Time Series Analysis of Satellite Greenness Indices for Assessing Vegetation Response to Community Based Rangeland Management

J.P. Angerer[1,2], J.K. Kretzschmar[3,4], J. Chantsallkham[5,6], K. Jamiyansharav[5,7], R. Reid[8,9], M.E. Fernández-Giménez[5,10]

[1]Blackland Research and Extension Center, Texas A&M AgriLife Research, Temple, TX, 76502 USA
[2]<jangerer@brc.tamus.edu>
[3]Department of Ecosystem Science and Management, Texas A&M University, College Station, TX 77843-2125
[4]<jkkretzschmar@neo.tamu.edu>
[5]Forest & Rangeland Stewardship, Colorado State University, Fort Collins CO 80523-1472,USA
[6]<jchantsaa@yahoo.com>
[7]<jkhishig@gmail.com>
[9]Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO, 80523-1472 USA
[9]<Robin.Reid@colostate.edu>
[10]<Maria.fernandez-gimenez@colostate.edu>

ABSTRACT

After the transition of Mongolia's agriculture sector to a market economy in the early 1990's, community-based rangeland management (CBRM) organizations have been established across Mongolia to cooperatively manage rangeland resources. We hypothesized that rangeland ecoregions under CBRM would have greater biomass than ecoregions managed using traditional herder practices. We used time series analysis of AVHRR (8-km resolution, 1982 to 2012) and MODIS Normalized Difference Vegetation Index (NDVI) (250-m, 2000 to 2013) to calculate integrated NDVI (iNDVI) as a proxy for vegetation biomass. To address whether CBRM response is scale related, we created buffers of increasing distance around livestock winter shelter locations in *soums* where CBRM programs had been initiated and *soums* without formal programs. Spatial averages of iNDVI were calculated within buffer boundaries for each location, stratified by ecological zone. A repeated measures mixed model with yearly rainfall as a covariate was used to test for differences in iNDVI for CBRM status over time for buffer distances of 1, 2, 5, 10, and 30 for MODIS, and 10 and 30 km for AVHRR. In general, results were similar across buffer distances indicating that average vegetation response was similar for distances greater than 1 km around sampling sites. For MODIS NDVI, sites in the Desert Steppe and Eastern Steppe did not have significantly higher productivity in CBRM managed *soums* over time, regardless of buffer size. Mountain and Forest Steppe (MFS) locations had higher iNDVI in non-CBRM sites throughout the time series for both NDVI data sets, although these differences were not statistically significant. CBRM sites in the Steppe zone had higher iNDVI throughout the time series for both MODIS and AVHRR.

Given that these differences occur throughout the AVHRR time series, they do not appear to be the result of CBRM activities. Our findings indicate that differences in vegetation response as a result of CBRM activities were not detected during the time series using productivity proxies from satellite imagery. In addition, the MODIS time series may be too short for detecting CBRM differences since it does not include data prior to when most CBRM programs were implemented.

Keywords: NDVI, community based rangeland management, Mongolia, AVHRR, MODIS

INTRODUCTION

Following the transition of Mongolia's agriculture sector to a market economy in the early 1990's, concerns about land degradation, in addition to large scale losses of livestock during a series of droughts and winter disasters (*dzuds*) in 1999-2002 led to the establishment of community-based rangeland management (CBRM) organizations across Mongolia. These organizations were formed to cooperatively manage rangeland resources (Fernández-Giménez et al., 2015). A major activity of these organizations is to locally manage their livestock herds to reduce overgrazing and improve pasture conditions. Many of these CBRM organizations have been in place since the late 1990's and provide an opportunity to study their effectiveness in managing rangeland resources.

Remote sensing-based vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), have been found to be suitable proxies for vegetation biomass or net primary productivity (Tucker et al., 1983; Tucker et al., 1985). The high spatial and temporal frequency of remote sensing imagery such as NDVI provides opportunities for examining trends in vegetation response, and evaluating these in relation to climate and management For example, NDVI products have been used to examine effects of land management and changing climate on rangeland degradation (Evans and Geerken, 2004; Wessels et al., 2007).

