classification. The regions were dominated by one or two biomes, typically grasslands, but additional biomes are reported as well.

Mean NPP was highest around Ulaanbaatar, where grassland values exceeded 200 g $C/m^2/yr$. NPP in the eastern and northern regions was about 150 g $C/m^2/yr$, while in the western region, NPP was only <50 g $C/m^2/yr$. We computed trends in annual production from 1982–2002. NPP decreased in the major biomes of the eastern region and Ulaanbaatar, was near zero in the northern region, and was slightly positive in the western region (Plate 2). Inter-annual NPP variability is high, ranging from 25–40% of the mean, with the exception of the western region. In this region, NPP is nearly constant through the first half of the record, but increases substantially during the second half of the record, likely associated with increased precipitation variability.

Analysis of rangeland recovery in Central Asia indicates that as growing season increases, there is more carbon uptake into soils, suggesting that there is carbon sequestration potential. Improved grazing management practices may prove useful for the Mongolian steppe situation, which is undergoing large increases in livestock numbers. Implementation of improved grazing practices can lead to sustainable carbon storage in rangeland ecosystems, and offset some of the negative impacts of climate warming by conserving soil moisture.

SUMMARY

Dramatic changes in land use have occurred in this region of East Asia during the last several decades. The extent of grassland conversion into croplands and grassland degradation has been largely in response to increased human population pressures and political reforms of pastoral systems. Rangeland ecosystems of this region are vulnerable to environmental and political shocks, and response of pastoral systems to these shocks have varied across the region. Indeed, this part of the world has experienced many perturbations in the recent decades such as the collapse of the livestock sector in some states of central Asia, expansion of livestock in China and Mongolia, intensification of cropland conversion, multiple *zud* of 1999–2001 in Mongolia, and recent intensive dust storm events.

However, this region has great potential for rangeland improvements and carbon sequestration, if appropriate land management practices are adopted. Traditional pasture management with greater mobility should be incorporated into rural development policies. For instance, traditional pastoral networks should be encouraged with new land reform policy in Mongolia. The traditional pastoral networks emerged as dissipative structures during the past in areas of limited natural resources (water and soil organic matter) and highly variable environment conditions. These strategies improved the resilience and sustainability of grazing on grazing lands in Mongolia and surrounding pastoral regions in Eurasia.

Comparative studies of culture and environment in Inner Asia have found that pasture degradation was associated with loss of mobility in pastoral systems. Pasture degradation was most severe at research sites in Buyatia and Chita Oblast', where the sedentarization level was the highest, compared to other research sites from Mongolia, Tuva (Russia), Inner Mongolia and Xinjiang (China). Nomadic land use practices are viewed as a viable and useful land use strategy in contemporary Asia.

Simulation studies using CENTURY confirmed that the Mongolian grasslands could lose significant amounts of carbon under more sedentary grazing systems or summer heavy grazing systems. The effect of different seasonal and yearlong grazing treatments on soil carbon levels indicated that more seasonal or nomadic grazing systems resulted in reduced grazing impacts on these rangelands. The influence of spring grazing on soil organic carbon levels was slightly greater than winter and fall grazing. A total soil organic carbon level decrease of about 25% was observed in the heavily grazed treatments at Xilingole research site compared to controls. However, a decrease in soil organic carbon was not observed in the heavily or overgrazed grassland sites in Mongolia relative to control sites. Thus, caution is advised to quantify carbon loss due to overgrazing.

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