Application of Composite-NDVI in Semiarid Rangelands

Keith T. Weber, GISP. GIS Director, Idaho State University GIS Training and Research Center, 921 S. 8th Ave, stop 8104. Pocatello, Idaho 8320-8104. webekeit@isu.edu

Fang Chen. Idaho State University GIS Training and Research Center, 921 S. 8th Ave, stop 8104. Pocatello, Idaho 8320-8104

Bhushan Gokhale. Idaho State University GIS Training and Research Center, 921 S. 8th Ave, stop 8104. Pocatello, Idaho 8320-8104

C. Guillermo Bueno. Consejo Superior de Investigaciones Científicas, Instituto Pirenaico de Ecología, Avenida Regimiento Galicia S/N P.O. BOX 64, Jaca, 22700 (Spain).

Concepcion L. Alados. Pyrenean Institute of Ecology (CSIC). Avda. Montañana 1005. P. O. Box 13034. Zaragoza, 50192 (Spain).

ABSTRACT

Ecosystem productivity is an important yet difficult metric to accurately measure. Satellite remote sensing has been used to arrive at broad-scale estimates of productivity but no single algorithm has been developed which is well suited across all ecosystems and biomes. Vegetation indices were some of the earliest estimates of productivity with the normalized difference vegetation index being the most commonly applied. Semiarid rangelands account for approximately 40% of the earth's terrestrial surface and typically exhibit spatially heterogeneous and seasonally dynamic land cover. For these reasons a single measure of productivity will nearly always underestimate the total annual productivity of rangeland sites. To address this potential problem, the composite NDVI (cNDVI) was developed which describes peak photosynthetic activity over a selected time series. In this study, cNDVI was used to compare two biophysically similar semiarid rangelands (the O'Neal Ecological Reserve in Idaho, USA and the Monegros study area in Aragon, Spain) under different grazing regimes (total rest, semi-extensive rest-rotation and continuous grazing, and intensive holistic planned grazing) to 1) equitably compare season-long productivity estimates and 2) better understand the spectral signature of the human decision-making process. Results reveal no difference in season-long cNDVI across all study areas and treatment types save for the holistic planned grazing treatment which exhibited higher cNDVI values ($P < 0.001$). This suggests there is little ecological difference between traditional semi-extensive grazing regimes but substantial, and apparently positive, effects resulting from holistic planned grazing.

KEYWORDS: season-long NDVI, growing season, holistic planned grazing, GIS, remote sensing, Idaho, Spain

INTRODUCTION

Rangeland ecosystems cover approximately 40% of the earth's terrestrial surface (Huntsinger and Hopkinson 1996, Branson et al. 1981) and are typically dominated by grass and shrub communities. These vegetation communities exist because of the semiarid or xeric nature of these sites. However, an effective hydrologic cycle (the capture, storage, and release of water) leads to healthy rangeland sites that produce green biomass (at least ephemerally) with minimal bare ground exposure. When the hydrologic cycle is disturbed, rangelands desertify and as a result, exhibit increasing amounts of bare ground exposure. Chronic desertification shifts lead to a loss of ecosystem functionality and a reduction in biodiversity (Daubenmire 1959, Schlesinger et al. 1990) with associated social and economic underpinnings (Savory 1999, Arnalds and Archer 2000, Griffin et al. 2001).

Ecosystem productivity is a related and important metric to evaluate and monitor, especially when desertification and the potential effects of global climate change are concerned (Tian et al 2000; Weber et al 2009). Measures of productivity are less direct however, than measures of bare ground exposure as the latter exists along a horizontal plane and –for the most part—can be measured and expressed as a unit of area or percent exposure. Unlike bare ground exposure, the definition of ecosystem productivity tends to be vague and open to interpretation. Further, measures of productivity tend to be more difficult to quantify with numerous methods available including above ground biomass (Chambers and Brown 1983), percent cover (Canfield 1941; Daubenmire and Daubenmire 1968), and canopy coverage (Gysel and Lyon 1980) to name but three. In most ecosystems, productivity measures are confounded by the fact that herbivores consume vegetation (the product of ecosystem productivity) while one is trying to measure productivity. Productivity estimates are typically made over large landscapes and for this reason, satellite remote sensing has been used to arrive at broad-scale estimates of ecosystem productivity. Similar to field based measures; remote sensing estimates are varied with no single algorithm being considered universally applicable. Some of the earliest and most common productivity algorithms are simple band ratios (SBR) which express an index of photosynthetically active vegetation. These vegetation indices (VI's) are varied also, but typically leverage a ratio of reflectance in the red band of a sensor to that of the near infra-red band of the sensor. Perhaps the best known and most widely applied VI is the normalized difference vegetation index (NDVI) (Rouse et al. 1973; Tucker 1979).

More recently, advanced algorithms have been developed in an attempt to systematically estimate ecosystem productivity. For instance, the Moderate Resolution Imaging Spectroradiometer (MODIS) provides an array of products that estimate vegetative productivity. The MODIS algorithms use photosynthetically active radiation (PAR) and its relationship with net primary productivity (NPP) to develop a variety of products. As some PAR is absorbed by the vegetation it is known as absorbed photosynthetically active radiation (APAR). APAR is a function of the spatial and seasonal variability of photoperiod, potential incident radiation, and the amount and geometry of displayed leaf material. It is similar to green leaf area index (LAI) but accommodates the fraction of absorbed photosynthetically active radiation (FPAR) which helps define the relationship of APAR and PAR as $APAR = PAR * FPAR$.

