Rangeland Assessments Using Remote Sensing: Is NDVI Useful?

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ABSTRACT
Two semi-arid rangeland sites were chosen to assess the applicability of NDVI as a predictor of vegetation cover and biomass. While geographically distant, both sites shared many traits and were considered biophysically similar environments. These sites, one in northern Mongolia and one in western USA, were the focus of field based vegetation studies and repeated remote sensing acquisitions between 2007 and 2008. Atmospherically corrected Satellite Pour l'Observation de la Terre (SPOT) imagery was used to develop NDVI models representing early, middle, and late segments of the growing season. Field-based biomass and percent cover of green vegetation were correlated with SPOT NDVI data for each imagery date at 100 sample locations for each study site using simple linear regression models. The resulting correlations were weak ($R^2 \leq 0.184$) and only five of the 18 relationships tested demonstrated statistical significance. When bare soil reached or exceeded 20%, NDVI was no longer statistically significant as a predictor variable for any vegetation characteristic tested in this study. These results suggest that NDVI might not be a useful estimate of vegetation cover or biomass in semi-arid rangelands, especially when bare soil cover is >20 percent.

KEYWORDS: biomass, vegetation cover, NDVI, remote sensing

INTRODUCTION

Rangelands around the world can have drastically different grazing management systems depending on the political, social, economic, and cultural settings. To study the effects of two contrasting traditional grazing systems on rangelands, we conducted rangeland assessments in two biophysically-similar rangelands of northern Mongolia and western USA. The grasslands of northern Mongolia are used by nomadic herders with their multiple livestock species at a greater grazing intensity, while the shrubland steppe of the western USA is grazed by sheep only at a lower grazing intensity. A core indicator of plant cover (Pellant et al., 2000) is used to provide information on the functioning of the two systems (Havstad and Herrick, 2003). Remote sensing assessment is used along with field data to enhance sampling and site representation (Booth et al., 2005). Current and anticipated future capability of moderate-resolution multispectral satellite systems do not provide the level of detailed identification of species and community type and productivity measurements required for similarity index calculations (Hunt et al., 2003), a desired choice of method for comparative studies such as ours. Band ratios including Normalized Difference Vegetation Index (NDVI) are among the possible options available. NDVI, the most commonly used band ratio, however, has important limitations (Philips et al., 2008), although it has been widely used in rangeland studies (Anderson et al., 1993, Purevdorj et al., 1998, Bayarjargal et al., 2000, Fukuo et al., 2001, Wylie et al., 2002, Zha et al., 2003, Kensuke et al., 2005, Bayarjargal et al., 2006, Erdenetuya and Khudulmur, 2008) with varying levels of success (Maynard et al., 2007). As vegetation cover decreases, NDVI becomes increasingly sensitive to the effects of bare soil (Richardson and Wiegand, 1977, Gao et al., 2000). Rangelands often have some amount of bare soil, especially in semi-arid environments such as our two study sites. NDVI is, therefore, expected to be impacted. Exactly how much bare soil can be present to warrant the successful use of NDVI in rangelands, however, is not well documented. The current literature lacks quantitative estimates of how much bare soil should be present in rangelands for NDVI to be useful. Here we present estimates of NDVI correlation with plant cover and biomass at point locations with varying amounts of bare soil exposure at the two study sites over two growing seasons. We evaluate the statistical significance and the portion of the variability in vegetation cover that NDVI can explain in three bare soil cover classes of up to 30 percent bare soil exposure.

METHODS

Study site description

Two sites were selected for this study, one representing the grasslands of northern Mongolia and one representing the shrub steppe of western USA. While latitude, elevation, topography, climate (e.g. extreme continental climate with cold winters and short summers), and some of the plant species are similar between the two sites, there are differences between the two sites in some variables (e.g. patterns of precipitation) in addition to the grazing systems (Figure 1).

Tsahiriin tal, northern Mongolia

Tsahiriin tal is a small valley located within the southern portion of the Darkhad Valley (51º2’17”N, 99º19’42”E) within Renchinlhumbe county of Khuvsgul province (Figure 1). The valley is used by 34 nomadic herding households as a summer pasture for 3 months at 1.191 AUM/ha grazing intensity with multiple livestock species of sheep, goats, cattle (includes yaks), and horses. Mean annual precipitation is less than 300 mm and monthly average temperatures ranges from less than -30 Cº in winter to close to 15 Cº in summers. Common plant species are *Poa pratensis* L., *Artemisia mongolica* (Fisch. ex Bess) Nakai, *Artemisia frigida* Willd., *Potentilla acaulis* L., and *Stipa krylovii* Roshev. The Tsahiriin tal valley floor consists of relic alluvial channels, terraces, and plains, as well as areas with closed depressions and hummocky rises. Soil parent materials are predominantly alluvial and lacustrine sediments. Calcareous grassland soils with organic-rich surface horizons are dominant throughout the site.

