NDVI Changes Over a Calendar Year in the Rangelands of Southeast Idaho

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ABSTRACT

Annual vegetation trends for the 2007 calendar year were analyzed across rangelands of southeast Idaho using MODIS 16-day composite NDVI. These data characterize rangeland phenology by providing maximum NDVI throughout each compositing period. Results illustrate NDVI values in semiarid rangelands of Idaho exhibit a bimodal curve and suggest maximum productivity occurs early in spring followed by a secondary period of heightened productivity in autumn. While these periods of photosynthetic activity are not analogous with above ground biomass or standing crop, these observations represent important considerations for improved understanding of rangeland dynamics and plant phenology, relative to ecosystem productivity.

KEYWORDS: Rangeland, remote sensing, NDVI, MODIS, digital change detection, vegetation index

INTRODUCTION

NASA's Earth Observing System (EOS) is a coordinated series of polar-orbiting low inclination satellites designed to support long-term global observations. Measurements collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments of EOS are used to calculate Normalized Difference Vegetation Indices (NDVI) which are the basis of this study exploring the phenological cycle of semiarid sagebrush-steppe vegetation communities in southeast Idaho.

The Terra satellite, also known as EOS-AM-1, has a morning equator crossing time (Hobish, 2009) and is considered the flagship of the EOS platforms. Terra provides global data on the state of the atmosphere, land and oceans (Netting, 2008) and includes five state-of-the-art instruments: an Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), a Multi-angle Imaging Spectro-Radiometer (MISR), a Clouds and the Earth's Radiant Energy System (CERES) monitor, a Measurements of Pollution in the Troposphere (MOPIT) sensor, and MODIS. On February 24, 2000, Terra began collecting a planned 15-year global data set. The Terra satellite orbits the earth at an altitude of 705 km and is sun-synchronous, so that it crosses any given latitude directly overhead at the same time each day.

The MODIS instrument employs a whiskbroom imaging-radiometer that consists of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located in four focal planes (Jensen 2005). These instruments provide daylight reflection and day/night emission spectral imaging for any point on the Earth at least every two days, under continuous operation (Graham, 2008). The MODIS sensor is a 36-band spectroradiometer that measures visible and infrared radiation from 0.4 to 14.5 µm, and was selected for diagnostic significance in Earth science. The individual spectral bands have spatial resolutions of 250 m, 500 m, or 1000 m at nadir. The measurements made by the MODIS sensor yield data used to develop products ranging from vegetation indices and productivity estimates, land surface cover, ocean chlorophyll fluorescence, as well as cloud and aerosol properties, fire occurrence, terrestrial snow cover, and sea ice cover (Running *et al.*, 1994).

There are 62 different MODIS products with full descriptions available on the Internet (EOS Data Products Handbook, Volume 1 [King, *et. al*, 2004]). The MODIS product used in this study was MOD13Q1 (250m vegetation indices with 16-day temporal granularity). The MOD13Q1 product is a composite of data from the Terra satellite and includes Normalized Difference Vegetation Index (NDVI) imagery as well as Enhanced Vegetation Index (EVI) imagery. Atmospherically corrected bi-directional surface reflectance with masking for water, clouds, heavy aerosols, and cloud shadows form the basis for these products. The vegetation index products represent a 16-day composite at 250-meter spatial resolution in a Sinusoidal projection. This particular composite allows the algorithm to include only values that are acquired during cloud free days and/or days when the data is considered more reliable due to the absence of water, clouds, and heavy aerosols in the atmosphere.