Gross Primary Productivity (GPP) describes the total light energy that has been converted to plant biomass. As some energy is lost during plant respiration, this fraction can be derived from GPP by subtracting leaf maintenance respiration and fine root mass maintenance respiration from GPP (Running et al 1999) to arrive at net photosynthesis (PsnNet). The fraction of photosynthetically active radiation (FPAR) is the least processed productivity estimate and is positively related to NDVI (Sellers 1992; Walko and Tremback 2005). NDVI can be considered a basic ecosystem productivity estimate from which other estimates can be calculated. For this reason, NDVI was chosen for use in this study. However, rangeland ecosystems exhibit strong seasonal dynamics and the use of a single NDVI may result in an incorrect assessment of ecosystem productivity. For this reason, a composite NDVI (cNDVI) can be used to better capture seasonal variability and the flush of grasses and forbs throughout an entire growing season.

This study uses cNDVI to enable basic ecosystem productivity comparisons between two biophysically similar study sites, the O'Neal Ecological Reserve in southeastern Idaho, USA, and the Monegros Study area in northern Spain. The goal of this comparison was to provide a better understanding of 1) ecosystem dynamics in semiarid rangelands and 2) cNDVI as an ecosystem productivity estimator relative to single-date NDVI.

MATERIALS AND METHODS

Study Area

The O'Neal Ecological Reserve, USA

The O'Neal Ecological Reserve is an area of sagebrush-steppe rangelands in southeastern Idaho approximately 30 km southeast of Pocatello, Idaho (42° 42' 25''N 112° 13' 0'' W), where many local-scale rangeland studies are being conducted (Figure 1). The O'Neal is relatively flat with an elevation of approximately 1400 m. This 50 ha site is composed of typical sagebrush steppe upland areas located on lava benches and receives < 0.38 m of precipitation annually (primarily in the winter). The dominant plant species include big sagebrush (*Artemisia tridentata*) with various native and non-native grasses and forbs, including Indian rice grass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*).

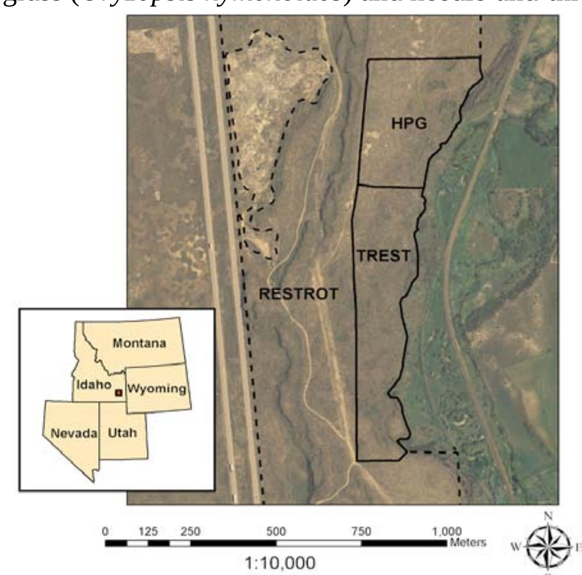

Figure 1. Location and general characteristics of the O'Neal Ecological Reserve in southeastern, Idaho.

The study area was divided into three treatment pastures (Table 1). The first was a simulated holistic planned grazing pasture where cattle graze at high density (66 Animal Units [AU]/ 11 ha) for a short period of time (6 days) during the first week of June each year (2006-2008) (cf. intensive grazing). The second treatment was a rest-rotation pasture where cattle graze at low density (300 AU/ 1467 ha) for long periods of time (30 days) during the late spring (May) of each year. This treatment is a type of extensive or semi-extensive grazing. The third treatment was a total rest pasture (13 ha) where no livestock grazing has occurred since June 2005.

Table 1. Stocking information and grazing details for the treatment pastures used in this study.

Treatment	Animal Days/ha
Holistic planned grazing (O'Neal)	36
Semi-extensive rest-rotation grazing (O'Neal)	6
Semi-extensive continuous grazing (Monegros)	11
Total rest (O'Neal)	0

The Monegros Study Area, Spain

The Monegros is a semiarid steppe region of the middle Ebro valley, Aragon, Spain (Figure 2) (41° 40' 18"N 0° 33' 51" W). The study area covers over 300 000 ha (3 000 km^2) with the valley receiving the majority of its water from the Pyrenees Mountains. It is a dry area with low precipitation (< 0.30 m annually). The dominant plant species is Rosemary (*Rosmarinus officinalis*) with various gypsophites found over a gypsum substrate in the more xeric areas. Scattered remnants of the original Juniper woodland community (*Juniperus thurifera*) are also present.