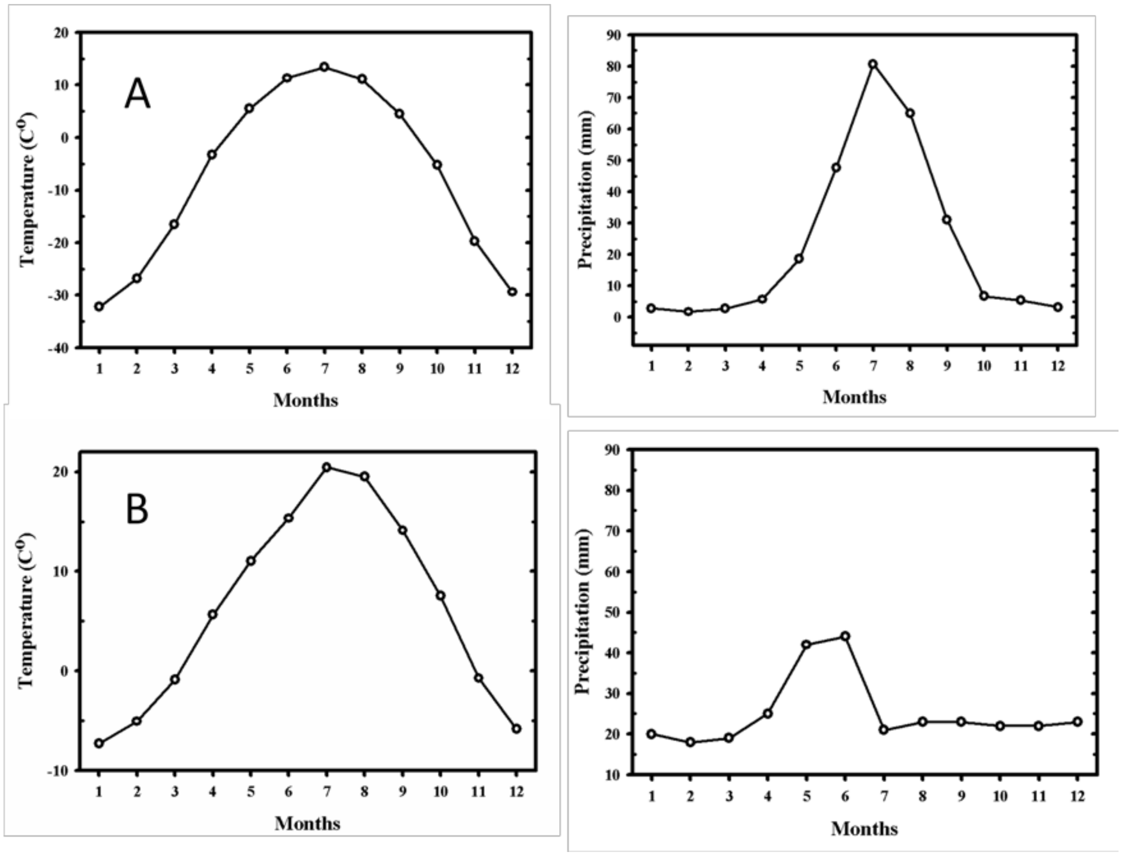

Figure 1. Long-term monthly averages of temperature and precipitation in Tsahiriin tal, northern Mongolia and the USSES, western USA.

US Sheep Experiment Station, western USA

This study site is the northwest portion of the US Sheep Experiment Station (USSES) headquarters (44º14’44”N, 112º12’47”E) rangeland. The USSES is grazed by only sheep during the spring and fall seasons at <0.62AUM/ha grazing intensity. The area is dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) with subdominant shrubs of antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), spineless horsebrush (*Tetradymia canescens* DC.), and yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.). The understory is cool season grasses and forbs including bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), Sandberg bluegrass (*Poa secunda* J. Presl), and arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.). Mean annual precipitation is approximately 326 mm. The soils are a complex of sandy loam aeolian deposits of varying depth over lava flows.