For this study, we sought to determine if differences in vegetation response resulting from CBRM pasture management activities could be detected using time series of NDVI. We hypothesized that improved livestock management on rangelands under CBRM would lead to increased vegetation biomass compared to lands managed using less formal, traditional herder neighborhoods, and that the increased vegetation response could be detected using NDVI as a proxy for vegetation biomass. A secondary objective was to examine whether vegetation response to CBRM activities is scale related in that individual herder activities for CBRM may be detected at the scale of their winter pasture boundaries, but not at increasing distances away from their winter pastures where they potentially have less control over the grazing management.

STUDY SITE

A total of 18 paired *soums* (an administrative unit similar to districts), with one of the pair having formal CBRM organizations active within its boundaries and the other having informal, traditional neighborhoods, were identified in four major ecological zones in Mongolia. The four ecological zones included: mountain and forest steppe (MFS), eastern steppe (ES), steppe (S), and desert steppe (DS). Within each *soum*, 4-5 winter shelters (used by herders for overwintering and protecting their animals) were identified for field sampling (see companion study, Reid et al. [2015]). These points served as the locations for the time series remote sensing analysis.

METHODS

We conducted time series analyses using NDVI from the MODIS-Terra platform (MOD13Q1-L3 product, 250-m resolution, 16 day maximum composite images from 2000 to 2013) (Huete et al., 2002) and AVHRR-NDVI3g (~8 km resolution, bimonthly, 16 day maximum value composite images from 1982 to 2012) (Pinzon and Tucker, 2014). We evaluated both NDVI products because of differences in the resolution and time series length between the two products. The AVHRR-NDVI3g product is coarser resolution, but has a longer time series (30 years) that includes a period before the majority of CBRM programs were initiated in Mongolia. The MODIS NDVI data have a finer resolution than AVHRR, but the time series is relatively short (14 years). In addition, the time series from 2000 to 2013 for MODIS occurs after many of the CBRM programs in Mongolia had already been implemented.

MODIS-NDVI tiles for the study area were acquired from the Land Processes Distributed Active Archive Center (LP DAAC; https://lpdaac.usgs.gov/). The tiles were mosaicked and reprojected to an Albers Equal Area projection using the MODIS Reprojection Tool (Dwyer and Schmidt, 2006) and were screened for pixels with negative NDVI (i.e. pixels with clouds, snow, ice, and water). AVHRR-NDVI3g data were acquired from the NASA Earth Exchange NDVI3g archive (https://nex.nasa.gov/nex/projects/1349/)and were reprojected to a common projection (Albers Equal Area) and clipped to the study area boundary.

For both NDVI data sets, a least squares, double logistic function in TIMESAT software (Jönsson and Eklundh, 2004; Eklundh and Jonsson, 2009) was used to fit seasonal curves to pixels in the NDVI time series, on a pixel-by-pixel basis. From the fitted curves, we extracted the time integrated NDVI (iNDVI) for each year to serve as a proxy for the yearly response of the vegetation biomass.

To address whether CBRM response could be scale related, we created buffers of increasing distance around the winter shelter locations in each *soum*. Buffer radii examined were 1, 2, 5, 10, and 30 km from the point locations for MODIS NDVI, and 10 and 30 km radii for AVHRR. Spatial averages of iNDVI were calculated within buffer boundaries for each location and year, stratified by ecological zone. A repeated measures mixed model, with CBRM status as a main factor, year as a repeated measure, and yearly rainfall as a covariate, was used to test for differences in iNDVI that could be related to CBRM status over time for each of the buffer distances.

For the precipitation covariate, we used the global Climate Prediction Center Unified Precipitation Data (Chen et al., 2008), which is an interpolation of daily precipitation measured from weather stations. The data have a pixel resolution of approximately 55 km and the daily data archive is available for 1979 to 2014. The precipitation raster's pixels were resampled to 1 km resolution and summed for each day of the year to determine annual rainfall in each pixel. Spatial averages of the annual precipitation were calculated within buffer boundaries for each location and year, stratified by ecological zone.

RESULTS

In both the MODIS-NDVI and AVHRR-NDVI analysis, rainfall was highly significant ($p<0.0001$) for the DS, MFS, and Steppe sites, providing an indication of the importance in controlling for precipitation differences across the study sites in the statistical model. The rainfall covariate for ES sites was significant ($p<0.05$) for the MODIS-NDVI analysis, but was not significant for the AVHRR-NDVI. Also, in general, the statistical analysis results for the buffer radii around the sample sites were similar; indicating that patterns in average iNDVI did not differ greatly with increasing scale from the sample locations in the ecological zones. Therefore, the results presented below will focus on the analysis using the 10-km buffer to allow comparisons between the MODIS and AVHRR datasets at similar scales.