The Normalized Difference Vegetation Index (NDVI)

NDVI is an environmental model based on deductive logic and empirical data and is the result of the relationship between the amount of near-infrared (ρ_{nir}) and red (ρ_{red}) spectral reflectance of land cover (Skidmore, 2002). Both near-infrared (ρ_{nir}) and red (ρ_{red}) spectral reflectance are measured at the sensor and are therefore considered empirically derived field measurements. However, because reflected energy travels through a large amount of atmosphere before it is measured by the sensor, numerous attenuation factors affect the signal measured at the sensor. While atmospheric correction algorithms can be used to eliminate these factors, none are perfect as several input variables required to complete the calculations are estimates or constants (e.g., optical thickness) while other factors are variable across a scene (i.e., viewing angle changes slightly from scene center to its edges). Nonetheless, NDVI is a valuable product that has been used to monitor seasonal and inter-annual changes in vegetation growth and activity (Jensen, 2005).

Bands 1 and 2 of the MODIS sensor collect measurements of surface reflectance in the visible red (620 – 670 nm) and near infrared (841-876 nm) regions of the electromagnetic spectrum (EMS). These bands are then used in a simple band ratio to estimate NDVI (Equation 1)

$$NDVI = (\rho_{nir} - \rho_{red}) / (\rho_{nir} + \rho_{red}) \qquad (1)$$

The chlorophyll of green leaves absorb most of the visible light within the red portion of the EMS for use in active photosynthesis, while the cell structure of leaves reflects light in the near-infrared portion of the EMS (Figure 1). A plant that is actively photosynthesizing will absorb most of the visible light available, resulting in ρ_{red} being very small and NDVI values being very close to one (1). In contrast, senescent vegetation will absorb much less visible light resulting in smaller NDVI values (close to zero). Water typically has an NDVI value less than 0, bare soils between 0 and 0.1 and vegetation >0.1 (Table 1).