Field methods

At each site, two seasons of field work were completed during the months of July and August in 2007 and 2008. Prior to field work, 100 random points were generated across each study area using Hawth’s tool in ESRI® ArcMapTM 9.2 software (ESRI Inc, 1999-2006). The same set of points was visited each year by navigating with a Trimble GeoXT GPS receiver with ± 3 m real-time horizontal accuracy. At each point, estimates of percent cover of shrub, litter, herbaceous cover, bare soil, and rock (coarse fragments > 75 mm) were made within a 10 m by 10 m plot centered on the point and aligned in the cardinal directions. Point-intercept method was used along two 10 m line transects that were oriented perpendicular to each other and intersected at the center of the plot at 5 m along each transect. Observations were recorded at every 20 cm along each 10 m line, beginning at 10 cm and ending at 990 cm, to indicate the cover type at the point. This resulted in 50 point measurements for each line and 100 point measurements for each plot. All herbaceous plants within a 0.44 m^2 cable hoop randomly tossed within each quadrant of each plot were clipped and weighed (without oven drying) to estimate total plant biomass. An average of the four biomass measurements was estimated for each plot. A subsample of the biomass samples were randomly selected from the set of all samples across each study site. These samples were dried to estimate the weight difference between wet and dry biomass samples. On average, 49.96 % (SD+5.02) of the weight was lost during drying. These differences were subtracted from all wet weights to convert the wet biomass estimates to dry biomass estimates.

Image analysis

To assess plant cover and biomass productivity, SPOT4 and SPOT5 images from early, middle, and late growing seasons in 2007 and 2008 were acquired (Table 1). All images were corrected for atmospheric effects using Idrisi's ATMOSC module (based on Chavez (1996) cos(t) model) and were projected in UTM Zone 47 North with WGS 1984 datum and Idaho Transverse Mercator with NAD 1927 datum for Tsahiriin tal and USSES, respectively. All images were co-registered to a georectified image source and then subset to the study sites. NDVI was estimated in each image subset using ENVI software (ENVI Version 4.3, ITT Industries Inc, 2006, Boulder, CO). NDVI values at the 100 random points within each study site were then extracted from each image for statistical analysis.

STATISTICAL ANALYSIS

Field-based biomass and green vegetation percent cover estimates were correlated with SPOT NDVI estimates from each date at the 100 sample locations at each study site using a simple linear regression model. To evaluate the SPOT NDVI prediction of rangeland biomass and green vegetation percent cover, coefficient of determination and p-values were summarized. Next, the 100 sample locations were subdivided into bare soil cover classes: 0-10%, 10-20% and 20-30% bare soil. There were only a few point locations (<10 at each site) where bare soil cover exceeded 30% and these points were excluded. The correlation between SPOT NDVI and vegetation percent cover was then evaluated by estimating coefficient of determination and p-values for each bare soil cover class to determine if NDVI is increasingly sensitive with increasing bare soil cover and becomes statistically insignificant with greater bare soil.

RESULTS

At the Tsahiriin tal study site, field-based mean green vegetation cover was 68 (SD±11.8) percent in 2007 and 49 (SD±7.6) percent in 2008. Field-based estimate of average dry forage was 712 kg/ha in 2007 and 605 kg/ha in 2008. There was no correlation between Aug 08, 2007 and June 02, 2008 NDVI estimates and field-based biomass estimates. Correlations were poor, when statistically significant correlation was found between May 10, 2008 and Aug 09, 2008 NDVI estimates and field-based biomass estimates (Table 1). Similar pattern was observed in the correlations between NDVI estimates and green vegetation percent cover estimates. The highest coefficient of determination was a low 0.20 (p-value <0.001) (Table 1).

At the USSES study site, field-based mean green vegetation cover was 74.8 (SD±18.3) percent in 2007 and 67.6 (SD±21.4) percent in 2008. Field-based estimate of average dry forage was 243.3 (SD+259.8) kg/ha in 2007 and 182.6 (SD±214.5) kg/ha in 2008. There was no or little correlation between NDVI and field-based biomass estimates (Table 1) and no correlation between NDVI and green vegetation percent cover, except for June 29, 2007 NDVI which explained 47 percent of the variability in vegetation cover.