For sites in the DS, there was no significant difference in vegetation response over time for the management types in both the MODIS-NDVI and AVHRR-NDVI time series after controlling for the effects of rainfall difference across sites (Figure 1a, Figure 2a). In both time series, there was a slight tendency for the non-CBRM sites to have higher iNDVI than CBRM sites (Figure 1a, Figure 2a).

For the ES sites, CBRM status was not significantly different for any year in the MODIS NDVI time series (Figure 1b). For the AVHRR-NDVI, sites with CBRM management had significantly higher iNDVI in 2010 and 2011 after controlling for rainfall differences across sites (Figure 2b). For the MODIS NDVI time series, there was a slight tendency for non-CBRM sites to have higher vegetation response (Figure 1b). However, the opposite was seen for the AVHRR-NDVI (Figure 2b). For years where the two time series overlap, the iNDVI time trends are similar, but the vegetation response, as indicated from the iNDVI, is much higher in the AVHRR than MODIS NDVI.

The MODIS-NDVI in the MFS locations had a significant CBRM status by time interaction ($p < 0.0001$); however there were no significant differences in CBRM status throughout the time series, indicating that differences in iNDVI between years was the dominant factor in the interaction (Figure 1c). This was also confirmed by the highly significant main effect for year ($p<0.0001$). The results were similar for the AVHRR time series, with no significant differences in CBRM status over time (Figure 2c).

CBRM sites in the S zone had significantly higher iNDVI in 2002 and 2010 than non-CBRM sites, and there was a trend for higher iNDVI at CBRM sites throughout the MODIS-NDVI time series (Figure 1d). For AVHRR, the iNDVI at CBRM sites was significantly higher than non-CBRM sites for 16 of the 30 years in the time series (Figure 2d). However, these differences existed throughout the time series (Figure 2d), indicating that these differences were likely not the result of CBRM management practices.

DISCUSSION

In general, we found few differences in vegetation response (as measured with iNDVI) for sites under the two different management approaches. Where differences did exist throughout the time series (e.g., in the MFS and S zones), these differences occurred throughout the time series and prior to when CBRM activities were implemented. These results somewhat contradict those in a previous study in the Gobi region of Mongolia (desert steppe areas) that found significantly higher iNDVI (6%) at sites under CBRM than in control areas 6 years after the initiation of the community based management (Leisher et al., 2012). These differences may be related to the use of the rainfall covariate to control for rainfall differences across sites, in addition to the longer time series that was available in our study.

For our study, a possible reason for not being able to detect significant differences in vegetation response resulting from CBRM management may be related to *soum* (and surrounding *soum*) livestock numbers and livestock forage use. In a companion study (see Gao et al., 2015), we examined forage use across all *soums* in Mongolia for the period from 2000 to 2014 and found high grazing pressure by livestock in about 32% of the country. Using data from the Gao et al. (2015) study, we compared the livestock forage use in the paired *soums* in each of the ecological zones. Although average forage use was slightly lower in the CBRM soums, the forage use was generally similar between the two management types (Table 1); therefore, the biomass response seen in this study may reflect the similar grazing by livestock within these *soums*. Another factor may be forage use by livestock moved from adjacent *soums*. Addison et al. (2013), in an examination of CBRM groups in the Gobi region of Mongolia, found that the boundaries of pastures under CBRM were not enforced and movements by herders and their livestock from adjacent areas were not controlled. In our case, uncontrolled use of forage in CBRM areas may have negated any biomass savings that would of occurred through reduced animal numbers or pasture deferment implemented by the CBRM group.