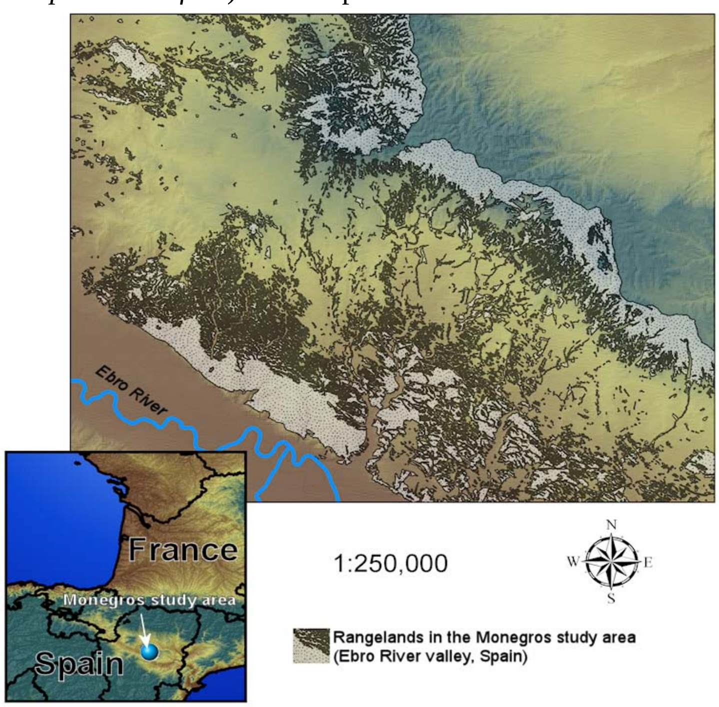

Figure 2. Location and general characteristics of the Monegros study area, northern Spain.

Grazing activity in the area consisted of various flocks of sheep grazed under a semi-extensive continuous regimen. Specifically, livestock were led by a shepherd to graze the fallow fields and rangeland steppe continuously throughout the year. Flocks were moved daily from shelters to the surrounding grazing areas where they stayed from morning until evening. Supplementary food was provided during the driest season and for reproductive females. Livestock productivity in the area is low, with an estimated stocking rate of 0.23 head ha^{-1} yr^{-1} (Pueyo et al. 2008) (Table 1).

Satellite Imagery

Satellite Pour l'Observation de la Terre (SPOT) collects data in 4 spectral bands from the visible (545 nm band center) through near-infrared (NIR) (840nm band center) and short-wave infrared (SWIR) (1665 nm band center) portions of the electromagnetic spectrum. These data are stored as raster imagery having a spatial resolution of 20 m x 20 m (SPOT 4) or 10 x 10m (SPOT 5). SPOT 5scenes were acquired on April 28, June 29, and September 15, 2007 for the O'Neal study area and SPOT 4 scenes were acquired for the Monegros study area on May 11, August 3, and August 19, 2007. These three scenes generally correspond with the early-growing season, mid-growing season, and late-growing season (senescence) for the respective study areas. All data were processed to reflectance by performing an atmospheric correction using the Cos(t) image-based absolute correction method (Chavez 1988) in Idrisi Andes software (Clark Labs, Worcester, MA). The imagery was then georectified (RMSE < 3.2 for O'Neal imagery and RMSE < 8.3 m for Monegros imagery) using high resolution aerial photography and projected into Idaho Transverse Mercator (O'Neal study area) or Universal Transverse Mercator (zone 30N, European datum 1950) (Monegros study area) using a first order affine transformation and nearest neighbor resampling.

A normalized difference vegetation index (NDVI) was calculated for each scene-date (n = 6) using Idrisi Andes with SPOT reflectance data (i.e. imagery that has been corrected for atmospheric effects). These NDVI data were then used to calculate a single composite NDVI (cNDVI) layer for each study area where the output value of each pixel represented the maximum value of each pixel from the set of input layers. Maximum NDVI was used as it has been linked to species richness by Bailey (1994) and Ivits et al. (2009). cNDVI has the potential to better characterize the vegetation of dynamic study sites where distinct vegetation communities (grasses, forbs, and shrubs) experience divergent periods of peak biomass and/or greenness. For instance, at the O'Neal study area cool season grasses like *Bromus tectorum* germinate and "green-up" early in the growing season (e.g., April and May) and then quickly senesce (June and July). During the senescent period of *Bromus tectorum*, native grasses such as Indian rice grass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*) are actively growing and achieving peak biomass. Using a single NDVI layer to characterize vegetation would likely result in an underestimation of productivity whereas a single cNDVI captures the maximum NDVI value for each pixel over an entire growing season, thereby improving the characterization of vegetation within dynamic, semiarid ecosystems.

Analysis

Three distinct treatments were identified across these study areas: 1) semi-extensive (cf. rest-rotation) grazing typified by long periods of herbivory and even longer periods of rest, 2) intensive (holistic planned) grazing where plants are grazed quickly by dense herds of herbivores and 3) total rest where no livestock grazing is used. The former (semi-extensive) was the only treatment found in both study areas thereby allowing direct comparisons to be made. The latter two treatments were unique to the O'Neal study area but still offer interesting insights relative to the effect of semi-extensive grazing on cNDVI values, as well as various inferences regarding the productivity at each of these study areas.