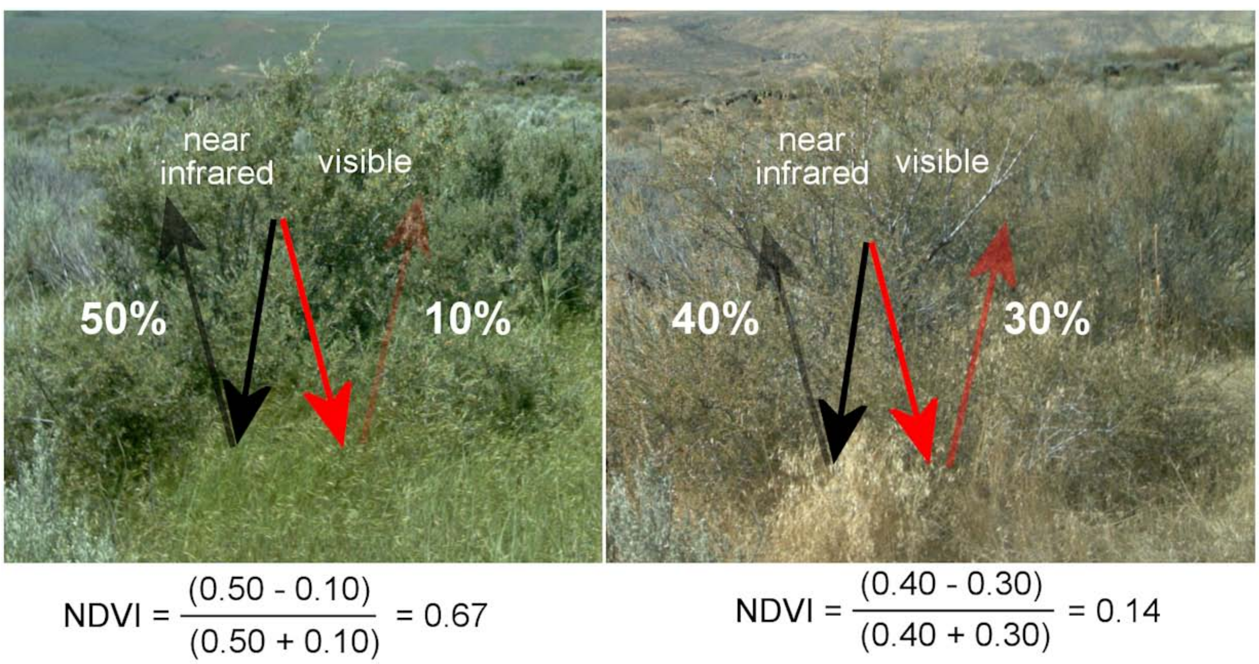

Figure 1. Photograph illustrating how the ratio of reflectance can change within a growing season. Photo on the left was taken in late-May while the photo on the right was taken in September (illustration by Keith T. Weber, modeled after Weier and Herring, 2008).

Table 1. Typical NDVI values for various cover types (from Holben [1986])

COVER TYPE	RED	NIR	NDVI
Dense vegetation	0.100	0.500	0.700
Dry Bare soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

The NDVI equation (Equation 1) results in a dimensionless value (index) that indicates the abundance and relative level of photosynthetic activity of green vegetation. Environmental conditions such as soil color, atmospheric conditions, litter abundance, etc., effect reflectance values in both the red and near-infrared regions of the EMS and thereby effect NDVI. The theory behind ratioing the components in the NDVI equation was that these noise factors (atmospheric conditions, etc.) would be compensated for; however, some still affect vegetation index values (e.g., litter) making these data difficult to apply directly. However, the calibrated hyperspectral sensor system of MODIS and the algorithms used to generate its various products further reduce the effects of the environmental factors and thereby increase the reliability of MODIS products. The MODIS product used in this study (MOD13Q1) includes the two vegetation indices (NDVI and EVI) as well as the source data (red and near-infrared reflectance) used to compute the respective indices (Table 2). In addition MOD13Q1 includes a layer indicating a reliability rating for each pixel throughout the 16-day compositing period (Table 3).

Table 1. Science Data Sets for MODIS Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V005 (MOD13Q1)

Science Data Sets (HDF Layers) (12)	UNITS	BIT TYPE	FILL	VALID RANGE	MULTIPLY BY SCALE FACTOR
250m 16 days NDVI	NDVI	16-bit signed integer	-3000	-2000, 10000	0.0001
250m 16 days EVI	EVI	16-bit signed integer	-3000	-2000, 10000	0.0001
250m 16 days VI Quality detailed QA	Bits	16-bit unsigned integer	65535	0, 65534	NA
250m 16 days red reflectance (Band1)	Reflectance	16-bit signed integer	-1000	0, 10000	0.0001
250m 16 days NIR reflectance (Band2)	Reflectance	16-bit signed integer	-1000	0, 10000	0.0001
250m 16 days blue reflectance (Band3)	Reflectance	16-bit signed integer	-1000	0, 10000	0.0001
250m 16 days MIR	Reflectance	16-bit signed	-1000	0, 10000	0.0001

reflectance (Band7)		integer			
250m 16 days view zenith angle	Degree	16-bit signed integer	-10000	-9000, 9000	0.01
250m 16 days sun zenith angle	Degree	16-bit signed integer	-10000	-9000, 9000	0.01
250m 16 days rel. azimuth angle	Degree	16-bit signed integer	-4000	-3600, 3600	0.1
250m 16 days composite day of the year	Julian day of the year	16-bit signed integer	-1	1, 366	NA
250m 16 days pixel reliability summary QA	Rank	8-bit signed integer	-1	0, 3	NA

Table 2.MOD13Q1 pixel reliability codes and descriptions

Rank Key	Summary QA	Description
-1	Fill/No Data	Not Processed
0	Good Data	Use with confidence
1	Marginal Data	Useful, but look at other QA information
2	Snow/Ice	Target covered with snow/ice
3	Cloudy	Target no visible, covered with cloud

This study used MOD13Q1 imagery data collected throughout 2007 to investigate the intra-annual NDVI curve for the Big Desert study area in southeast Idaho. The investigation sought to determine the type of trendline exhibited over semiarid sagebrush-steppe rangelands to better understand seasonal changes in vegetation and the phenological cycle of the shrubs, grasses, and forbs found in the region.