IMPLICATIONS

Natural differences in site response, and the uncertainty associated with the effectiveness of the CBRM activities, make detection of vegetation response resulting from CBRM activities difficult using coarse spatial, and temporally limited resolution, productivity proxies from satellite imagery. Field assessments conducted at these sites in 2011 and 2012 indicated that the effect of management types varied among ecological zones and were limited to slightly higher litter biomass and plant connectivity, less soil erosion, and lower abundance of annual plant species on CBRM pastures (Reid *et al.*, 2015). Given these slight differences, it is unlikely that these field-acquired, vegetative indicators would be easily detected by the coarse resolution MODIS or AVHRR imagery. Wessels (2007) points out the need for long-term field monitoring programs to complement remote sensing studies and improve detection of important indicators such as species change and erosion that are not easy to detect with coarse resolution, long-term remote sensing datasets. Long-term monitoring programs are needed to aid in improving detection of management from remote sensing. Additionally, monitoring of pasture utilization would also be important for documenting whether CBRM activities such as pasture deferment or stocking rate reductions are having their intended effects.

Despite its finer spatial resolution compared to the AVHRR time series, the MODIS time series does not provide baseline information prior to CBRM establishment. Examining vegetation response with a long time series such as with the AVHRR-NDVI dataset is important for ensuring that differences in vegetation response under different management programs can be attributed to management, and not be the result of inherent differences between the sites being evaluated. In this study, if the MODIS-NDVI had been the only product used, it could have led to a false interpretation of the CBRM management effects in the S and MFS ecological zones. Although the resolution of the AVHRR imagery is lower, the long time series provides an opportunity to examine long-term trends to evaluate whether the areas chosen are different and could prove useful in a-priori selection of sites and *soums* for CBRM evaluation.

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Table 1. Average estimated forage use (+/- standard error [SE]) by livestock across years for *soums* with community based rangeland management (CBRM) versus those using traditional management (non-CBRM) during the period from 2000 to 2014 by ecological zone. See Gao *et al.* (2015) for methods on calculation of forage use.

Ecological Zone	**CBRM**	**+/- SE**	**Non-CBRM**	**+/- SE**
Desert Steppe	41.7	0.9	46.1	0.7
Eastern Steppe	38.5	1.0	31.6	0.6
Mountain and Forest Steppe	70.5	1.1	72.7	1.6
Steppe	61.3	1.4	69.6	2.6