One-hundred sample points were randomly generated across each treatment pasture at each study area (n = 400) and the cNDVI value at each point was extracted using ESRI's ArcGIS software (Sample tool). Single factor analysis of variance (ANOVA) was used to compare cNDVI values following a pair-wise approach. Specifically, cNDVI values from the semi-extensive grazing pasture of the O'Neal study area were compared to cNDVI values from the semi-extensive pastures of the Monegros study area, cNDVI values from the semi-extensive grazing pasture (O'Neal) were compared to cNDVI values from the total rest pasture (O'Neal), and cNDVI values from the total rest pasture (O'Neal) were compared to cNDVI values from semi-extensive grazing pastures of the Monegros study area. In total, six comparisons were made to test all possible pair-wise combinations. In all cases, P-values < 0.001 were considered significant.

To better understand ecosystem dynamics and compare cNDVI to single-date NDVI, a season long NDVI curve was created and cNDVI loadings determined by finding the difference in pixel values between cNDVI and each single-date NDVI layer. As a result of this calculation, pixels with a value of zero indicate a location where cNDVI was equal to the single-date NDVI. The proportion of zero-value pixels in each output layer was used to determine relative loading of the cNDVI layer and thereby better understand seasonal ecosystem dynamics of semiarid rangelands.

To interpret the results of image processing within an ecological context, 2007 field observations of land cover derived from point-intersect vegetation transects (n = 150; n = 50 per treatment pasture) were used. Percent cover estimates (Tibbits et al., 2007) for shrubs, grasses, litter, and bare ground were compared between pastures as each of these functional groups contributed substantially to the NDVI and cNDVI values under analysis. Land cover functional groups were compared using ANOVA

RESULTS AND DISCUSSION

cNDVI values of the semi-extensive grazing pastures for the O'Neal ($\underline{x}$ = 0.44) and Monegros ($\underline{x}$ = 0.42) study areas were not different (P = 0.08, and F = 3.06 [$F_{critical}$ = 3.88]) (Table 2). While biophysically similar, these sites experienced very different land use and land tenure. The rest-rotation pasture at the O'Neal study area (USA) was part of a large grazing allotment administered by the USDI Bureau of Land Management and were grazed by cattle under a semi-extensive regimen. Likewise, the pastures of the Monegros study area (Spain) were grazed by sheep under a semi-extensive regimen. The similarity in grazing regimen may explain the corresponding cNDVI values since the primary treatment (temporally) impacting the land in both cases was rest and relatively low stocking rates.

If long periods of rest result in a similar signature upon the landscape regardless of the myriad differences of use applied by the rancher or shepherd during the grazing period, then one would expect to see no difference in cNDVI when comparing any semi-extensive grazing pasture with a total rest pasture. Indeed, the cNDVI values of the semi-extensive grazing pasture at the O'Neal ($\underline{x}$ = 0.44) and the total rest pasture at the O'Neal ($\underline{x}$ = 0.46) were not different (P = 0.02). Likewise, the cNDVI values of the semi-extensive grazing pastures from the Monegros study area ($\underline{x}$ = 0.42) and the total rest pasture at the

O'Neal study area ($\underline{x}$ = 0.46) were not different (P = 0.004). The latter inference is less well defended however, as the F-statistic (8.31) might indicate a significant difference between these treatment pastures. For reasons explained below, the author has chosen to be conservative in any conclusions drawn in these comparisons and readers are encouraged to review the assessment of error and bias to better understand the conservative approach taken.

Table 2. Results of single-factor ANOVA comparisons among all treatments.

			Semi-extensive		Intensive
	Treatments	Total rest	Monegros	O'Neal	O'Neal
	Total rest	X			
Semi extensive	Monegros	P = 0.004 (F = 8.30)	X		
	O'Neal	P = 0.018 (F = 5.61)	P = 0.081 (F = 3.06)	X	
Intensive	O'Neal	P = 0.041 (F = 4.20)	P = 0.000 (F = 13.74) **	P = 0.000 (F = 17.42)**	X

F-critical = 3.89

** indicates statistically significant results

The comparison of cNDVI values between the holistic planned grazing pasture ($\underline{x}$ = 0.47) and semi-extensive grazing pastures at both the O'Neal and Monegros study areas were different (P < 0.001; F = 17.42 and F = 13.75 for the O'Neal and Monegros comparisons, respectively). To understand this result, one must revisit the inference drawn earlier. Temporally, the holistic planned grazing pasture received six days of grazing and 359 days of rest annually. In contrast, the semi-extensive grazing pasture at the O'Neal received 30 days of grazing and 335 days of rest. Meanwhile in Monegros the animals graze all year, with only sporadic rest periods in some cases of two or three months where the sheep are moved to other areas. Following the logic established earlier to understand the results of comparisons between semi-extensive grazing (i.e., partial rest) and total rest treatments one would be lead to infer that rest was the primary treatment again where the holistic planned grazing pasture is concerned. However, upon closer examination the stocking rate applied to this intensively grazed pasture was found to be six- fold higher (36 animal days/ha) than the semi-extensive rest-rotation pasture (6 animal days/ha) at the O'Neal. In light of these figures, it appears the intensity of grazing has been sufficient to overwhelm the effect of rest thus yielding a treatment that is statistically unique when compared to the other production pastures. However, this alone does not explain all differences as cNDVI values for the holistic planned grazing pasture was not different from the cNDVI values for the adjacent total rest pasture.

