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Original Research

Estimation and Prediction of Grassland Cover in Western Mongolia Using MODIS-Derived Vegetation Indices☆

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ABSTRACT

Spectral indices derived from satellite observations, such as the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), are widely used for grassland monitoring and management around the globe. In this study we contrasted performance of NDVI and EVI metrics obtained from Aqua and Terra, the two satellite platforms carrying the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, for estimating grassland cover measured at ground level on ninety-two 1 × 1 km blocks distributed from semidesert to high montane grasslands in the Sailugem Range of western Mongolia, where overgrazing and overstocking of domestic livestock are concerns for pastureland management. We also explored utility of late spring (May) vegetation indices for forecasting vegetation cover at the peak of the growing season (July). Vegetation indices developed using MODIS 1-km monthly data (MOD13A3 and MYD13A3) were strongly related to on-the-ground field estimates of the percentage of vegetation cover in July (74−85% variation explained), with second-order polynomial regressions demonstrating better fit to the data than first-order regressions, Aqua vegetation indices (VIs) explaining slightly more variance than Terra's VIs, and NDVI performing comparably to EVI for both Aqua and Terra. Both Aqua and Terra VIs for May were highly predictive of July vegetation cover ($R^2 = 0.80-0.84$). We conclude that monthly MODIS NDVI and EVI datasets can be useful for rangeland managers in western Mongolia to monitor and predict summer pasture conditions at the regional level, where science-based guidance on grazing policy and practices is much needed.

Introduction

Grasslands occupy over one-quarter of the Earth's terrestrial surface, excluding Antarctica and Greenland (Olson et al., 1983; Groombridge, 1992; White et al., 2000). Grasslands also support much biological diversity, including the greatest plant species richness at smaller spatial grains (< 50 m^2) of any ecosystem (Wilson et al., 2012) and the highest concentrations of herbivorous animals (White et al., 2000). In addition to acting as sink or source for atmospheric CO_2 (Frank, 2002), thereby playing an important role in regulation of regional and global climate (Yatagai and Yasunari, 1995), grasslands are an integral component for sustaining water quality, soil conservation, agriculture, and recreation (National Research Council, 1994; White et al., 2000; Marsett et al., 2006). Last, > 20 million households depend on grasslands as pastures for livestock (De Haan et al., 1997). In aggregate, the tremendous ecological, economic, social, and cultural values of grasslands make them a critical global resource.

Management of grassland resources at local, regional, and global levels requires timely monitoring of indicators reliably reflecting vegetation cover, productivity, biomass, and plant species composition (White et al., 2000). Grassland monitoring and management is challenging because grasslands often occupy vast and remote areas such that field surveys of grassland conditions are expensive. Moreover, grasslands demonstrate high variability in response to climate variables and anthropogenic impact, thereby requiring frequent sampling (Reeves et al., 2001; Tueller, 2001; Marsett et al., 2006).

Since the 1970s, satellite-borne remote sensing has been used for monitoring and research of grassland and rangeland ecosystems (Booth and Tueller, 2003; Liu et al., 2005). Satellite-derived vegetation indices (VIs), representing arithmetic combination of two or more bands reflecting spectral characteristics of vegetation, have been widely applied for phenological monitoring, vegetation classification, and derivation of structural vegetation parameters, such as plant greenness, vigor, productivity, biomass and leaf area index (Huete et al., 2002). Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) are the most often used global-based VIs for monitoring of terrestrial vegetation (Huete et al., 2002) and have been applied in grasslands and rangelands research and monitoring around the world, such as Mongolia and Japan (Purevdorj et al., 1998), China (Akiyama and Kawamura, 2007), the United States, Africa, Mongolia (Boone

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et al., 2007), Italy (Colombo et al., 2011), and Brazil (Ferreira et al., 2004).

NDVI and EVI have different limitations for monitoring vegetation cover. EVI is a modified expression of the NDVI metric with improved sensitivity to high biomass regions and vegetation monitoring ability due to reduction of atmospheric influence (Huete and Justice, 1999), yet EVI is more sensitive to topography-induced uncertainty (Matsushita et al., 2007). For this reason, NDVI offers optimal performance in mountain areas (Matsushita et al., 2007) but is subject to uncertainty due to different atmospheric and canopy background conditions (Liu and Huete, 1995).

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor is one of the most widely used sources for NDVI and EVI data by researchers and environmental managers for grassland assessment and monitoring (Huete et al., 2002; Li et al., 2010; Cui et al., 2012). NDVI and EVI exhibit variable performance for different grassland areas and regions (Huete et al., 2002; Ferreira et al., 2004; Kawamura et al., 2005; Guo et al., 2007; Li et al., 2010; Luo et al., 2010; Zhao and Ma, 2007; Cui et al., 2012; Nakano et al., 2013) warranting further exploration of the relative performance of these indices for different applications.