Table 1. SPOT NDVI correlation with rangeland biomass and green vegetation percent cover at 100 sample points at each study site

Images	Associated timing in the growing season	Correlation with rangeland biomass (R^2 (p-value))	Correlation with vegetation percent cover (R^2 (p-value))
Tsahiriin tal study site, Mongolia			
SPOT4, Aug 08, 2007			
SPOT5, May 10, 2008	Late growing season	0.006 (p=0.432)	0.020 (p=0.163)
SPOT5, June 02, 2008	Early growing season	0.110 (p=0.001)	0.145 (p<0.001)
SPOT5, Aug 09, 2008	Mid growing season	0.018 (p=0.185)	0.043 (p=0.040)
	Late growing season	0.143 (p<0.001)	0.205 (p<0.001)
USSES study site, USA			
SPOT5, April 28, 2007	Early growing season	0.044 (p=0.038)	0.004 (p=0.557)
SPOT5, June 29, 2007	Mid growing season	0.182 (p<0.001)	0.474 (p<0.001)
SPOT5, Sep 15, 2007	Late growing season	0.001 (p=0.791)	0.001 (p=0.771)
SPOT5, June 28, 2008	Mid growing season	0.041 (p=0.044)	0.005 (p=0.478)
SPOT5, Aug 18, 2008	Late growing season	0.030 (p=0.087)	0.000 (p=0.973)

When correlations between green vegetation percent cover and NDVI were examined in different bare soil classes in Mongolia, the Aug 08, 2007 NDVI estimates were not statistically significant as a predictor variable in all bare soil classes (Figure 2, panel A). The NDVI estimates from summer 2008 were statistically significant as a predictor variable in all bare soil classes of 0-10% and 10-20%, except for the June 2 NDVI in 10-20% bare soil class. The 2008 NDVI estimates explained 3.8-36.6 percent of the variability in vegetation cover (Figure 2, panel A). All 2008 NDVI estimates, however, were no longer statistically significant as a predictor variable in the bare soil class of 20-30%.

At the USSES study site, all 2007 NDVI estimates were statistically significant as a predictor variable in 0-10% and 10-20% bare soil classes, except for the April 26 and Sep 15 NDVI in 10-20% bare soil class. The 2007 NDVI estimates, however, were not significant in all 20-30% bare soil classes, except for the June 29 NDVI. None of the 2008 NDVI estimates was statistically significant as a predictor variable for any of the bare soil classes (Figure 2, panel B).

