

Changes in Pastoral Land Use and their Effects on Rangeland Vegetation Indices

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ABSTRACT

Extensive livestock production has been Mongolia's major industry for centuries and traditional nomadic herding lifestyle and Mongolia's expansive rangelands sustain this industry. After the democratic election and economic liberalization in 1992, formerly state-owned collectives were disbanded and Mongolia's livestock population was privatized. There was no longer a state institution to formally regulate pasture use and herders became responsible for pasture use management. We studied the changes in pastoral land use management in Tsahiriin tal of northwestern Mongolia and their effects on rangeland Normalized Difference Vegetation Index (NDVI), a remote sensing satellite-based estimate of rangeland vegetation productivity. We estimated NDVI from the collective (pre-1992) and post-collective (1992-present) period using six different Landsat Thematic Mapper satellite images and compared the mean NDVI estimates from the two periods. Our results indicate that three major changes occurred in pastoral land use management. First, grazing distribution changed from localized clusters to a more evenly distributed pattern. Secondly, the grazing animal species changed from predominantly sheep to herds of sheep, goats, cattle, and horses. Third, grazing intensity increased by over 800 animal units. Our results also indicated that NDVI values from the post-collective period are significantly lower than the NDVI values from the collective era indicating that rangeland vegetation productivity might be declining in Tsahiriin tal. This decline in NDVI might be largely associated with the increased grazing intensity from the collective era to the post-collective period.

KEYWORDS: *Grazing, pastoralism, GIS, remote sensing*

INTRODUCTION

Mongolia is one of the five most heavily grazed places in the world (Asner et al., 2005). Extensive livestock production has been Mongolia's major industry for centuries and traditional nomadic herding lifestyle and Mongolia's expansive rangelands sustain this industry. Mongolia's current livestock population is over 40 million and consists of cattle (2.4 million), sheep (16.9 million), goats (18.3 million), horses (2.2 million), and camels (0.2 million) (Mongolian Statistics Review Book, 2007). The livestock population was substantially smaller at the beginning of the twentieth century, but continually increased throughout the last century despite the dramatic institutional, political, and economic changes that took place as Mongolia transitioned from feudal to socialist and then democratic socio-political system (Sankey et al., 2006). The livestock population has more than doubled since Mongolia became a democratic country in 1992 and began its transition into market economy (Mearns, 2004).

After the economic transition in 1992, the livestock collectives or *negdels* of the socialist regime were disbanded and Mongolian herders were no longer employed by the state collectives forcing them to become economically self-sustaining. Transportation, access to markets, and veterinary and social services were no longer provided by the government. As a result, many herders migrated to areas near settlements and urban centers for better access to market, services, and goods. These changes lead to dramatically increased use of rangelands near urban centers (Mearns, 2004). Increased grazing pressure on rangelands has been most apparent around Ulaanbaatar (FAO Crop and Grassland Service, 2008). Most rangeland studies, therefore, have focused on areas surrounding Ulaanbaatar, which is not representative of the entire country. The remaining rangelands are largely unstudied. Local-scale studies in rural, less populated areas have not been common. Effects of the grazing land use changes in rural areas are not well understood, even though land use management changes also occurred in these areas (Sankey et al., 2006). Several remote sensing studies have described rangeland productivity throughout Mongolia (Purevdorj et al., 1998; Kogan et al., 2004; Erdenetuya and Khudulmur, 2008), but these studies were conducted at a nationwide, coarse scale without site-specific analysis of land use changes.

We studied a summer pasture in the Darkhad Valley of northern Mongolia using Global Positioning System (GPS) and remote sensing techniques. Our objectives were to: 1) document grazing land use patterns during the collective (pre-1992) and post-collective (1992-present) periods at a local scale using GPS mapping methods, 2) evaluate changes in grazing land use from the collective era to the post-collective period, and 3) assess the effects of land use changes on rangeland vegetation productivity using Landsat satellite images from the two periods. We selected the decade of 1980 (1981-1990) to represent the collective era and the current decade of 2000 (2001-2008) to represent the post-collective period. We chose these two decades due to the absence of major regime shifts within them, the presence of a major shift between them in the decade of 1990, and the availability of satellite imagery during the growing seasons (images prior to 1980 were not available).