Initially, this similarity appears to confound the inferred results, but in fact, after careful investigation of land cover the results become even more meaningful. Statistical analysis of land cover functional groups (grasses, shrubs, forbs, and litter) within each treatment pasture were compared using single-factor ANOVA. This comparison used percent cover calculations derived from vegetation transects (n=150 with 50 20-m transects collected in each treatment pasture) collected during the summer of 2007(Tibbitts et al. 2007). No difference was found in percent indicates no difference in percent grass cover between the treatment pastures (P > 0.269) and no difference in percent cover of shrubs between the holistic planned grazing and semi-extensive rest-rotation pastures (P = 0.687). Similarly, no difference in percent shrub cover was found between the total rest and rest-rotation pastures ($P = 0.249$). However, a difference in percent shrub cover was found between the holistic planned grazing and total rest pastures ($P = 0.002$). The ANOVA tests comparing percent litter cover also revealed statistically significant differences among all three treatments ($P < 0.001$) and pair-wise comparisons revealed differences between the holistic planned grazing and semi-extensive rest-rotation pastures ($P < 0.001$), as well as between the holistic planned grazing and total rest pastures. No statistical differences in litter cover were found between the total rest and rest-rotation pastures ($P > 0.001$).

These differences in land cover (specifically shrub and litter functional groups) help explain the differences observed in cNDVI. Specifically, one must recall that a reflectance value (and the indices derived from these values) represents the measured reflectance of the earth's surface within each ground resolution cell (i.e., pixel, Lillesand and Kiefer 2000). The pixel may be comprised of homogenous or heterogeneous land cover and when the latter is the case, a mixed pixel results. Within semiarid rangelands, mixed pixels are the norm and while one pixel may contain higher proportions of shrubs than another which contains a higher proportion of litter, the reflectance values of these pixels may be indistinguishable especially where broad wavebands are used. For this reason, no difference was found in cNDVI values between the total rest (with higher percent cover of shrubs) and holistic planned grazing pastures (with higher percent cover of litter).

The higher cNDVI values observed for the holistic planned grazing pasture at the O'Neal study area relative to all other production pastures was attributed to higher proportions of litter cover ($P < 0.001$) found in the holistic planned grazing pasture. Litter, while not photosynthetically active, affects all simple band ratio vegetation indices which rely upon the near-infrared band (780nm – 890nm) (Roberts et al. 1993; van Leeuwen and Huete, 1996; Asner et al. 1998; Nagler et al. 2000). This band is sensitive to the cellulose structure of plants, including the cellulose found non-photosynthetic vegetation (litter). According to Nagler et al. (2000), dry grass litter has high reflectance within the NIR band and low reflectance in the red band. This pattern of reflectance is quite similar to that seen for photosynthetically active vegetation and as a result, pixels comprised primarily of litter can have NDVI values identical to green vegetation (e.g., NDVI ~ 0.55).

The higher proportions of litter cover found within the holistic planned grazing pasture is a function of high animal impact. In comparison, total rest cannot provide the same amount of litter for two reasons. First, under long periods of rest not as many plants will grow (Savory 1999) and secondly, because the dead plant material tends to remain standing to breakdown gradually through aerial oxidation and physical weathering rather than in contact with the soil where biological decomposition occurs much more rapidly. In this case, a much more gradual chemical/physical breakdown replaces rapid biological decay (Savory 1999). Partial rest, as seen in the semi-extensive grazing pastures, exhibits nearly the same effect as total rest, i.e., fewer individual plants grow and chemical/physical breakdown predominates while some individual plants are overgrazed due to prolonged presence of grazing animals. Subsequently, less litter is laid upon the ground both because less plant material is present and also because of lower animal impact.

The ecological significance of this difference should not be overlooked as biologically degrading litter (i.e., litter in contact with the soil) adds organic matter to the soil and reduces the soil's surface temperature which, in turn, allow a higher percent volumetric water content in the active root zone of the soil (Weber and Gokhale 2009).

Season-long NDVI for both the O'Neal and Monegros study areas exhibited an interesting curve (Figure 3). In both cases, high NDVI values were achieved at the end of the growing season with an NDVI trough exhibited in mid-summer. The majority (>60%) of values loaded into the cNDVI layer were contributed by the end of growing season NDVI layers (Figure 4a, b). This suggests that the rate of photosynthetic activity during satellite overpass in mid-summer is very low, with peak photosynthetic rates occurring during the cooler parts of the year in semiarid rangelands such as the O'Neal and Monegros study areas.