MODIS sensors are installed on two satellite platforms—Terra and Aqua—that complement each other by both collecting NDVI and EVI daily data (Wang et al., 2007). Studies have revealed comparable performance of Terra and Aqua VIs (Yang et al., 2006; Wang et al., 2007); however, others have reported inconsistencies in the satellites' index values (Yang et al., 2006; Djavidnia et al., 2010; Wang et al., 2012). An understanding of the relationships between VI values derived from Terra MODIS and Aqua MODIS is critical for refining their use for environmental monitoring yet still poorly developed (Yang et al., 2006; Wang et al., 2007; Colombo et al., 2011).

The issue of sound remote sensing monitoring of grasslands is particularly germane in Mongolia, where rangelands make up roughly three-fourths of the country's land area, providing pasture for some 56 million head of livestock, and supporting livelihoods for some 26% of the country's inhabitants while generating about 13.5% of Mongolia's Gross Domestic Product (Erdenesan, 2016). However, an estimated 75% of Mongolia's pastureland is overgrazed and overstocked with domestic livestock such that significant degeneration caused both by anthropogenic and climate factors is a major concern for decision makers (Stumpp et al., 2005; Naidansuren and Bayasgalan, 2012; Hilker et al., 2014). Our objectives were to 1) compare performance of Aqua and Terra satellites, 2) compare NDVI versus EVI to explain variation in percentage of vegetation cover in the western Mongolia grasslands, and 3) explore the utility of late spring VI values for predicting percentage of vegetation cover at the peak of the growing season (July) as a proxy of pasture quality and forage availability. Our work combined NDVI and EVI derived from Terra MODIS and Aqua MODIS 1 km resolution monthly data tiles (products MOD13A3 and MYD13A3) with our own on-the-ground estimation of vegetation cover at 92 sites sampled throughout the Sailugem Range in western Mongolia. Our work tests the hypotheses that Aqua and Terra sensors, as well as NDVI and EVI, perform equally well in the conditions of short-grass steppe of western Mongolia and that early-season NDVI and EVI values are positively correlated with midseason grassland vegetation cover within a given year.

Materials and methods

Study Area

Our geographical focus was the Sailugem Range of western Mongolia, a high montane grassland region traditionally used for intensive livestock grazing by Kazakh people while having high value for conservation of wildlife including endangered Altai argali *(Ovis ammon ammon)* and Siberian ibex *(Capra sibirica)* (Maroney, 2005; Paltsyn et al., 2011). The region and entire country still lack policy and adequate management practices, as well as a rangeland monitoring system, to advance sustainable range use that balances conservation values and pastoralist livelihoods (Addison et al., 2012; Naidansuren and Bayasgalan, 2012). Total number of livestock in the area increased by 47% and reached historical maxima in the past 25 years: from 503 486 in 1990 to 742 084 in 2014 due mainly to a 350% increase in the number of goats, which increased from 100 082 in 1990 to 355 793 in 2015 (Department of Statistics under the Government of Bayan-Olgii Aimag, 1990 – 2015).

The increase in livestock populations in Sailugem Range, as well as entire Mongolia, has been caused by two factors: 1) collapse of centralized economy followed by mass unemployment after the breakdown of the Soviet Union (Reading et al., 2006) and 2) high global demand for cashmere produced by goats (Naidansuren and Bayasgalan, 2012). Increasing goat herds cause severe degradation of pastures due to goats' destructive grazing habits leaving a shortage of forage for other livestock and wild ungulate species (Naidansuren and Bayasgalan, 2012). Livestock grazing in Sailugem Range even occurs in the Silkhemiin Nuruu National Park, established for protection of highly endangered Altai argali and snow leopard protection (Paltsyn et al., 2011). Local authorities have rights to regulate livestock number and distribution; however, they have very low capacity and resources for adequate rangeland management (Fernandez-Gimenez et al., 2008) and try to avoid unpopular livestock regulation decisions.

All sampled sites occurred in the southern part of Sailugem Range, Bayan-Olgii Aimag, Mongolia, along the border with the Russian Federation (49°11'N – 49°46'N, 88°44'E – 90°26'E) (Fig. 1). The area is characterized by undulating mountains and hills, wide intermountain depressions, and high plateaus within an elevation range between 1 500 m and 3 400 m above sea level (average elevation—2 350 m). Climate is strongly continental with a short growing season (April – August), severe winters, and ca. 250 – 400 mm of annual precipitation with average annual temperature – 6°C to – 7°C (Hilbig, 1995; Modina, 1997). The landscape is dominated by alpine short-steppe grasslands (dominated by *Cobresia*), with higher altitudes (2 900 – 3 400 m above sea level) covered by barren rock and moss, lichen, and low shrubs and intermountain depressions (1 500 – 1 800 m) by dry steppe (dry wormwood – grass steppes with *Caragana* and bunchgrass *Achnatherum*), semideserts (dominated by *Stipa* and *Caragana*) and, in some areas, by wetlands.