METHODS

Study Area

The Big Desert study area is approximately 71 km northwest of Pocatello with the center of the study area located at approximately 113º 4’ 18.68” W and 43º 14’ 27.88” N. The Big Desert study area extends over nearly 120,000 hectares (Figure 2) and exhibits a topography that is flat to gently rolling hills with frequent lava outcrops. Dominant shrubs include Wyoming big sagebrush (*Artemisia tridentate wyomingensis*), three-tip sagebrush (*A. tripartite*), and Green Rabbitbrush (*Chrysothammus viscidiflorus*). The understory is mainly bluebunch wheatgrass (*Agropyron spicatum*) with Sandberg bluegrass (*Poa sandbergii*) and bottlebrush squirreltail (*Sitanion hystrix*). Cheatgrass (*Bromus tectorum*) is the most common non-native invasive species. In addition, some portions of the Big Desert study area have been seeded with crested wheatgrass (*Agronpyron cristatum*) (Wakkinen *et al*., 1992) (Sander and Weber, 2005) as a result of wildfires. Livestock (primarily sheep) graze much of the study area and in August 2006, the Crystal Fire burned nearly 90,000 ha (Osmond *et al*., 2006) of the Big Desert.

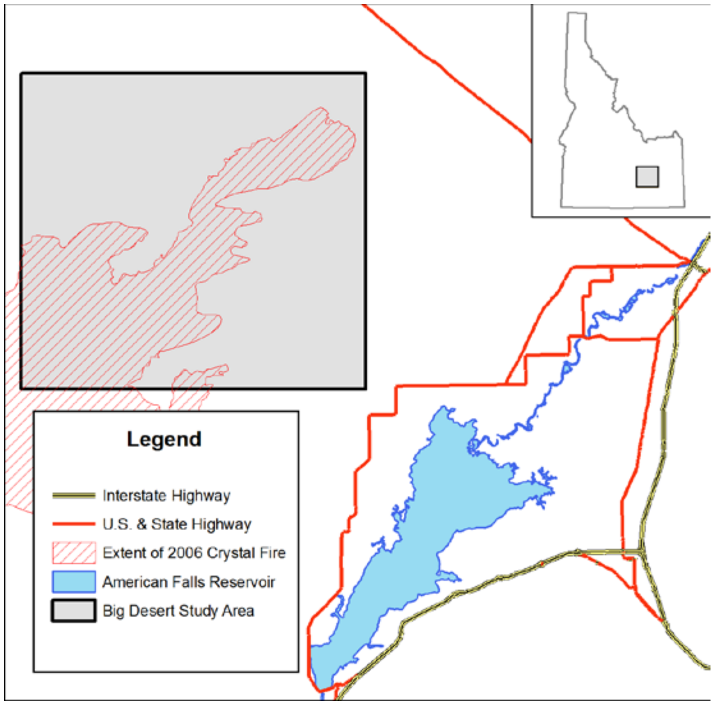

Figure 2. Location of the Big Desert study area in southeast Idaho.

Sample Design

The sample points (*n* = 119) used to extract NDVI values from the MODIS NDVI product were a subset of field sample locations used in previous studies between 2006 and 2008 (Tedrow *et al*., 2008; Anderson *et al*., 2007; Underwood *et al*., 2006). In each of these previous studies, vegetation data were collected at approximately 100 randomly located sample points. Many of these sampling points were linked to a set of four photographs taken at the sample site looking north, south, east, and west. The subset of sample points used in this study were outside the perimeter of the 2006 Crystal Fire and were a minimum of 350 meters from all other sample points to avoid the possibility of two sample points being located in the same 250-m pixel and to reduce any spatial autocorrelation effects. In cases where two points were located within the same pixel, the sample point containing more current and complete field data was selected for use in this study. The final set of samples (*n* = 119) included 69 with field photographs taken at the time of data collection (Figure 3).