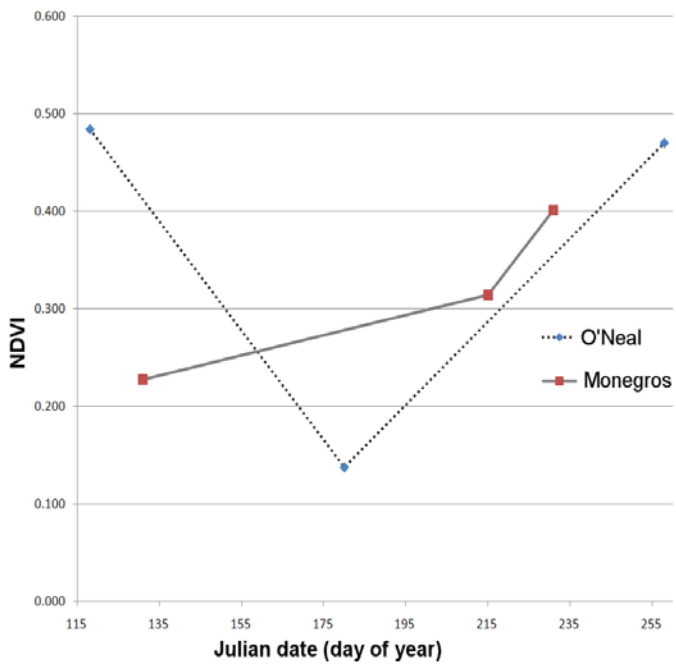

Figure 3. Season-long NDVI curves for the O'Neal and Monegros study areas.

While biophysically similar to the O'Neal, the growing season in the Monegros study area appears to be shifted to the left (i.e., there is a slightly earlier growing season). It is hypothesized that NDVI values from early April would be relatively high and similar to those observed for the O'Neal in late April. In both cases, however, the majority of pixels (>60%) constituting the cNDVI were derived from late season imagery (Figure 4). Still, substantial data was contributed from other portions of the growing season (40%) which supports continued use of cNDVI instead of single-data imagery. In addition, the contribution loadings observed in this study mirror the phenology of these study areas quite well as forbs and grasses tend to "green-up", mature, and senesce at different times throughout the growing season. Future research should be directed toward developing a better understanding of these results, and specifically understanding the composition and characteristics of late season vegetation relative to observed spectral reflectance patterns.

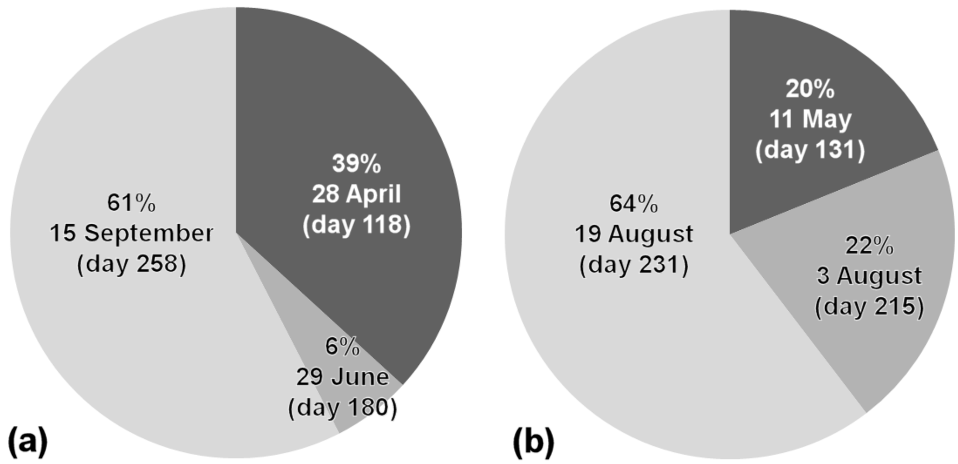

Figure 4. Contribution of single-date NDVI for the cNDVI layers in both the O'Neal (a) and Monegros (b) study areas. Note: contribution totals exceed 100% as single-date maximum NDVI values for some pixels remained consistently high throughout the year. These pixels represents roads and other static NDVI features within the study areas.

While no difference in cNDVI was noted among similar treatments within environmentally and biophysically similar sites, the single statistically significant difference reported in this study relates to a substantial difference in grazing treatment. This treatment resulted in higher cNDVI values compared to most other treatments examined in this study. The specific grazing treatment followed holistic planned grazing principles and used a relatively high density of livestock (36 animal days/ha) grazed for short time periods (6 days). This difference in grazing treatment represents a difference in land management and the manifestation of the human decision making process upon the landscape. As a result, the impact of anthropic effects upon the ecosystem is evident.

Assessment of Error and Bias

This study used SPOT 5 (O'Neal study area) and SPOT 4 (Monegros study area) imagery to calculate cNDVI values for the 2007 growing season. The cNDVI values were compared by treatment (total rest, semi-extensive grazing [e.g., rest-rotation], and intensive holistic planned grazing) within study areas and among study areas. While Theau et al. (2010) demonstrated that direct comparison of various vegetation indices across sensors is not valid, this study made exclusive use of the SPOT sensor with the only difference being the type of SPOT sensor used (i.e., SPOT 5 or SPOT 4). For this reason, direct comparison of cNDVI values was considered valid.

Another concern related to the SPOT imagery is spatial resolution. All SPOT 4 imagery has a spatial resolution of 20 m while SPOT 5 imagery has a spatial resolution of 10 m. Consequently, each SPOT 4 pixel contains four SPOT 5 pixels. As each pixel can contain only one index value it is understood that SPOT 4 pixels are more highly generalized than the SPOT 5 pixels. As a result, one would expect higher variance in all SPOT 5 derived products (NDVI and cNDVI). This was not the case however, as the standard deviation of cNDVI values for the O'Neal study area was 0.121 compared to a standard deviation of 0.244 for the Monegros study area. This may be attributable to more homogeneous land cover at the O'Neal which is likely a function of its much smaller extent (1500 ha compared with 300000 ha).