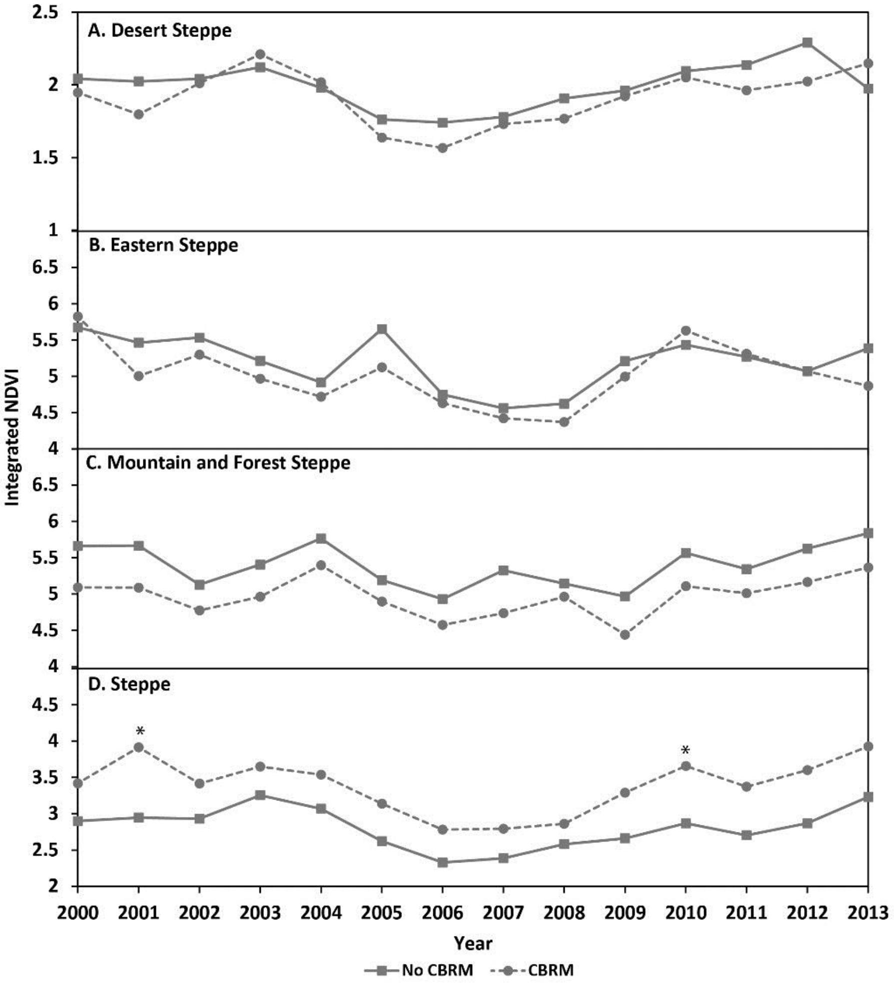

Figure 1. Least square means for time integrated Normalized Difference Vegetation Index (iNDVI) from the MODIS sensor by year, management treatment (Community Based Rangeland Management [CBRM] vs. traditional management [No CBRM]) and ecological zone. Means reflect adjustment for the covariate in the mixed model analysis to control for the effects of rainfall difference across sites within each ecological zone. Means with a "*" indicate a significant difference ($p<0.05$) between CBRM and No-CBRM means for that year.

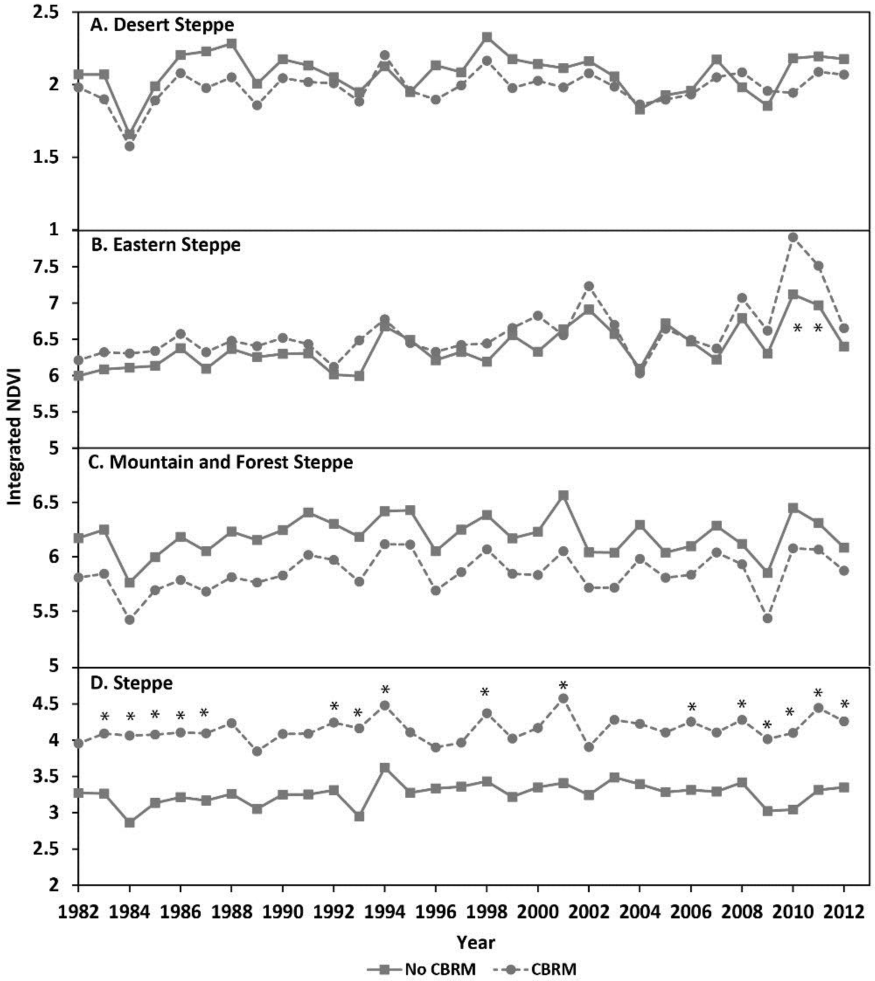

Figure 2. Least square means for time integrated Normalized Difference Vegetation Index (iNDVI) from the AHVRR sensor by year, management treatment (Community Based Rangeland Management [CBRM] vs. traditional management [No CBRM]) and ecological zone. Means reflect adjustment for the covariate in the mixed model analysis to control for the effects of rainfall difference across sites within each ecological zone. Means with a "*" indicate a significant difference (p<0.05) between CBRM and No-CBRM means for that year.