Analytical Approach

To obtain remotely sensed estimates of conditions of ground vegetation, we accessed Aqua and Terra MODIS VIs Monthly L3 Global 1km SIN Grid V006 datasets (MYD13A3 and MOD13A3, tile h23v04) for May, June, and July 2013 downloaded from NASA's EOSDIS Reverb website (http://reverb.echo.nasa.gov/reverb/). For field sampling, the MODIS tiles were reprojected to WGS 1984 UTM Zone 45 projection and clipped to our study area. Longitude and latitude of the center of each 1 × 1 km pixel in the study area were calculated in ArcGIS 10.2.2 (ESRI, 2014). To obtain colocated and temporally coincident estimates of ground conditions for MODIS-derived VIs, between 18 July and 3 August 2013, we sampled the percentage of vegetation cover at 92, 1 × 1 km blocks (see Fig. 1), each of which represented a single pixel of MODIS 1-km resolution Monthly VI tile. All sampled blocks were located on relatively flat terrain 1 495 – 2 860 m above sea level that we purposely selected to represent the full range of grassland cover present in the region from montane grassland tundra to dry grassland and semidesert mediated by the logistical constraints of traveling through this remote region. To select the maximal range of grasslands cover for sampling, we used reprojected MODIS EVI and NDVI images and topographic maps of the study area.

To estimate percentage of vegetation cover in each sampled block, we first navigated to the block center and then walked an ever-increasing and spiral-shaped, 4 800-m-long transect guided by a

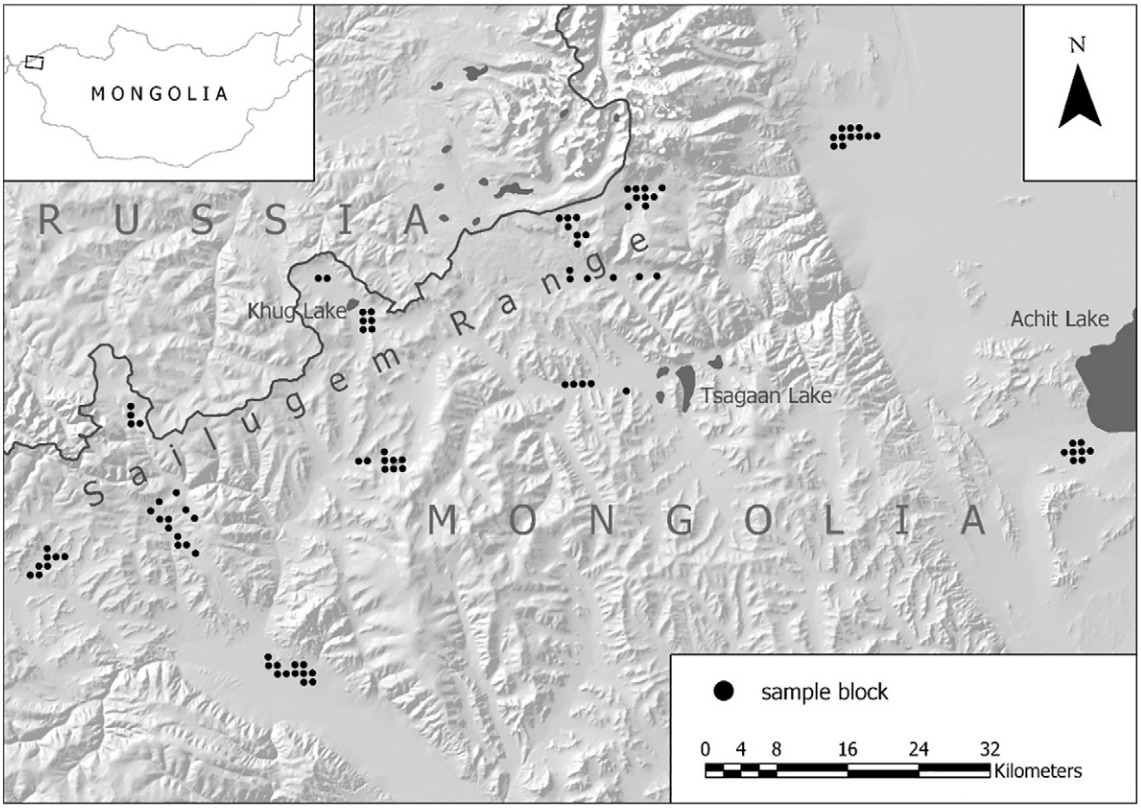

Figure 1. Location of ninety-two 1-km^2 sampling blocks measured in July—August 2013 to contrast Moderate Resolution Imaging Spectroradiometer—derived vegetation indices and percentage of vegetation ground cover in grasslands and semideserts of Sailugem Range, western Mongolia.

hand-held Global Positioning System unit accurate to ca. 10 m (Fig. 2). We stopped every 25 paces along the transect to make point measurements of vegetation cover (green vegetation vs. bare ground or dry vegetation litter at the sampling point touched by a pin placed at the leading edge of the surveyor's foot). Point estimates accumulated along a given transect were used to calculate proportion of points that were vegetated among all points sampled within a given sampling block (average $n = 215$ points per sampled block, range $= 167 - 255$ depending on stride length of surveyor).