Changes in pastoral land use in Mongolia

Traditionally, herders camp near rivers, lakes, and springs in the summer season for access to water and use pastures far from water in the winter months due to the availability of snow as a water source (Fernandez-Gimenez, 2002). When the state livestock collectives were established in the 1960s, they followed this general seasonal pastoral land use pattern. Collectives provided well-funded infrastructure including transportation for moving camps, development of wells and water tanks in waterless pastures, veterinary services, supplemental feed supplies, and monthly salary for the herders

(Fernandez-Gimenez, 1999). This allowed better distribution of grazing land use including the use of pastures more distant from water sources and community centers.

Herding households were aggregated into units known as *suuri* which consisted of 1-2 households (Fernandez-Gimenez, 1999). Each *suuri* was responsible for a fixed-sized, medium to large herds of animals of one species. Managers of collectives, namely the collective leader who was also typically the *sumiin darga* or county governor, made decisions regarding the timing and location of all movements, and coordinated all herders (Mearns, 2004). Each *sum* or county had one collective.

After the first democratic election and the pastoral economic liberalization in 1992, collectives were dismantled and all formerly state-owned animals were privatized. Although pasture land remained, and still is publicly owned, there was no longer a state institution to formally regulate pasture use. Herders were left to regulate their own pasture use management and were responsible for all production inputs and costs as the infrastructure and salary collectives provided were no longer available (Fernandez-Gimenez, 2002). At the same time, economic conditions in urban areas declined and many formerly non-herding state employees moved to the countryside to become herders with animals they acquired through privatization (FAO Crop and Grassland Service, 2008). The limited economic opportunities outside the livestock industry doubled the number of herding households (Mearns, 2004). This meant that the animals were re-distributed amongst a greater number of households initially following the regime shift in 1992. The number of animals steadily increased throughout the decade, however, at least partially due to several consecutive winters in the decade with relatively mild weather.

Today, many herders prefer to camp near settlements to take advantage of the veterinary and social services, as well as access to markets, schools, shops, and telecommunications in remote areas. Towns and settlements (*sumiin tuv* and *aimgiin tuv*) are the only places where such services are available. Herders also tend to stay close to major roads to be able to deliver their goods to markets or trade with traveling stores (Fernandez-Gimenez, 1999). Herders currently make their own decisions regarding how many and what type of animals to herd. There is no limit on the number of animals each household can own. Most herders now have several different species of livestock rather than a single species (Sankey et al., 2006).

Remote sensing of rangeland productivity

Remote sensing satellite images have been commonly used to study rangelands. Different image classification approaches and band ratios have been used to assess rangeland conditions through estimates of biomass, productivity, or percent vegetative ground cover (Jensen, 1996). The amount of total green vegetation can be estimated using Normalized Difference Vegetation Index (NDVI) (Jensen, 1996; Montandon and Small, 2008). This index is calculated using the spectral properties of vegetation reflectance in the red (R) and near-infrared (NIR) wavelengths (Rouse et al., 1974). Green vegetation typically has low reflectance in the red portion (630-690nm) of the electromagnetic spectrum due to the absorption of radiation by chlorophyll pigments, and high reflectance of the near-infrared portion of the spectrum (760-900nm) by leaf mesophyll (Jensen, 1996). NDVI is expressed as (Rouse et al., 1974):

$$NDVI = \frac{NIR\ band - R\ band}{NIR\ band + R\ band}$$

NDVI values range between -1 and 1. Higher values represent greater amounts of photosynthetic vegetation (Jensen, 1996). In semi-arid grasslands, NDVI has been successfully correlated with field

based measurements of grassland biomass and some of the previously published correlation coefficients (R^2) have ranged 0.74-0.96 (Anderson et al., 1993; Fukuo et al., 2001; Wylie et al., 2002; Zha et al., 2003; Kensuke et al., 2005). In Mongolia, several coarse-scale studies have estimated the nationwide rangeland productivity using NDVI (Purevdorj et al., 1998, Bayarjargal et al., 2000, Bayarjargal et al., 2006, Erdenetuya and Khudulmur, 2008). NDVI has not been commonly used for land use change detection purposes in Mongolia, although NDVI has been widely used for change detection purpose in other regions of the world (Jin and Sader, 2005; Cakir et al., 2006; Numata et al., 2007).