The dates of imagery acquisition representing early-growing season, mid-growing season, and late-growing season conditions were not ideal for the Monegros study area. Optimally, imagery representing early-growing season conditions could have been collected in April (instead of May) and mid-growing season imagery could have been collected in mid-May (instead of early August). In addition, the fact that the mid-growing season imagery was collected within two weeks (16 days) of the late-growing season imagery also poses some problems. As a result, cNDVI values may have been underestimated for the Monegros study area.

While the authors have made every attempt to ensure consistency across all experimental variables, the fact remains that numerous slight differences exist (e.g., SPOT 5 imagery was compared with SPOT 4 imagery and the dates of image acquisition were not ideal) in this comparative study. It is for these reasons that the significance threshold of $P < 0.001$ was selected. With this decision, it is hoped that false inferences will be avoided and the reported results will be received with confidence.

CONCLUSIONS

Composite NDVI values were calculated throughout the 2007 growing season and compared for two biophysically similar (i.e., located at similar latitudes and having similar growing seasons, precipitation regimes, range of elevation, and the presence of similar vegetation functional groups) semiarid rangeland sites: the O'Neal Ecological Reserve (Idaho, USA) and Monegros study area (Aragon, Spain). In general, no difference was found between these geographically distant study areas, substantiating the hypothesis that biophysically similar areas will exhibit similar spectral signatures over a landscape. As the primary land use (Cummins 2009) found in both study areas was livestock grazing with partial rest it was not surprising that no difference was found in cNDVI when these pastures were compared. However, comparison of a total rest pasture with partial rest pastures also failed to reveal differences in cNDVI, suggesting that semi-extensive grazing with partial rest manifests no detectable difference on the landscape relative to total rest.

The most significant result of this research was the difference in the cNDVI values observed between the holistic planned grazing pasture and all other production pastures included in this study. This suggests that holistic planned grazing 1) can have considerable effect on the landscape and 2) the result of the some human decision making processes (i.e., application of holistic planned grazing) are detectable through satellite image processing techniques. In this case, the effect of holistic planned grazing was a positive one for the ecosystem. As a result of high animal impact, the holistic planned grazing pasture exhibited a higher percent cover of litter, which subsequently resulted in higher cNDVI values.

Ecologically, the cumulative effect of holistic planned grazing led to significantly higher soil moisture levels (Weber and Gokhale 2009) most probably as a consequence of higher litter cover, manure deposition, and a higher degree of trampling/hoof action which both breaks the crust of the soil and introduces organic matter into the soil, which in turn improves the soils ability to capture and retain moisture (Savory 1999).

ACKNOWLEDGEMENTS
This study was made possible by a grant from the National Aeronautics and Space Administration Goddard Space Flight Center (NNX06AE47G). ISU would also like to acknowledge the Idaho Delegation for their assistance in obtaining this grant. In addition, field research in the Monegros study area was supported by projects CGL2008-00655/BOS from the Ministry of Science and Innovation of Spain.

LITERATURE CITED
Arnalds O. and S. Archer. 2000. Rangeland Desertification. Kluwer Academic publishers, Dordrecht, Netherlands. p209

Asner, G. P., C. A. Wessman, and S. Archer. 1998. Scale Dependence of Absorption of Photosynthetically Active Radiation in Terrestrial Ecosystems. Ecological Applications 8(4):1003-1021

Bailey, N. 2004. Birds in Europe: Population Estimates, Trends, and Conservation Status. Birdlife International, Cambridge, UK. Birdlife conservation series No. 12

Branson, F.A., G.F. Gifford, K.G. Renard, and R.F. Hadley. 1981. *Evaporation and Transpiration.* Pages. 179–200 in E.H. Reid (Ed.) Rangeland hydrology. Range Sci. Ser. 1. 2nd ed. Soc. for Range Management, Denver, CO.

Canfield, R. H. 1941. Application of Line Interception in Sampling Range Vegetation. Journal of Forestry 39:388-394

Chambers, J. C. and R. W. Brown. 1983. Methods for Vegetation Sampling and Analysis on Re-vegetated Mine Lands. USDA FS Gen. Tech. Tep. INT-151 57pp

Chavez, P. S. 1988. An Improved Dark-object Subtraction Technique for Atmospheric Scattering Correction of Multispectral Data. Remote Sensing of Environment 24:459-479

Cummins, B. 2009. Bear Country: Predation, Politics, and the Changing Face of Pyrenean Pastoralism. Carolina Academic Press, Durham, North Carolina. 355pp.

Daubenmire, R. F. 1959. A canopy-coverage Method of Vegetation Analysis. Northwest Science 33:43-64.

Daubenmire, R. F. and J. B. Daubenmire. 1968. Forest Vegetation of Eastern Washington and Northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60pp.