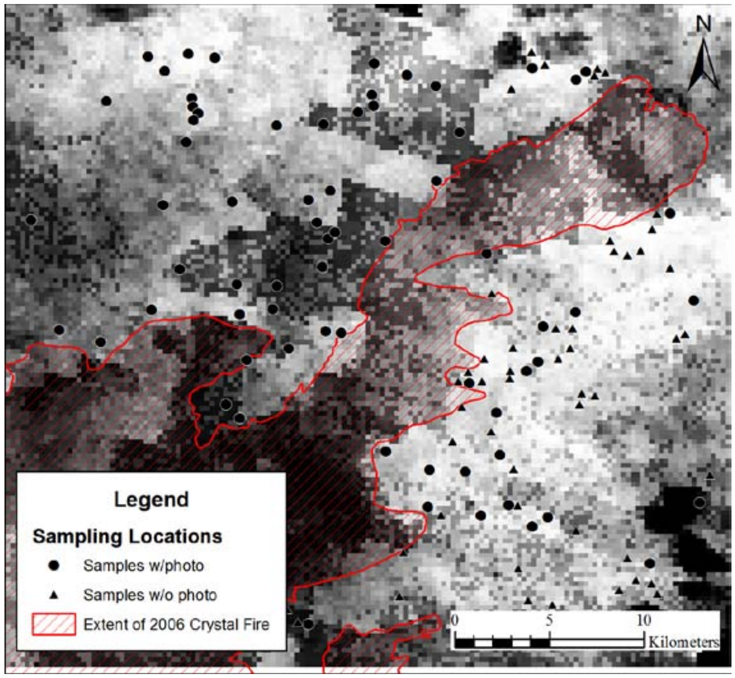

Figure 3. Locations within the Big Desert study area used to extract NDVI values from MODIS imagery (cf. Figure 2).

Image Data

The MOD13Q1 data for the 2007 calendar year included 23 data files obtained via the Internet (ftp://e4ftl01u.ecs.nasa.gov/MOLA/MYD13Q1.005). The file naming system employed at this site followed convention that provided much useful information and facilitated the discovery and selection of imagery (e.g., file names [MOD13Q1.A2007145.h09v04.005.2007181101531.hdf] can be interpreted using Table 4).

Table 4 File naming Convention used for MODIS files obtained from NASA

Name Part	Description
MOD13Q1	Product Short Name – MODIS Sensor from Terra Satellite
A2007145	Julian Date of Acquisition (A-YYYYDDD)
H09v04	Tile Identifier (horizontal XX vertical YY) from the Sinusoidal Tiling System (Figure 4). The longitudinal minimum is -140.0151 and the longitudinal maximum is -104.4217. The latitudinal minimum is 40.00 and the latitudinal maximum is 50.00.
005	Collection Version
2007181101531	Julian date of Production (YYYYDDDHHMMSS) Y = 2007, D = 181, H = 10, M = 15, S = 31
Hdf	Data format

