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Original Articles

Suitability of NDVI and OSAVI as estimators of green biomass and coverage in a semi-arid rangeland

Rachel R. Fern[a,*], Elliott A. Foxley[a], Andrea Bruno[b], Michael L. Morrison[a]

[a] Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA
[b] East Foundation, San Antonio, TX 78216, USA

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ABSTRACT

Rangelands are often too large and inaccessible to determine biomass accumulation and vegetation cover by ground surveys alone, particularly in semi-arid regions where productivity per unit area is typically low and highly variable. Thus, the development of remote sensing derived spectral indices have been of particular interest to rangeland managers as a more cost-effective means of measuring the characteristics, biomass, and extent of vegetation. The Normalized Difference Vegetation Index (NDVI) is the most widely used spectral vegetation index (VI) by ecologists and agriculturalists today. However, regions with sparse vegetation or soils that generate high reflectance values (e.g., dry sandy soils) can severely hinder the reliability of the NDVI as an accurate estimator of green biomass, saturate remote sensors or produce biased estimates of green biomass and vegetative cover. The Optimized Soil Adjusted Vegetation Index (OSAVI) is a newly formed alternative that can accommodate greater variability due to high soil background values. We evaluated the suitability of the NDVI and OSAVI as potential estimators of green biomass and vegetative coverage in a semi-arid rangeland in south Texas. We compared coverage estimates of herbaceous, bare-ground, and woody vegetation calculated from classified satellite images stacked with either an NDVI or OSAVI band to those from traditional ground surveys. OSAVI-derived coverage estimates of herbaceous and woody vegetation did not significantly differ from those produced by ground surveys in 2015. However, NDVI-based estimates for woody vegetation, as well as bare ground, did differ significantly from estimates generated from ground surveys ($p = 0.012$, 0.018). In 2016, the OSAVI-derived estimates for all three land cover classes were not significantly different than those produced by ground surveys. Our results suggest the OSAVI to be the most appropriate VI-based estimator of green biomass and vegetative coverage in the semi-arid regions of southern Texas.

1. Introduction

Although spectral vegetation indices have a long history of use by remote sensing scientists, they are an increasingly popular tool used by agriculturalists and rangeland ecologists (Curran et al., 1992; Henebry, 1993; Wabnitz et al., 2008). Determining biomass accumulation and vegetation cover of rangelands using ground surveys can be time consuming and costly, particularly on large, semi-arid regions where productivity per unit area is typically low and highly variable from year to year. Thus, the development of remote sensing derived spectral indices have been of particular interest to rangeland managers as a more cost-effective means of measuring the characteristics, biomass, and extent of vegetation (Eisfelder et al., 2012).

The Normalized Difference Vegetation Index (NDVI) is the most widely used spectral vegetation index (VI) by ecologists and agriculturalists today (Horning et al., 2010; Yagci et al., 2014; Lee et al., 2016). Similar to most VIs, the NDVI transforms reflectance measurements from the reflectance peak of vegetation in the near-infrared (NIR) and red wavelength ranges where chlorophyll absorbs light energy for photosynthesis. The purpose of this two-band design is to reduce variability caused by reflectance of the soil background, illumination, and view angle variation. However, regions with sparse vegetation or soils that generate high reflectance values (e.g., dry sandy soils) can saturate remote sensors or produce biased estimates of green biomass and vegetative cover (Huete et al., 1997; Nicholson and Farrar, 1994). Remote sensing scientists have addressed this through formulating new spectral vegetation indices that can accommodate greater variability due to soil reflectance (e.g., Soil Adjusted Vegetation Index, SAVI; Optimized Soil Adjusted Vegetation Index, OSAVI). Although the NDVI is still used for estimating biomass and coverage in areas with wildly varying vegetation types, its use in semi-arid rangelands is becoming increasingly suspect especially in regions with sandy soils (Bowers and

* Corresponding author.
E-mail address: rachel.fern@tamu.edu (R.R. Fern).

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Hanks, 1965; Gu et al., 2008).

The Rio Grande Plains, or "brush country", encompasses the Coastal Sand Plain, Tamaulipas Thornscrub, and Lower Rio Grande Valley ecoregions of Texas (Omernik, 1987). The region, as a whole, is primarily managed for agricultural use. However, in the smaller, Tamaulipas Thornscrub and Coastal Sand Plan regions, wildlife based management often outpaces agricultural interests. Frequent and reoccurring drought presents unique challenges to cattle ranching in this region as naturally available vegetation is often sparse (Taylor, 2014). Thus, landowners are charged with the task of developing profitable management systems that balance the needs of sustainable cattle and/or wildlife enterprises as well as those of sensitive wildlife populations in the presence of frequent and reoccurring drought. Accurate and cost-effective vegetation monitoring is crucial to any effective rangeland management strategy and spectral VIs can provide a valuable tool towards reaching this end. However, the use of the NDVI in this region is questionable, at best, due to the high sand content of the soils and sparse vegetation (Eastwood et al., 1997; Elmore et al., 2000; Todd and Hoffer 1998).

Here, we evaluate the suitability of the NDVI and OSAVI as potential estimators of green biomass and vegetative coverage in a semi-arid rangeland in south Texas. We compared coverage estimates of herbaceous, bare-ground, and woody vegetation calculated from classified satellite images stacked with either an NDVI or OSAVI band to those from traditional ground surveys.