METHODS

Study site description

Our study site is Tsahiriin tal valley located within the southern portion of the Darkhad Valley in northwestern Mongolia (Figure 1). Tsahiriin tal is within Renchinlhumbe *sum* of Khuvsgul *aimag* and was within the Renchinlhumbe collective territory. Tsahiriin tal is approximately 5km x 6km in dimension (~30,000 m²). It is at 1650m elevation and experiences extreme continental climate with cold winters, short summers, and a summer-wet, winter-dry annual precipitation pattern (Figure 2). Mean annual precipitation is less than 300 mm with more than half of the yearly total falling during the months of June-August. Monthly average temperatures range from less than -30 C° in winter to close to 15 C° in summer.

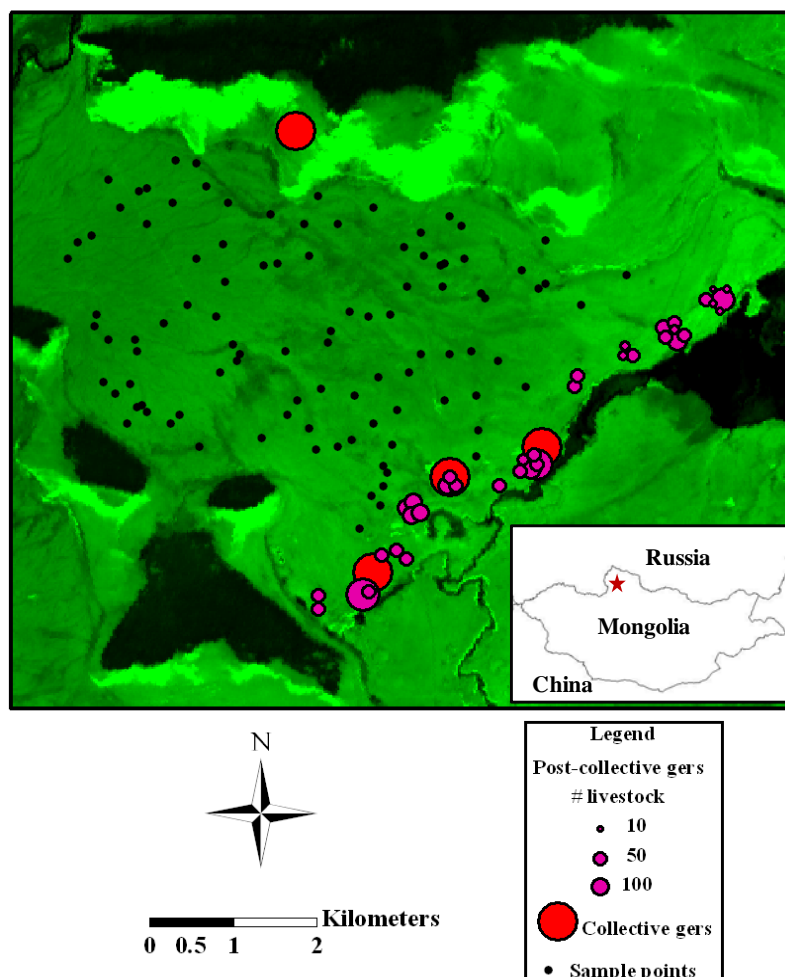


Figure 1. The Tsahiriin tal study site and documented ger or household distribution during the collective and post-collective period.