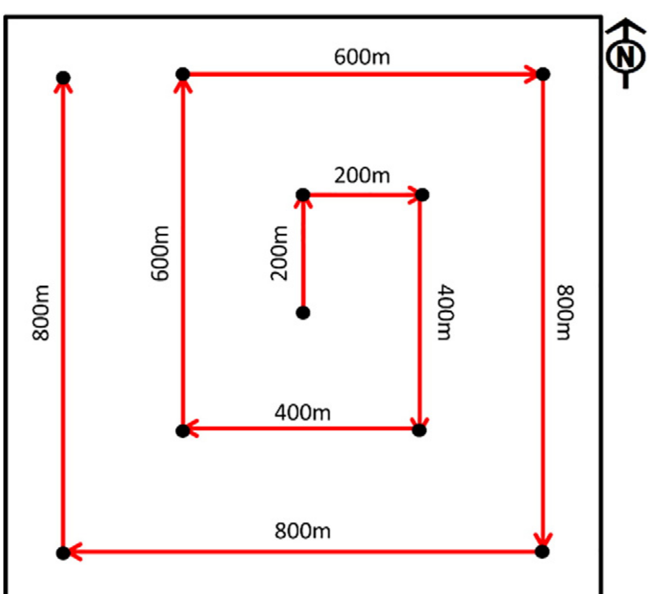

Figure 2. Transects used for sampling vegetation cover on each of ninety-two 1 × 1 km blocks aligned with the Moderate Resolution Imaging Spectroradiometer grid in the Sailugem area of western Mongolia, July—August 2013. The *black frame* represents a 1 × 1 km sampling block, *red lines* depict segments of a 4 800-m-long sampling transect, and *arrows* indicate the direction of movement during sampling.

Estimates of the percentage of vegetation cover for selected blocks were associated with respective NDVI and EVI values of appropriate pixels for May, June, and July 2013 Terra MODIS (MOD13A3) and Aqua MODIS (MYD13A3) 1 km resolution Monthly VI tiles. First- and second-order polynomial least squares regressions relating Terra and Aqua NDVI and EVI datasets to on-the-ground vegetation cover were fit and model performance contrasted with model coefficient of determination (R^2 and R^2adj), root mean square error (RMSE), and Akaike's Information Criterion (AICc). Best regressions were used to extrapolate maps of vegetation cover in our study area using ArcGIS 10.2.2 (ESRI, 2014).

Results

The number of reliable pixels among the ninety-two 1 × 1 km blocks sampled on the ground varied among the MODIS datasets for May, June, and July 2013 (Table 1) ranged from highest for Terra in June ($n = 82$) to lowest for Terra in July ($n = 51$). Only pixels of highest reliability

Table 1
Pixel reliability (NASA LP DAAC, 2016) for ninety-two 1 × 1 km sampled blocks for MODIS Terra and Aqua datasets for May, June, and July 2013 in the Sailugem area of western Mongolia.

Pixel reliability (QA)	Aqua			Terra		
	May	June	July	May	June	July
0—Good data	69	52	59	70	82	51
1—Marginal data	20	40	33	22	10	41
3—Cloudy	3	0	0	0	0	0

Table 2
Linear ($ax + b$) and second-order polynomial regressions ($ax^2 + bx + c$) describing the relationship between July 2013 Aqua- and Terra-derived MODIS vegetation indices and percentage of vegetation cover on 1 × 1 km blocks with QA = 0 ($n = 59$ for Aqua and $n = 51$ for Terra) sampled in Sailugem Range in western Mongolia, July—August 2013.

Satellite	Vegetation index	Order	a	b	c	R^2adj	*RMSE*	*AICc*	*ΔAICc*
Aqua	NDVI	1st	135.3	12.4	NA	0.795	11.6	461.2	15.0
		2nd	−293.9	327.1	−10.3	0.844	10.1	446.2	0
	EVI	1st	193.8	13.9	NA	0.803	11.4	459.0	10.3
		2nd	−554.1	430.2	−3.3	0.837	10.3	448.7	0
Terra	NDVI	1st	130.7	18.3	NA	0.711	12.8	409.3	7.9
		2nd	−258.1	295.9	−1.7	0.758	11.6	401.4	0
	EVI	1st	188.3	18.3	NA	0.739	12.2	404.1	2.1
		2nd	−367.6	343.9	6.3	0.755	11.7	402.0	0

$P < 0.0001$ for all regressions.