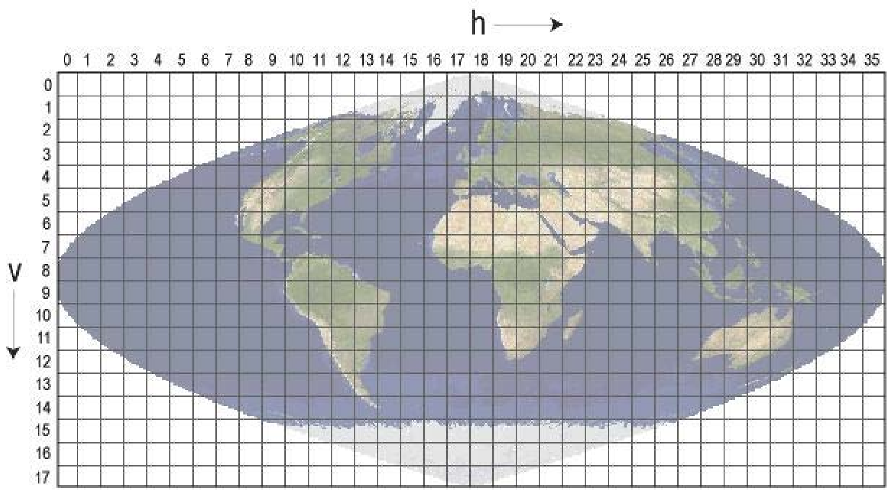

Figure 4. MODIS Sinusoidal Tiling System (from http://modis-land.gsfc.nasa.gov/MODLAND_grid.htm).

GIS Processing

The first of the 12 layers in each HDF dataset contained NDVI imagery. These data were projected into Idaho Transverse Mercator (NAD83) and then clipped to the Big Desert study area using ESRI ArcGIS. The ESRI Spatial Analyst Tool (Sample) was used to create a spreadsheet of the NDVI values extracted at each of the 119 sample points throughout the 2007 calendar year. These data were then summarized, graphed, and analyzed to illustrate and interpret the minimum, maximum, and mean NDVI for each 16-day compositing period across the 2007 calendar year.

RESULTS AND DISCUSSION

The annual NDVI curve for the semiarid sagebrush-steppe vegetation communities of Big Desert study area (Figure 5) shows an initial increase in vegetation productivity in early March with maximum NDVI values achieved in early June.

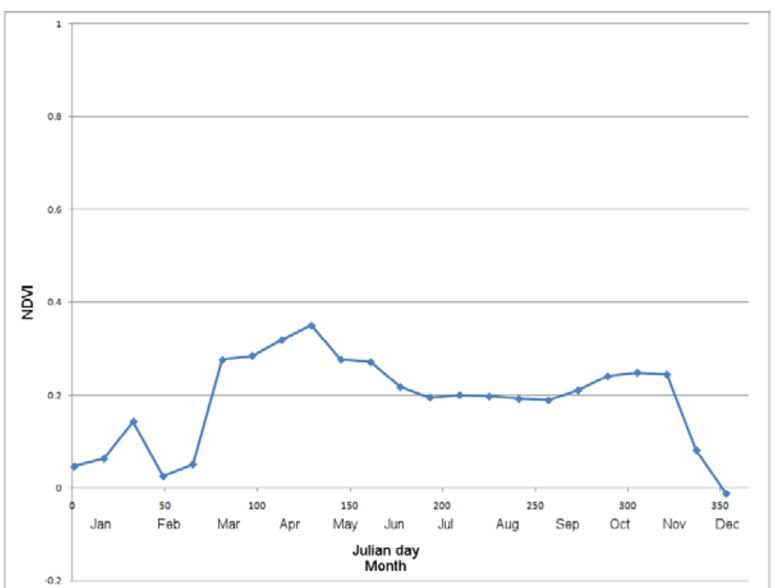

Figure 5. Extracted mean NDVI values for the Big Desert study area throughout the 2007 calendar year.

To visualize difference between vegetation dynamics in semiarid ecosystems relative to other ecosystems, data for the Big Desert were plotted with data for the Albermarle Pamlico Estuarine System (APES), a drainage area in North Carolina and Virginia (Figure 6). The APES plot is also based on similar MODIS 250 m NDVI composites (Knight *et al.*, 2006).

