Spatial Pattern of NDVI in Semiarid Ecosystems of Northern Spain

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ABSTRACT
Understanding the distribution of landscape variables presents several advantages to researchers focusing on ecological studies. The Normalized Difference Vegetation Index (NDVI) is a relatively common productivity variable used to assess, monitor, and compare landscapes. In this study, an NDVI layer was created using Satellite Pour l'Observation de la Terre 4 (SPOT 4) satellite imagery to compare the pattern of NDVI values at waterholes/shelters relative to the pattern of NDVI values at random locations in semiarid rangelands of northern Spain. Single factor ANOVA revealed that NDVI values at waterholes/shelters were significantly lower than those at random locations. Analysis of topographic variables (slope) revealed that NDVI values at gentler slopes (≤5°) were significantly higher ($P < 0.001$) than values at steeper slopes (>5°) within grazed areas, while NDVI values in areas with steeper slopes (>5°) were significantly higher ($P < 0.001$) under total rest. Land use, specifically semi-extensive livestock grazing, appears to be the main factor governing the observed NDVI distributions.

Keywords: rangelands, spatial pattern, ANOVA, NDVI

INTRODUCTION

Human activities and climatic conditions impact ecosystems and may involve continuous or discontinuous transitions from one stable state to another. Discontinuous transitions result in the most catastrophic changes to ecosystems and these changes are often abrupt and irreversible (Kefi et al. 2007). It is important to detect early signs of potential transitions that can negatively alter ecosystem services and cause the loss of ecological and economic resources. Vegetation patchiness can be used as a signature of imminent discontinuous transition (Kefi et al. 2007). It is especially important within arid and semiarid ecosystems as they are more vulnerable to desertification processes (Savory 1999, Kefi et al. 2007). Spatial pattern analysis can be used to quantify vegetation patchiness and various efforts have already been made to better understand the spatial pattern of vegetation and its connection with desertification (Bergkamp et al. 1996, von Hardenberg et al. 2001). Rietkerk et al. (2002) have developed a model using plant density, soil water, and surface water to explain observed spatial patterns of vegetation whereas von Hardenberg et al. (2001) developed a similar model using biomass density and availability of groundwater to explain the observed spatial patterns of vegetation. In spite of these efforts, researchers are still searching for comprehensive techniques to explain the variety of observed spatial patterns and understand if these patterns are the result of pre-existing environmental heterogeneity, spatial self-organization (Rietkerk et al 2002), applied land use practices, or a combination of these factors. In addition, it is important to investigate the relationship between spatial pattern and biodiversity, ecosystem resilience, and desertification.

Normalized Difference Vegetation Index (NDVI)

A landscape productivity parameter such as the Normalized Difference Vegetation Index (NDVI) can be used to understand various characteristics of a vegetation community. Comparisons between vegetation communities can be used to understand the distribution and structure of vegetation within a study area. NDVI has been applied in numerous studies and used to evaluate the conversion of one land cover type to another (Deyong et al. 2009, Lunetta et al. 2006, Martinez and Gilabert 2009) and ecological responses to environmental change (Pettorelli et al. 2005). These authors found NDVI was effective to monitor habitat degradation and fragmentation, and the ecological effects of climatic disasters such as drought or fire. The spatial patterns of NDVI values were studied by Wang et al. (2001) in response to changes in temperature and precipitation. They reported a strong correlation between the general spatial distribution of NDVI values and the pattern of average annual precipitation while the influence of temperature on NDVI values was observed only during the early and late parts of the growing season (Wang et al 2001). Roberts et al. (1997) also used NDVI to assess spatio-temporal patterns of vegetation relative to various atmospheric properties derived from AVIRIS hyperspectral data. Based upon these applications, NDVI was chosen to assess the spatial pattern of vegetation in semiarid rangelands of northern Spain relative to land use and land tenure (Cummins 2009).

This study uses a combination of point analysis and topographic analysis performed using NDVI values and focuses on the spatial distribution of NDVI values in the middle Ebro valley (i.e. Monegros study area) of northern Spain. The distribution of NDVI values at waterholes/shelters were analyzed using single-factor ANOVA to better understand the impact of land use and potential long-term degradation of the ecosystem. In addition, the effect of topography (specifically slope) on the pattern of NDVI values was also evaluated. These data were important to study the impact of land use with respect to ecosystem stress and potential desertification.

The hypotheses tested in this study include 1) lower NDVI values were expected in response to increased bare soil and the loss of vegetation in those sites experiencing overgrazing of plants, 2) NDVI values were expected to be different in response to topographic effects (i.e., slope) due to both differential livestock use and runoff patterns.