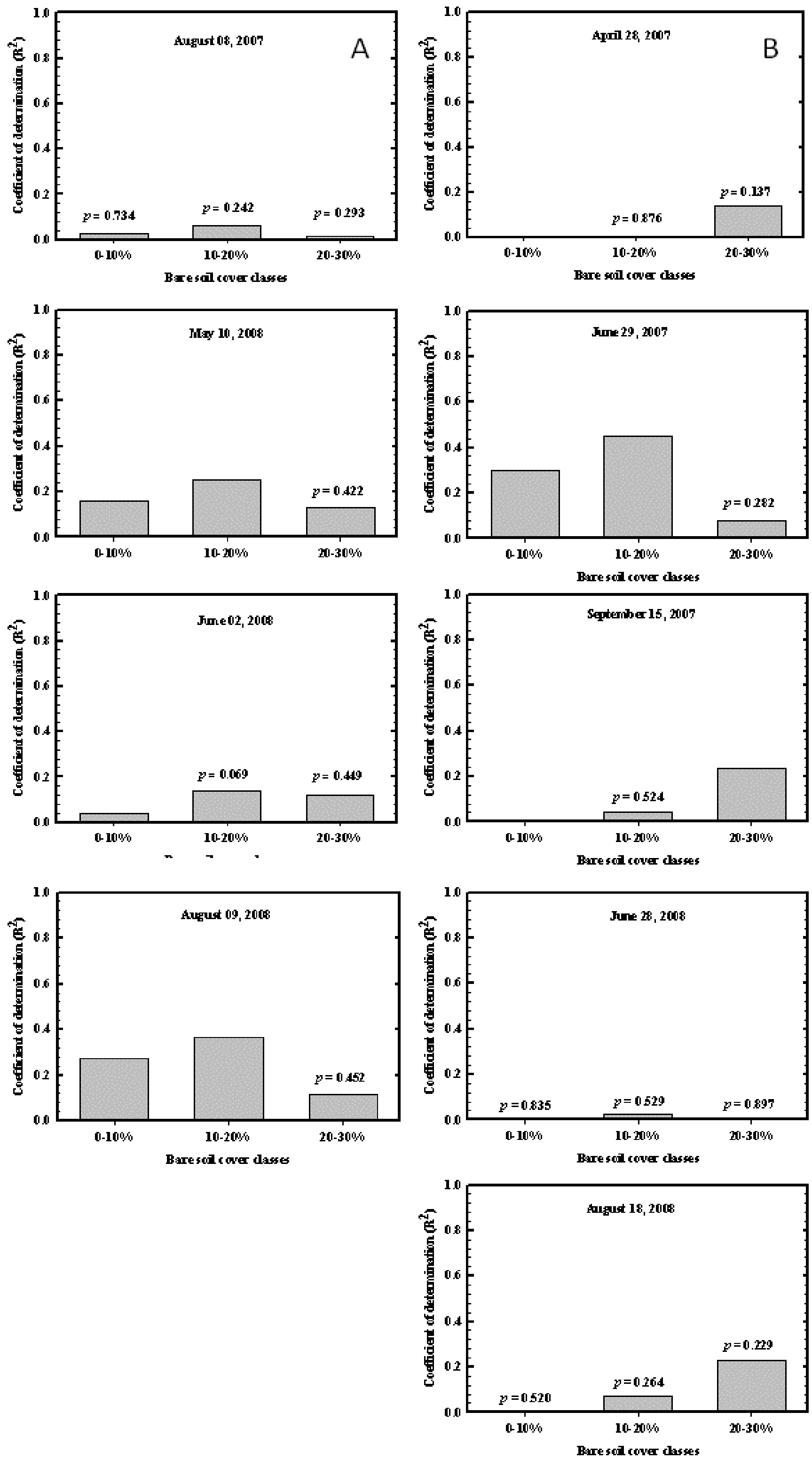

Figure 2. SPOT NDVI prediction of green vegetation cover in Tsahiriin tal, northern Mongolia (panel A) and the USSES, western USA (panel B). P-values are provided in cases where NDVI estimates were not statistically significant as a predictor variable.

DISCUSSION

The results of this study in the Tsahiriin tal valley of northern Mongolia and the USSES in the western USA indicate two patterns in NDVI correlation with vegetation cover and biomass. Firstly, NDVI correlation with vegetation percent cover and biomass in both years was absent in many cases at both sites. When NDVI was statistically significant as a predictor variable, the correlation was very poor. Our best NDVI correlation with vegetation cover during the two years yielded a coefficient of determination of 0.47 at the USSES and 0.20 at the Tsahiriin tal valley. The best coefficient of determination between NDVI and biomass was a low 0.14 in Tsahiriin tal and a low 0.18 at the USSES during this two year study. While NDVI estimates from the two sites were not expected to be similar due to differences in grazing management as well as other potential factors, NDVI was expected to be correlated with either field-based vegetation cover estimates or biomass estimates at each site. Despite careful georegistration and simultaneous or nearly simultaneous timing of field data collection and image acquisition, NDVI and field-based plant cover and biomass estimates produce poor correlation at both rangeland sites. Although NDVI has been successfully used in other studies, our study results indicate that NDVI might be poorly correlated with vegetation cover and biomass in semi-arid rangeland sites with little local-scale variability. NDVI correlation with vegetation cover and biomass might be greater in areas with various biomes and community types. However, our rangeland sites each represent a single biome with little variability in life-form and species distribution.

Secondly, NDVI appears to be increasingly impacted by the amount of bare soil present. NDVI estimates at our study sites were mostly significant as a predictor variable of vegetation cover in 0-10% bare soil cover class, and sometimes significant in 10-20% bare soil cover class, and almost never significant in 20-30% bare soil cover class. These results indicate that in semi-arid rangeland sites NDVI sensitivity increases with increasing bare soil cover. At our study sites, when bare soil cover reaches 20-30%, NDVI appears to reach a threshold where it is no longer statistically significantly correlated to vegetation cover. This result has important implications for future use of NDVI in semi-arid rangeland sites. NDVI might not be a useful estimate of vegetation cover at sites with greater than 20% bare soil.

CONCLUSIONS

The results from two biophysically similar semi-arid rangelands over two years with different grazing management systems indicate that NDVI is not well correlated with field-based estimates of green vegetation cover and biomass. The statistical significance of NDVI as a predictor variable of vegetation cover decreases as bare soil cover increases. When bare soil reached or exceeded 20% at our study sites, NDVI was no longer statistically significant as a predictor variable of any vegetation characteristic tested in this study. These results suggest that NDVI might not be a useful estimate of vegetation cover in semi-arid rangelands, especially when bare soil cover is >20 percent.

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