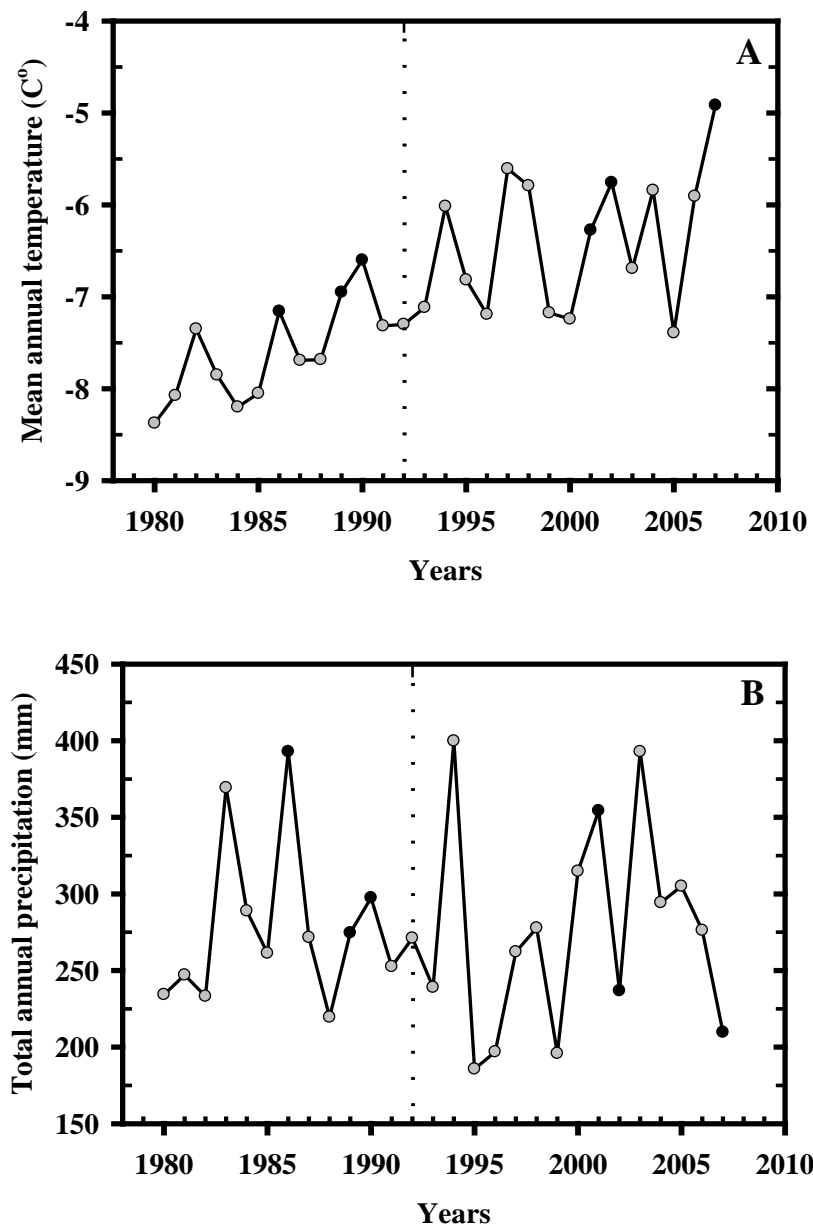


Figure 2. Mean annual temperatures (A) and total annual precipitation (B) in 1980-2007 for Renchinlumbe county, Khuvsgul province, Mongolia. The six years selected for this study are marked with black circles. Dashed line marks the regime shift in 1992 from collective to post-collective periods.

Tsahiriin tal is bordered to the north and south by small bedrock-controlled hills with exposed limestone outcrops and herbaceous vegetation on the southerly aspects, and Siberian larch (*Larix sibirica*) forests on the northerly aspects (Figure 1). The valley is bordered by Hugiin gol river to the west, and by Tsagaan nuur lake to the east (Figure 1). Common plant species are *Poa pratensis* L., *Artemisia mongolica* (Fisch. ex Bess) Nakai, *Artemisia frigida* Willd., *Potentilla acaulis* L., and *Stipa krylovii* Roshev.

The valley floor within Tsahiriin tal consists of relic alluvial channels, terraces, and plains, as well as areas with closed depressions and hummocky rises. Ten to twenty meters of topographic relief spans the highest landscape positions (terraces and hummocks) to the lowest (channels and depressions). Soil parent materials are predominantly alluvial and lacustrine sediments. Soils associated with the

alluvial features include calcareous grassland soils with organic-rich surface horizons in the more well-drained positions, and similar soils with more strongly developed subsurface clay-rich horizons in the lower (and sometimes wetter) landscape positions. These soils would include Typic Calcicryolls and Ustic (or Oxyaquic) Argicryolls, respectively, as classified by the United States soil classification system (Soil Survey Staff, 1998). Soils associated with the hummock/depression features include frost-churned (cryoturbated) permafrost and weakly developed non-permafrost soils. These soils would be classified as Aquic Haploturbels and Ustic Eutrocryepts (Soil Survey Staff, 1998).