(MODIS QA = 0, or "Good data") were used to build regression models (NASA LP DAAC, 2016).

Vegetation cover estimated in the field varied from 4% to 100% (average 57%) on the 92 sampled blocks. The ground-level vegetation cover in July was strongly and positively correlated with Terra and Aqua MODIS EVI and NDVI sampled in the same month (> 71% of variance explained, Table 2). Top-ranked models were second-order polynomial regressions, which demonstrated better fit (ΔAICc > 2.0 units) to the data than did first-order regressions in all cases. Second-order polynomial regressions for the Aqua VI explained ~8% more variance in vegetation cover and had smaller RMSE than Terra for both NDVI and EVI in July. However, these same regressions with NDVI and EVI had < 1% difference in amount of variation in vegetation cover explained for both Aqua and Terra (see Table 2, Fig. 3).

Maps of the vegetation cover calculated using second-order polynomial regressions on the base of Aqua and Terra NDVI and EVI reflect similar rangeland conditions (Fig. 4).

In terms of predicting future ground vegetation conditions, strong positive correlations were evident between ground estimates in July 2013 and satellite NDVI and EVI monthly data for May and June 2013 (Table 3) with > 79% of variance explained for May-estimated VIs and >78% for June-estimated VIs. For May and June 2013, Terra performed slightly better than Aqua for both NDVI and EVI (1 — 3% more variance explained). EVI performed slightly better than NDVI for May and June for both Aqua and Terra (< 2% more variance explained). Notably, R^2 values for Terra in May were higher than for July 2013, the month when on-the-ground conditions were sampled (see Table 3).

Discussion

Our analysis demonstrated that 1-km resolution monthly Aqua and Terra MODIS NDVI and EVI for July 2013 reliably indexed the degree of vegetation cover in the grasslands of western Mongolia for the same month. Clearly, second-order polynomial regressions describe relationships between VIs and percentage of vegetation cover better than first-order models; however, second-order polynomial regressions should be used with caution for areas with dense vegetation cover (percentage of vegetation cover > 80%), especially for NDVI, because at such thresholds the predicted relationships seemed to saturate (see Fig. 3). Moreover, saturation effects are clearly evident in the maps of model-extrapolated vegetation cover (see Fig. 4): maximal percentage of vegetation cover does not exceed 80 — 87% even for areas with high and

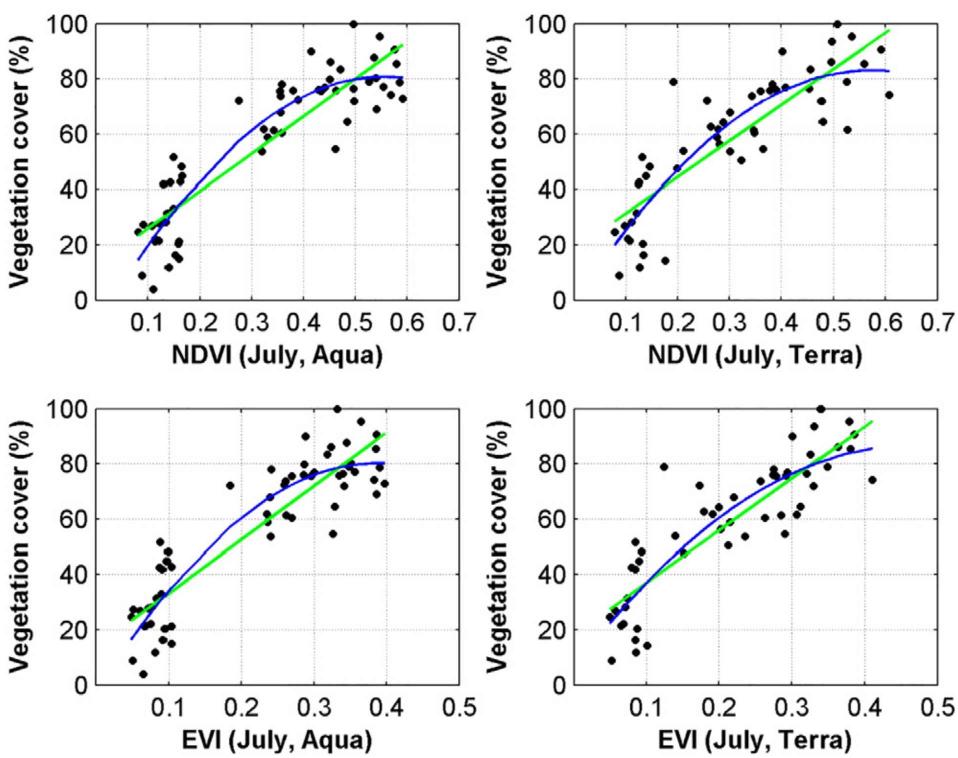

Figure 3. First- (in green) and second-order polynomial (in blue) regressions describing the relationship between July 2013 Aqua- and Terra-derived Moderate Resolution Imaging Spectroradiometer vegetation indices and percentage of vegetation cover at sampling sites with QA = 0 ($n = 59$ for Aqua and $n = 51$ for Terra) in western Mongolia.