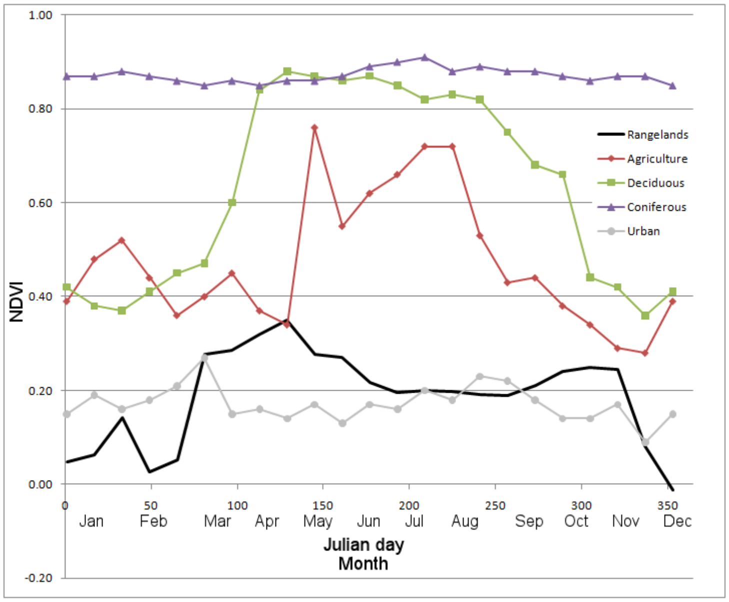

Figure 6. Intra-annual NDVI curves comparing the Big Desert study area (a semiarid sagebrush-steppe rangeland ecosystem) with other land cover types.

The intra-annual NDVI trends illustrated in figure 6 show curves with characteristics distinctive of each land cover type. Coniferous forests show little variation in NDVI values throughout the calendar year which is the result of the "evergreen" nature of these forests. Urban areas exhibit NDVI values between 0.1 and 0.3 with a peak in March. Deciduous and agricultural land cover types exhibit intra-annual NDVI variation resembling a bell-shaped curve. NDVI values for these land cover types exhibit early spring green-up which remain green and retain relatively high NDVI values even late in the calendar year.

Semiarid rangeland vegetation exhibits a unique intra-annual NDVI curve that is consistently lower than that seen in more mesic vegetation communities. In addition, the NDVI curve for the rangeland vegetation described in this study exhibited a singular bimodal distribution (cf. mean NDVI curve, figure 5). This trend accurately captures the vegetation dynamics of rangelands which may be responding to periods of high ambient temperature, low soil moisture, and low humidity levels, resulting in periods of non-optimal photosynthesis due to a potentially negative evapotranspiration balance (Potter 1993; Ivits et al., 2009).

Another of the EOS satellites is AQUA. Like Terra, AQUA also contains a MODIS sensor and collects data similar to Terra. However, AQUA has an afternoon equatorial overpass time with an alias of EOS-PM. Among the MODIS/Aqua vegetation index products is a similar 250-meter 16-day composite. Together, these two products, MOD13Q1 and MYD13Q1 (TERRA and AQUA, respectively) have a phased production cycle. The Terra 16-day period starts on Julian Day 1 while the Aqua 16-day period starts 8 days later on day 9. The use of both products would result in doubling the number of composite observations (n = 46) and may provide a more detailed insight into intra-annual vegetation dynamics and the phenological cycles of semiarid rangelands.

CONCLUSIONS

Many rangeland studies in semiarid ecosystems have used satellite imagery acquired during the months of June and July (Weber and McMahan, 2003; Anderson, J. *et al.*, 2007; Tedrow, L. *et al.* 2008; Underwood, J. *et al.* 2006) as this time period is widely considered representative of peak biomass production. However, intra-annual NDVI values and the annual NDVI curve presented in this paper indicate that imagery acquired in earlier months (April and May) or still later in the growing season (September) may result in a more accurate estimation of productivity in semiarid ecosystems. Peak biomass production, however, is not necessarily the same as peak photosynthetic activity and the relationship between these two metrics requires further study and understanding. This is especially important to sound land management and land stewardship to better ensure the sustainability of semiarid rangeland ecosystems.

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