Gokhale B. S. and K. T. Weber. 2010. *Correlation between MODIS LAI, GPP, PsnNet, and FPAR and Vegetation Characteristics of Three Sagebrush-Steppe Sites in Southeastern Idaho*. Pages 77-88 in K. T. Weber and K. Davis (Eds.) Final Report: Forecasting Rangeland Condition with GIS in Southeastern Idaho. 193pp.

Griffin, D.W., C.A. Kellogg, and E.A. Shinn. 2001. Dust in the Wind: Long Range Transport of Dust in the Atmosphere and Its Implications for Global Public and Ecosystem Health. Global Change and Human Health 2(1): 20-33

Gysel, L. W. and L. J. Lyon. 1980. *Habitat Analysis and Evaluation*. Pages 305-317 in S. D. Schemnitz (Ed.) Wildlife Management Techniques Manual, 4th ed. Revised. The Wildlife Society, Washington, DC

Huntsinger, L. and P. Hopkinson. 1996. Viewpoint: Sustaining Rangeland Landscapes: A Social and Ecological Process. Journal of Range Management 49:167-173

Ivits, E., G. Buchanan, M. Cherlet, and W. Mehl. 2009. Phenological Trends Derived from SPOT VEGETATION Time Series to Indicate European Biodiversity Decline: Case Study of Farmland Birds. Proceedings of International Symposium for Remote Sensing of Environment, Stresa Italy (ref 347)

Lillesand, T. M. and R. W. Kiefer. 2000. Remote Sensing and Image Interpretation. 4th edition. John Wiley & Sons, New York. 724pp.

Nagler, P. L., C. S. T. Daughtry, and S. N. Goward. 2000. Plant Litter and Soil Reflectance. Remote Sensing of Environment 71:207–215

Pueyo, Y., C. L. Alados, O. Barrantes, B. Komac, and M. Rietkerk. 2008. Differences in Gypsum Plant Communities Associated with Habitat Fragmentation and Livestock Grazing. Ecological Applications. 18: 954-964

Roberts, D. A., J. B. Adams, and M. O. Smith. 1993. Discriminating Green Vegetation, Non-Photosynthetic Vegetation, and Soils in AVIRIS data. Remote Sensing of Environment. 44(2/3): 255–270

Rouse, J.W., Jr., R.H. Haas, J.A. Schell, and D.W. Deering. 1973. Monitoring the Vernal Advancement and Retrogradation (green wave effect) of Natural Vegetation. Prog. Rep. RSC 1978-1, Remote Sensing Center, Texas A&M Univ., College Station, 93pp. (NTIS No. E73-106393)

Running, S. W., R. Nemani , J. M. Glassy, and P. E. Thornton. 1999. MODIS Daily Photosynthesis (Psn) and Annual Net Primary Production (NPP) Product (MOD17), Algorithm Theoretical Basis Document, Version 3.0, 29 April 1999, 1-59

Savory, A. 1999. Holistic Management: A New Framework for Decision Making. Second Edition. Island Press, 616pp.

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. M. Jarrell, R. A. Virginia, and W. G. Whitford. 1990. Biological Feedbacks in Global Desertification. Science 247:1043-1048

Sellers, P.J., 1992: Canopy Reflectance, Photosynthesis and Transpiration. Part III: A Re-analysis using Enzyme Kinetics-electron Transport Models of Leaf Physiology. Remote Sens. Environ., 42, 187-216

Tian, Y. and Y. Zhang, Y. Knyazikhin, R. B. Myneni, J. M. Glassy, G. Dedieu, and S. W. Running, 2000, Prototyping of MODIS LAI and FPAR Algorithm with LASUR and LANDSAT Data, IEEE Transactions On Geoscience And Remote Sensing, Vol. 38, No. 5, 2387-2401

Tibbitts, J., J. Anderson, and K. T. Weber. 2010. *2007 Range Vegetation Assessment at the O'Neal Ecological Reserve, Idaho*. Pages 19-30 in K. T. Weber and K. Davis (Eds.) Final Report: Forecasting Rangeland Condition with GIS in Southeastern Idaho. 193pp. URL = http://giscenter.isu.edu/research/techpg/nasa_oneal/to_pdf/2007_field_report.pdf visited 30-Mar-09

Tucker, C.J. 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sensing of Environment, 8, 127-150

Van Leeuwen, W.J.D., and A.R. Huete. 1996. Effects of Standing Litter on the Biophysical Interpretation of Plant Canopies with Spectral Indices. Remote Sensing of Environment, 55:123-138

Walko, R. L. and C. J. Tremback. 2005. Modifications for the Transition from LEAF-2 to LEAF-3. ATMET Technical Note. 1. 13pp.

Weber, K. T. and B. S. Gokhale. 2010. *Effect of Grazing Treatment on Soil Moisture in Semiarid Rangelands*. Pages 165-180 in K. T. Weber and K. Davis (Eds.) Final Report: Forecasting Rangeland Condition with GIS in Southeastern Idaho. 193pp.

Recommended citation style:
Weber, K. T., F. Chen, B. Gokhale, C. G. Bueno, and C. L. Alados. 2009. *Application of Composite-NDVI in Semiarid Rangelands*. Pages 71-84 in K.T. Weber and K. Davis (Eds.), Final Report: Comparing Effects of Management Practices on Rangeland Health with Geospatial Technologies (NNX06AE47G). 168 pp.