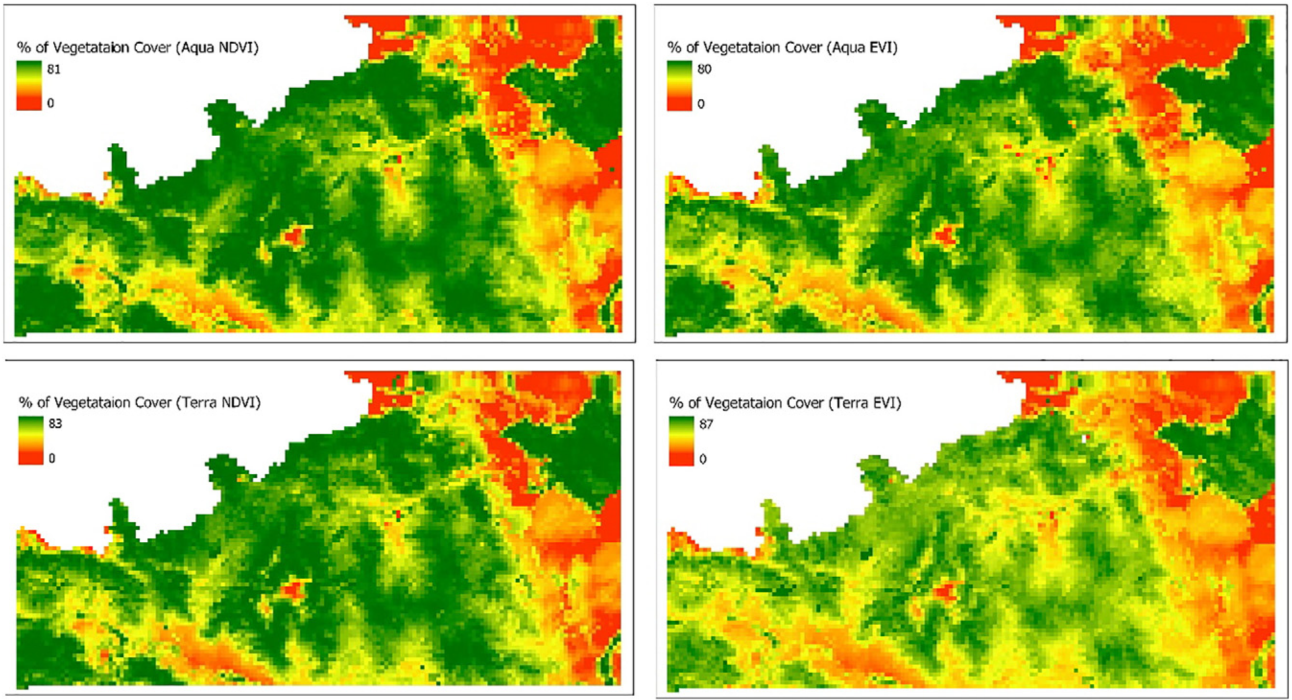

Figure 4. Maps of vegetation cover for Sailugem Range, western Mongolia, in July 2013, extrapolated from second-order polynomial regressions presented in Table 2.

dense vegetation (e.g., wetlands in the north-east corner of our study area). Furthermore, areas with very low vegetation cover (< 5%), such as deserts and rocks at high elevation, can generate negative projections when the 2nd polynomial order models are applied. Thus, these statistical models are most appropriate for typical short-grass Mongolian mountain and dry steppes with vegetation cover 10 − 80%.

Our results are consistent with the results of Purevdorj et al. (1998), who reported for other Mongolian grasslands that second-order polynomial regression outperformed first-order models in describing the relationship between percentage of vegetation cover and NDVI derived from simulated Advanced Very High Resolution Radiometer data. However, Li et al. (2010) reported that first-order models performed better than second-order models in reflecting relationships between percentage of vegetation cover and VIs (NDVI and EVI) derived from MODIS VI 16-d, 250-m resolution datasets in the grasslands of Northern Hebei Province in China. Similarly, Cui et al. (2012) demonstrated that a first-order model described variance of percentage of vegetation cover based on the EVI derived from MODIS Terra/Aqua Surface Reflectance Daily L2G Global 500-m and 1-km SIN Grid datasets better than a power regression. Despite contrasting study outcomes, these studies and our study indicate that monthly MODIS-derived VIs provide useful inference about actual ground conditions in the region studied.