Field study

Tsahiriin tal was visited in the summers of 2007 and 2008 to map current grazing land use and to interview local herders, veterinarians, and government officials regarding grazing land use in the collective era. Current grazing land use was documented by mapping the geographic location of each household's summer camp in the summer of 2007 using a Trimble GeoXT GPS receiver with ± 3 m real-time horizontal accuracy. The name of every household camping in Tsahiriin tal in the summer of 2007 was acquired and their livestock numbers were obtained from the local government records. In the summer of 2008, the former veterinarian from Tsahiriin tal during the collective period was interviewed regarding the grazing intensity and distribution during the collective period and the collective-period household locations were mapped with associated herd sizes.

Image analysis

Landsat 4 Thematic Mapper (one image) and Landsat 5 Thematic Mapper (five images) images from the peak of six different growing seasons were selected. Landsat 4 and 5 Thematic Mapper images have 30m x 30m spatial resolution and six spectral bands spanning 0.45-2.35 μ m of the electromagnetic spectrum. Three of the images represent the collective era (acquisition dates: July 23, 1986, August 17, 1989, and July 19, 1990) and the other three represent the post-collective period (acquisition dates: August 9, 2001, July 20, 2002, and July 17, 2007). All images were corrected for atmospheric effects using Idrisi's ATMOSC module (based on Chavez (1996) cos(t) model) and projected in UTM Zone 47 North, WGS 1984 projection and datum. Each image was co-registered to a georectified July 9, 2007 SPOT4 image with 20m x 20m resolution (root mean squared error ranged between 0.43-0.96) using ENVI software (ENVI Version 4.3, ITT Industries Inc, 2006, Boulder, CO). All images were then subset to the Tsahiriin tal area and NDVI was estimated in each image subset using ENVI software.

Statistical analysis

Using Hawth's tool in ESRI® ArcMap™ 9.2 software (ESRI Inc, 1999-2006), 150 random points were generated within the study area and NDVI values from each image date was extracted to these points. The extracted NDVI values were then used as samples. The 1986, 1989, and 1990 NDVI values at each sample point were averaged to produce a mean value for the collective era at each point location, whereas 2001, 2002, and 2007 NDVI values were averaged to produce a mean value for the post-collective era at each point location. The NDVI values from the two periods were then compared for a statistically significant difference using analysis of variance (ANOVA) test (SPSS 14.0 for Windows, 2005).

RESULTS

Both during the collective era and now, the valley has been used as summer pasture. During the collective era, the valley was largely grazed by sheep only, totaling in 360 animal units (all species were converted to a common unit, a cow and calf combination) for 3 months a year. There were 4

collective-owned sheep herds herded by 4 households. Each herd included 450 animals of which 20-30 were goats (Table 1). The Renchinlumbe collective was dismantled in 1992. The valley is currently used as summer pasture by 34 households (Figure 1) for 3 months a year and is grazed by 1191 animal units consisting of cattle, sheep, goats, and horses (Table 1) which are distributed in numerous small herds. In addition, there are 3 spring camps and 3 others that were being built in the summer of 2007. Total grazing intensity in Tsahiriin tal increased by approximately 830 animal units between the two time periods, which has more than tripled the grazing pressure from the collective period. The ANOVA test indicated that the Landsat image-derived NDVI values from the collective era was significantly greater than the post-collective NDVI values ($p\text{-value} < 0.0001$) (Figure 3), suggesting that greater quantities of photosynthetic vegetation were present during the three years analyzed from the collective versus the contemporary period, respectively.