2. Methods

2.1 Study area

The Coloraditas Grazing Research and Demonstration Area (CGRDA) is a 7684-ha area located on the 60,000-ha San Antonio Viejo Ranch (SAV). SAV is one of six properties of the East Foundation that are managed as a living laboratory to support wildlife conservation and other public benefits of ranching and private land stewardship. The CGRDA is representative of south Texas rangeland ecosystems and encompasses the Coastal Sand Plain and Texas-Tamulipan Thronscrub ecoregions. Low-growing woody plants, dense shrubs (*Prosopis glandulosa*, *Acacia greggii*, *Celtis ehrenbergiana*, *Colubrina texensis, Aloysia gratissima, Lantana urticoides*), and cacti (*Opuntia engelmannii* var. *lindheimeri*, *Opuntia leptocaulis*) dominate the vegetation in this area. The CGRDA is comprised of 10 pastures (Fig. 1) each assigned to 1 of 4 cattle grazing systems. Four pastures are assigned to a continuous grazing system with 2 pastures maintained under a high stocking rate (1 Animal Unit [AU]/14 ha) and 2 pastures under a moderate stocking rate (1 AU/20 ha). Six pastures are assigned to a rotational system with 3 pastures, 1 herd maintained under the high stocking rate and 3 pastures, 1 herd maintained under the moderate stocking rate. Grazing was deferred on all pastures for two years prior to the onset of cattle grazing in December 2015. We compared pre- and post-grazing vegetation cover estimates from ground surveys.

2.2 Ground surveys

We collected vegetation composition and structure data from 141 permanent 20-m transects each October in 2015 and 2016. We allocated transects proportional to the area of ecological sites that occur in each pasture using stratified sampling resulting in 12–16 transects per pasture (Bonham, 2013). Sample size for belt transects was determined by a power analysis with an 80% chance in detecting a 20% change in canopy cover at $P \leq 0.05$. Detecting a 20% change in bare ground required the highest number of transects out of the 4 measurements, therefore, we used this as the minimum number of transects placed in each pasture.

We marked each transect start with a t-post and collected data in a random, predetermined direction (N, S, E, W). On each transect we sampled 5, 20 × 50 cm quadrats (5 m spacing) randomly placed at either 0, 0.5, 1, 1.5, 2, or 2.5 m from the left side of the tape and facing away from the transect start. The specifics for transect direction and quadrat spacing start remained constant for each transect over the course of the study.

At each transect, we collected percent cover of woody, herbaceous, litter, and bare ground. We defined woody canopy cover as the portion of foliage cover projected on the ground (Bonham, 2013). We collected woody canopy cover along each of the 20 m transects by recording the amount of the ground (in centimeters) covered by woody plant materials (leaves and branches) and succulent (cacti) that intercepted the line transect by species (Canfield, 1941; Higgins et al., 2012). If a gap in the canopy exceeded 0.5 m for an individual, we recorded separate cover measurements. We calculated percent canopy cover by summing the intercept measurements for an individual species, dividing by total line length and converting to a cover percentage. We calculated total percent cover by adding cover percentages for all species, which may exceed 100% when overlapping canopies by different species are recorded (Coulloudon et al., 1999).

We defined herbaceous cover as the non-woody vegetation, such as grasses and forbs, projected onto the ground (Bonham, 2013). We defined bare-ground as the amount of soil that is not covered by any type of vegetation (Holecheck et al., 2011). Within each quadrat, we measured percent canopy cover by 4 functional groups (grass, forb, bare ground, litter ≤ 100%) in 5% increments, this included increments of 1% for coverages < 5%. (Higgins et al., 2012). When woody or succulent cover was rooted within the frame, we made note of percent cover, species, and abundance. For the purpose of this analysis, we combined grass and forb cover into herbaceous cover and litter and bare ground into bare ground cover.

2.3 Imagery processing

We conducted a series of processing functions using imagery captured during the same growing season as when ground surveys took place (summer of 2015 and 2016) (Fig. 2). Two Landsat 8-OLI tiles (< 6% cloud cover) that encompassed the study area were acquired (courtesy of U.S. Geological Survey) and processed in ENVI 5.1 (NASA Landsat Program, 2015, 2016). We corrected for atmospheric conditions and converted the original image format of Digital Numbers (DN) to radiance and then surface reflectance. Each image was first resized to the rectangular extent of the LC pasture complex and then extracted by the study area mask in ESRI ArcGIS ArcMap 10.5. Both extracted images (2015 and 2016) were then spatially subset by bands 2–5 corresponding to Landsat 8-OLI band designations: blue, green, red, and NIR. Bands were stacked and two vegetation indices were calculated per image using the band math tool in ENVI 5.1. NDVI was calculated according to the standard formula [(NIR-Red)/(NIR + Red)] in which the drop in reflectance between the Near-Infrared (NIR) band and Red band is divided by the increase in reflectance. This creates index values between −1 and 1 (Rouse et al., 1973). We then stacked the NDVI as a band on the NIR-RGB image for, both, 2015 and 2016. Similarly, the OSAVI was calculated using ENVI's band math tool using the standard formula [(NIR-Red)/(NIR + Red + 0.16)] and stacked as a band on the NIR-RGB image for, both, 2015 and 2016. Based on the Soil Adjusted Vegetation Index (SAVI), this VI uses a reflectance constant of 0.16 to adjust for high background reflectance (e.g., areas with sparse vegetation and high soil reflectance) (Rondeaux et al., 1996; Ren et al., 2018).

We classified each VI-NIR-RGB stacked image using Maximum Likelihood supervised classification into three land cover classes: herbaceous, woody, and bare-ground. We calculated statistics for each class to estimate land cover coverage and performed an accuracy assessment for each classified image using ground truth points collected from ground surveys. We compared 2015 and 2016 classification accuracy (as a function of overall accuracy, Kappa coefficient, and producer's accuracy) and coverage estimates derived from VI-NIR-RGB