Aqua MODIS EVI and NDVI for July outperformed Terra's VIs to describe vegetation cover in the same month, yet this difference was not statistically significant. Similarly, a study by Yang et al. (2006) reported comparable performance of Terra and Aqua 8-d reflectance and Leaf Area Index (LAI) products over large areas but revealed noticeable differences at smaller scales (a few kilometres) due possibly to atmospheric effects (Yang et al., 2006). Wang et al. (2007) found that NDVI values derived from Terra MODIS and Aqua MODIS 250-m resolution, 16-d datasets covering the northwestern part of China are similar for different vegetation types. Wang et al. (2012) found higher uncertainty in estimation of vegetation using Terra MODIS NDVI time series for forest and tundra ecosystems in North America and explained this fact by Terra MODIS calibration degradation. Djavidnia et al. (2010) also reported inconsistent estimations of ocean chlorophyll-a concentrations from Terra and Aqua MODIS sensors.

Table 3
Coefficient of determinations (R^2) for second-order polynomial regressions describing the relationship among May, June, and July 2013 Aqua- and Terra-derived MODIS vegetation indices and percentage of vegetation cover on 1 × 1 km blocks with QA = 0 (see Table 1) sampled in Sailugem Range, western Mongolia, July − August 2013.

Satellite	Vegetation index	R^2_{May}	R^2_{June}	R^2_{July}
Aqua	NDVI	0.798	0.783	0.850
	EVI	0.813	0.803	0.843
Terra	NDVI	0.826	0.807	0.768
	EVI	0.840	0.810	0.765

$P < 0.0001$ for all regressions.
NDVI, Normalized Difference Vegetation Index; EVI, Enhanced Vegetation Index.

In our study the slight difference between performance of Aqua and Terra may be explained by several factors. First, Aqua and Terra monthly 1-km resolution data are calculated using MODIS 16-d, 1-km resolution datasets that overlap the month (Didan and Huete, 2006). Thus, for Aqua MODIS monthly July 2013 datasets, three 16-d tiles covering the period from June 18 to August 4 were used. For producing the July 2013 Terra MODIS dataset, the 16-d tiles covered the period 26 June–12 August. Different atmospheric conditions in these days could affect the monthly datasets produced from Aqua and Terra data. Second, Aqua and Terra satellites have a 3-h difference in equatorial crossing time and reflect different atmospheric conditions over the same area that can affect all levels of the datasets, including monthly data (NASA, 2016). Third, Aqua has an ascending orbit, whereas Terra has a descending orbit (NASA, 2016) such that MODIS data are resampled differently using Aqua versus Terra datasets for the same area. For these reasons, Aqua and Terra VI monthly data yield slightly different indices of ground conditions depending on season and their performance may therefore vary for any particular application.

We did not detect any meaningful biological difference in the performance of July NDVI and July EVI for Aqua or Terra in reflecting ground-estimated vegetation cover in our study area. Multiple publications demonstrate that MODIS NDVI and EVI exhibit variable performance for different regions and grassland areas. Huete et al. (2002) reported that MODIS-derived NDVI generated a higher range of values over semi-arid sites but a lower range over the humid forested sites in the south-eastern United States and Brazil. However, both NDVI and EVI had a similar range in values for the intermediate mesic grasslands (Huete et al., 2002). A related study in Northern Hebei Province, China, reported that MODIS-NDVI was more often correlated with on-the-ground measurements of vegetation cover in grassland, shrub, and forest areas than MODIS-EVI (Li et al., 2010). Classification of grasslands of Inner Mongolia (China) based on MODIS-EVI data provided better results than classification based on MODIS-NDVI dataset (Zhao and Ma, 2007).

Our studies contrasted with the wider literature, suggesting the importance of exploring the performance of MODIS NDVI and EVI and assessing the suitability for a particular area. Tan et al. (2008) showed that MODIS NDVI is more sensitive to small variations in vegetation and performs better in sparse vegetation areas than MODIS EVI over the North America continent. Classification of general vegetation domains (herbaceous, woody, and forested) in Brazilian savannah using MODIS NDVI and EVI datasets showed better performance of NDVI (75% of data correctly classified) over EVI (71% of data correctly classified), although EVI better performed for separation of grassland and shrub biomes (Ferreira et al., 2004). MODIS-EVI demonstrated the strongest correlation with field samples of dry biomass and vegetation cover among other 17 VIs (including NDVI) in grasslands of the Qinghai–Tibet Plateau, China (Cui et al., 2012). A study of different vegetation types in Northwest China demonstrated similar correlations of MODIS NDVI and EVI values with data collected using a spectrometer in the field for arid and semiarid areas, while in relatively high grass meadows NDVI saturated and EVI performed better (Guo et al., 2007). Our conclusions about ecologically insignificant differences in performance of NDVI versus EVI for reflecting percentage of vegetation cover in mountain grasslands of western Mongolia are consistent with results of some studies in similar environmental conditions that report similarity of the indexes (e.g., Huete et al., 2002; Guo et al., 2007).