Table 1: Summary of livestock population in Tsahiriin tal during the collective and post-collective period

| Total number | Collective period | Post-collective period |
|--------------------|-------------------|------------------------|
| Sheep | 1680 | 1169 |
| Goats | 120 | 755 |
| Cattle | 0 | 613 |
| Horses | 0 | 161 |
| Total livestock | 1800 | 2698 |
| Total Animal Units | 360 | 1191 |
| Households | 4 | 34 |

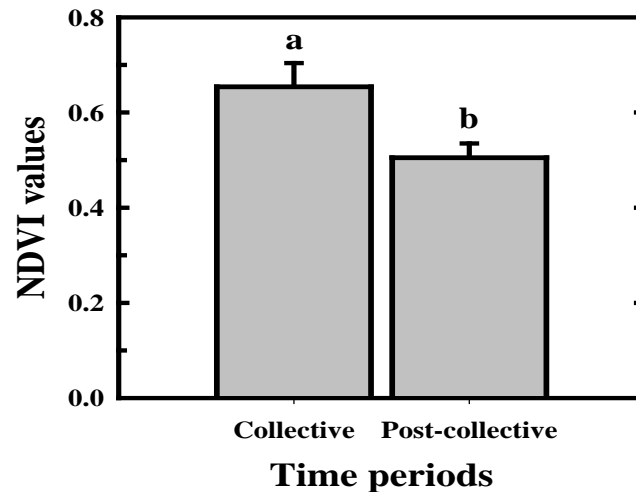


Figure 3: Landsat-derived mean (with standard error) Normalized Difference Vegetation Index (NDVI) values from the collective and post-collective periods. Different letters indicate statistically significant differences at a significance level of 0.05.

DISCUSSION

Pastoral land use changes

Three major changes were observed in pastoral land use in Tsahiriin tal during our study period (Table 1 and Figure 1). First, during the collective era, livestock grazing pressure was distributed in a few localized clusters with equally-sized, larger herds, while it is now distributed more evenly

throughout the valley with numerous smaller herds. Similar to other areas of Mongolia (Bedunah and Schmidt, 2004), this change in Tsahiriin tal is associated with increased number of herding households and might be expected to result in a substantially different effect on the rangeland. The presumed cause of the difference relates to the length of recovery time for the plants between different grazing events (Voisin, 1988; Savory, 1999). Numerous smaller herds represent a continuous grazing system, in which plants are frequently grazed with little recovery time between grazing events leading to depletion of root reserves in plants. Fewer, larger herds, on the other hand, emulate a high-intensity, short-duration grazing system, in which plants receive a relatively longer recovery period between more intense grazing events.

Secondly, the grazing animal species composition changed in Tsahiriin tal from herds of predominantly a single species of sheep to four different species of cattle, sheep, goats, and horses. Although sheep remains a proportionally large component of the current herds, our livestock survey from Tsahiriin tal indicates that the number of goats is now fairly close to the number of sheep. This might be associated with the increased price of goat cashmere in Mongolia due to a more direct market in China. During the centrally planned economy prior to 1992, herders did not have direct access to the market and the Mongolian government traded goat cashmere and paid herders fixed rates of monthly salary (Agriteam, 1997). Herders, therefore, did not have the economic incentive to herd large numbers of goats that they presently have. Cashmere currently continues to increase at the domestic and foreign markets (Mongolian Statistics Book, 2007). Herders can sell goat cashmere to travelling stores, if they camp nearby major roads, or they can ship their goat cashmere to major cities to sell for higher prices. Herders can also have up-to-date information on marketing and cashmere prices through the national public radio (Bedunah and Schmidt, 2004).

The number of cattle has also increased in Tsahiriin tal. This might be due to meat and dairy consumption. Majority of the milk consumed on a daily basis during the summer season comes from cattle. Although sheep might have been milked during the collective period, it's more time-efficient to milk cows. Cows produce greater amount of milk per animal compared to sheep and only a few cows can produce the same amount of milk as a whole herd of sheep. Cattle also produce greater amount of meat per animal. Having some cattle in the herd, therefore, help increase one's herd size without consuming many animals in a given year to meet the meat requirement. The increased number of cattle has the greatest proportional impact on the changes in total animal units from the collective to contemporary period. When livestock numbers are converted to grazing animal units, the current number of cattle translates to more than twice as many animal units as does the current number of sheep. Such change in grazing animal species is known to have substantially different effects on the grazed vegetation community because different grazing animal species prefer different plant species (Vallentine, 2001). This might suggest that the plant species present in the Tsahiriin tal valley now receive more evenly distributed grazing pressure compared to the collective period when only plant species palatable to sheep were grazed.