MATERIALS AND METHODS

Study area

This study focuses upon the xeric-steppes of the middle Ebro valley, Aragon, Spain and is referred to as the Monegros study area (Figure 1). The dominant plant species in the area is Rosemary (*Rosmarinus officinalis*) with various gypsophile plant species occurring over a gypsum substrate in the most xeric areas. Scattered remnants of the original Juniper woodland community (*Juniperus thurifera*) are also present. The study area covers over 300000 ha (3000 km^2) with the valley receiving the majority of its water from the Pyrenees Mountains, yet it is a dry area with low precipitation (< 0.30-m annually). Grazing activity in the Monegros study area consisted of various flocks of sheep grazed under a semi-extensive 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 0.2 head ha^{-1} yr^{-1} (Pueyo et al. 2008).

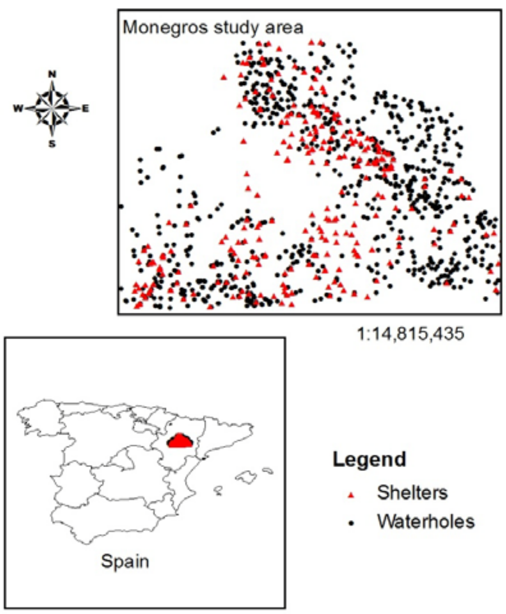

Figure 1. Monegros study area in northern Spain and locations of waterholes and shelters used in this study.

Data acquisition and preparation

Satellite Pour l'Observation de la Terre 4 (SPOT 4) collects data in 4 spectral bands from the visible (545 nm band center [green] and 645 nm band center [red]) 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. One SPOT 4 image was acquired on May 11, 2007 for use in this study. The SPOT 4 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

= 8.3 m) using 0.5-m x 0.5-m aerial photography and projected into Universal Transverse Mercator (zone 30N, European datum 1950) using a first order affine transformation and nearest neighbor resampling. NDVI was calculated using the VEGINDEX module of Idrisi Andes and the red and near- infrared bands of SPOT 4 imagery.

A point shapefile was created describing the location of all known waterholes and shelters within the study area (n = 755). An equal number of random points (n = 755) were generated using Hawth's tools for ArcGIS and stored within a second shapefile. One constraint placed upon the random points was that they could not be located within 100 m of a waterhole or a shelter to avoid regions of overlap during future proximity analysis.

Point analysis

The "Sample" tool within ESRI's ArcGIS 9.3 was used to extract NDVI values at each waterhole/shelter location as well as at each random location. The resulting data were exported to a MS Excel spreadsheet for further analysis. Single-factor ANOVA was used to determine whether mean NDVI values at waterholes/shelters were statistically different from those at the random points.

Topographic analysis

A digital elevation model (DEM) (20-m x 20-m pixels; RMSE = 7.42 [Pueyo 2005]) available for a portion of the study area (total area approximately 1800 km^2 [i.e. 40 % of the study area]), was used for topographic analysis. Using this DEM, a slope model was generated in Idrisi Andes with slopes expressed in degrees (°). The slope model was used to determine 1) if livestock favored specific slopes, and 2) if slope affected the spatial distribution of vegetation as indicated by the spatial distribution of NDVI values.

Within the area covered by the slope model, a sub-region where livestock grazing had been excluded since 2003 (area ~ 55 km^2) was selected for further analysis. Two sets of random points were created in the total rest region representing two slope classes (i.e. $\leq$5.0° [77% of the entire study area] and >5.0° [23% of the entire study area]) (n = 124, n = 62 within each slope class). Similarly, two sets of waterholes/shelters points were selected using the same two slope classes (n = 124, n = 62 within each slope class). These classes were selected as the slope threshold (~5°) has been cited as the point where livestock use is reduced due to slope (Ganskopp and Vavra 1987; Holechek et al. 2000). The waterholes/shelters area was considered a grazing area and later compared with the total rest area. Single-factor ANOVA was used to determine the effect that grazing stratified by slope had upon NDVI values.

RESULTS AND DISCUSSION

Point analysis

The results of single factor ANOVA (Table 1) comparing NDVI values at waterholes/shelters with NDVI values at random points indicate that NDVI values were statistically higher (P < 0.001) at random locations. This suggests that vegetation characteristics differ between these areas and may be the result of higher percent land cover, higher productivity, or differences in biodiversity at the random locations relative to that found at the waterholes/shelters.