High correlations between percentage of vegetation cover in July 2013 and MODIS VIs in May and June 2013 imply that on-the-ground conditions of grasslands in the Sailugem range in July probably can be predicted from VIs measured 1 − 2 mo earlier. July to early August is the peak of the short growing season in western Mongolia when NDVI and EVI have maximal values reflecting the highest vegetation growth, percentage of vegetation cover, and biomass (Chu and Guo, 2012; Cui et al., 2012; Nakano et al., 2013). Our study revealed that MODIS NDVI and EVI datasets for May and June could be reliably used to make projections of maximal annual vegetation cover on the mountain pastures, at least during 2013 when our fieldwork was conducted. May-based projections of the vegetation cover and biomass might be of higher importance because they allow predictions of summer pasture quality before Mongolian herders with their livestock depart for grazing areas (herders arrive at summer pastures in the Sailugem region at the middle of June and stay there until the middle of August). Forecasting rangeland conditions reliably ahead at least 1 mo can help avoid livestock concentration in areas with unfavorable pasture conditions.

Implications

We conclude that monthly Aqua and Terra NDVI and EVI datasets that are readily available and do not require complex processing can be useful for rangeland managers and decision makers of western Mongolia as a tool for monitoring and predicting of summer pasture conditions (on the basis of percentage of vegetation cover) at the regional level. Given our findings, preference in this case should be given to Aqua Vis, which performed slightly better than Terra VIs to reflect vegetation cover in our study area in July, and second-order polynomial models. Although vegetation cover is only one of many parameters that can be monitored and used for grassland management in western Mongolia, vegetation cover is the most frequently used indicator in remote sensing to measure grassland production and level of pasture degradation (Liu et al., 2004; Li et al., 2010; Cui et al., 2012) because it strongly reflects the ecological value of grasslands, especially in the highland and arid landscapes (Guo et al., 2006; Cui et al., 2012; Yan and Lu, 2015). Also, as was demonstrated by the research of Fernandez-Gimenez and Allen-Diaz (1999), vegetation cover was the only parameter that demonstrated the most reliable response to grazing and precipitation across mountain steppe, steppe, and desert-steppe in Central Mongolia. At the same time, vegetation cover has a strong positive correlation with the aboveground biomass in rangelands ($R^2 = 0.60 - 0.96$) (Li et al., 2006; Al-Bakri and Abu-Zanat, 2007; Eckert and Engesser, 2013; Yan and Lu, 2015). Furthermore, as was reported by Fernandez-Gimenez (1997 and 2000), Mongolian herders generally rely on vegetation cover in their traditional assessment of pasture quality; therefore, this indicator can be better understood and accepted by local communities than other grassland parameters. Our studies suggest that decision makers in western Mongolia responsible for environmental monitoring and grassland management could benefit from incorporating simple vegetation cover analysis based on MODIS VIs in their decision-making process that will be consistent with traditional herders' knowledge and practices. More specifically, our preliminary findings indicate that MODIS VIs can enable broad-scale and rapid monitoring of summer pasture conditions at the regional level and also potentially be converted to practical and understandable advice for herders on best locations of summer camps with sufficient advance notice (at least 1 mo) to influence herder decision making each year. Currently community-based pasture management and community ownership of large sets of seasonal pastures (khoshuun), as well as strengthening of community-based rangeland management organizations with allocation of full management rights to them, may be a feasible option to sustainable pasture management in Mongolia where private property on pastureland is unconstitutional (Fernandez-Gimenez et al., 2008; Naidansuren and Bayasgalan, 2012; Bruegger et al., 2014). In this case a simple rangeland monitoring tool with the ability to monitor and predict conditions of summer pastures using traditional herder indicators (e.g., vegetation cover) could be quite valuable for decision making by rangeland management organizations on pasture use. Further research would be useful to understand the stability of the patterns we observed in 2013 over different years and MODIS VI data of different resolution (250 and 500 m) and especially to corroborate our conclusion that NDVI and EVI estimates for May and June can predict percentage of vegetation cover in the peak of growing season in other years and in other regions. Together, such inquiry would support more fully participatory decision making for sustainable management of grazing areas in western Mongolia, where the ramifications for biodiversity conservation and sustainability of herder livelihoods are so significant.

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