Third, the grazing intensity at our study site increased by over 800 animal units resulting in more than three times greater grazing pressure in the Tsahiriin tal valley during the present decade compared to the collective era. During the collective era, herders camped in the Tsahiriin tal valley for three months a year. Currently, the valley is still used as summer pasture. However, different families can now spend varying amount of time at the summer pasture. Due to the ambiguity in current pasture management regulation and the lack of formal institution to coordinate herders in Mongolia, out-of-season pasture use and trespassing in customary grazing lands have become more common (Mearns, 2004; Fernandez-Gimenez, 2002). Furthermore, the Tsahiriin tal valley is at a fork of two major

roads, one leading to Renchinlumbe town and the other leading to Tsagaan Nuur town via a major bridge across the Hugiin gol river. Renchinlumbe is the nearest town to Tsahiriin tal and is approximately 17km from Tsahiriin tal. This proximity to towns and the two major roads provides a convenient place for herders to stay. Herders can travel to either or both towns easily to take advantage of the veterinary and social services, as well as access to markets, schools, shops, and telecommunications in Renchinlumbe and Tsagaan Nuur towns. Furthermore, the major roads in Tsahiriin tal provide opportunities for the herders to deliver their goods to markets or trade with traveling stores. Traveling stores tend to stop by herders close to the road more often and trade with those households rather than traveling long distances to visit individual households that are camped in remote areas.

Effects of land use change on rangeland productivity

Our Landsat image analysis results indicate that the observed changes in pastoral land use might have had significant effects on the rangeland productivity in Tsahiriin tal. The NDVI values from the post-collective period are significantly lower compared to the collective era, when livestock grazing intensity was lower in Tsahiriin tal. This indicates that rangeland productivity might have decreased in Tsahiriin tal compared to that during the collective era. Among the changes discussed above, the grazing intensity increase might have contributed most to this decrease in NDVI values. Our results of low biomass productivity in Tsahiriin tal are consistent with nationwide trends documented in Mongolia (Damdinsuren et al., 2008). The United Nations Environment Programme statement on Mongolia's environmental health (2002) indicates that over 70% of Mongolia's pastureland is degraded due to overgrazing. Furthermore, it states that the diversity of plant species has decreased by 80% near urban centers due to overgrazing. In contrast, however, other rangeland assessments continue to suggest that Mongolian rangelands are currently healthy and can support an even greater number of animals than the current population of 65 million animals in sheep units (a conversion, used in Mongolia, of all livestock species into a single species) (Mongolian Statistics Book, 2007). Tserendash's review (2008) of Mongolian rangeland assessment indicates that it can support 86 million animals in sheep units.

In addition to the grazing land use changes, we explored climate variables from the two time periods to determine if precipitation and temperature were confounding variables that could have contributed to the observed decrease in NDVI values. Nationwide trends indicate an increase in the annual mean temperature and a decrease in the annual mean precipitation (Asian Development Bank and the Clean Air Initiative for Asian Cities Center, 2006). Similarly, the long-term climate data (1974-2007) from the local weather station in Renchinlumbe indicates that annual average temperatures have continually increased over the last 30 years, although precipitation fluctuated (Figure 2). This might suggest that if temperatures continue to increase in northern Mongolia in the face of global climate change, it might have an important impact on rangeland productivity. The effects of the current grazing management system combined with this increase in temperature might further accelerate the observed decline in rangeland productivity.

CONCLUSIONS

Our results indicate that rangeland productivity has declined in the rural, remote valley of Tsahiriin tal in northern Mongolia. This decline appears to be associated with the changes in grazing land use management over the last twenty years. In particular, increased number of livestock might be associated with this decrease in rangeland productivity. Such patterns could continue and further reduce rangeland productivity in Tsahiriin tal if current rangeland use is to continue without formal rangeland management institution or organized, well-structured efforts by the herding households.

Herders can use seasonal pastures close to urban settlements for shorter periods of time or camp with fewer animals to sustain healthy rangeland productivity. Herders, however, need to be better coordinated at a local scale for such management changes. Some nationwide, coarse-scale rangeland assessments continue to suggest that Mongolian rangelands are healthy and can support even greater numbers of livestock than the current size. However, our local-scale study suggests that there are areas where such recommendations should not apply.

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