Table 1. Results of single-factor ANOVA comparing NDVI values between waterholes/shelters (*n* = 755) and random points (*n* = 755).

Group	Mean NDVI	Variance	P-value
Waterholes / shelters	0.220	0.030	0.000
Random points	0.305	0.051	

Vegetation type, phenology**,** and distribution, as well as soil type, climatic conditions, and land use are all factors that affect NDVI values (Pettorelli et al. 2005, Bounoua et al. 2000, Nagler et al. 2000, Verhulst et al. 2009). Alados et al. (2005) have shown that grazing can favor biodiversity and heterogeneity of plant species. Furthermore, Pueyo and Alados (2006) have demonstrated that the availability of the gypsum substrate is an important factor governing plant community patterns in semiarid Mediterranean landscapes such as the Monegros study area.

Topographic analysis

The results of single-factor ANOVA examining the cumulative effects of slope (≤5.0° and >5.0°) and land treatment (grazing or total rest) on NDVI values indicate NDVI values were statistically higher in areas with gentler slope ($\underline{x}$ = 0.34 and $\underline{x}$ = 0.16 in ≤5.0° and >5.0 slope areas, respectively [$P < 0.001$]) where grazing was allowed, suggesting an effect of either grazing, slope, or a combination of these factors (Table 2). However, there was no difference in NDVI values within the slope classes ($P = 0.98$) in the total rest area ($\underline{x}$ = 0.22 and $\underline{x}$ = 0.22 for ≤5.0° and >5.0 slope areas, respectively). This suggests that slope alone has little effect on observed NDVI values.

Table 2. Results of single-factor ANOVA comparing NDVI values within two slope categories (≤ 5.0° and > 5.0°) and two treatments (grazing and total rest) (*n* = 62)

	Grazing $_{\leq 5°}$	Grazing $_{> 5°}$	TR $_{\leq 5°}$	TR $_{> 5°}$
Grazing $_{\leq 5°}$	-	*	*	-
Grazing $_{> 5°}$	*	-	-	*
TR $_{\leq 5°}$	*	-	-	0.98
TR $_{> 5°}$	-	*	0.98	-

* P ≤ 0.001

The results of single factor ANOVA tests performed on the waterholes/shelters and random points comparing grazed areas with ≤5° slope to total rest areas with ≤5° slope indicate that the NDVI values were statistically different (Table 2). These results indicate that land management decisions (i.e. grazing) have very tangible effects on the landscape. Furthermore, these results imply that sheep may show a preference for gentler slopes but also make use of steeper slopes to cause a detectable difference in NDVI when compared with areas of total rest. Holechek et al. (2000) report that sheep and goats use rugged terrain better than cattle because of their smaller size, more surefootedness, and stronger climbing instinct. Holechek et al. (2000), Cook (1966), Gillen et al. (1984), Ganskopp and Vavra (1987), and Pinchak et al. (1991) estimated there can be 30% or more reduction in grazing activity when slope exceeds 10% (5.7 °). This factor seems to have been borne out by this study and helps explain the differences seen in NDVI values. Further, this demonstrates the effect of topography on the spatial pattern of NDVI-values in response to land use and animal-specific use of the available landscape.

MANAGEMENT IMPLICATIONS

The results of this study describe a difference in NDVI values between areas of semi-extensive continuous grazing and total rest. In addition, NDVI differences were noted due to the interactive effect of slope. These results may be interpreted to imply that grazing is detrimental, however, such a conclusion would be premature and ill-founded. A more correct interpretation of the results presented here is that overgrazing of plants is detrimental. Grazing by itself, however, does not necessarily lead to overgrazing of plants. Rather, sedentary grazing systems tend to lead to overgrazing (Weber and Horst 2009) while more highly mobile grazing practices have been demonstrated to effectively improve semiarid rangelands (Voisin 1988, Savory 1999, Weber and Gokhale 2010).

CONCLUSIONS

NDVI values at waterholes/shelters were different from NDVI values at random points. The difference was attributed primarily to grazing. However, other factors affecting NDVI are important to consider. The interactive effect of grazing and topography was explored and an indirect relationship with slope was observed. Livestock selection for gentler slopes was shown to affect NDVI-values differentially by slope. However, livestock use of steeper slopes (>5°) was still sufficient to cause a difference in NDVI-values compared to areas with similar slopes (>5°) but managed under a total rest treatment. The results of this study demonstrate the tangible effects of the human decision-making process and the role of anthropic forces forming and changing the landscapes and ecosystems of the world.

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