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Remote sensing data to assess compositional and structural indicators in dry woodland

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ABSTRACT

Integrating field-based and remotely sensed data has proven valuable for assessing on-the-ground diversity of plants across a range of spatial scales. Here we assessed whether remotely sensed data is a good indicator of vegetation composition and structure in dry, *Prosopis flexuosa*-dominated woodlands. Our objectives were (1) to quantify on-the-ground vegetation composition and structure using (A) field-based methods and (B) remotely sensed images and analysis techniques, and (2) to evaluate how well the data extracted from remotely sensed data estimate field-based measures of vegetation composition and structure. We selected 40 individuals of *P. flexuosa* in Ischigualasto Provincial Park (San Juan, Argentina) and its influence zone. Each individual was the center of a plot (1500-m^2) where we recorded richness (compositional indicator) and abundance (structural indicator) of trees, shrubs and other plants (i.e. cacti, grasses and forbs). To assess woodland structure, we evaluated canopy area of each *P. flexuosa* and the proportion of adult *P. flexuosa* trees in a plot. In addition, we used Landsat 8 OLI to calculate SATVI (Soil Adjusted Total Vegetation Index) values from the pixel that corresponds with the center of each sample plot, and then estimated first- and second-order texture measures (in 3 × 3 and 5 × 5 moving window sizes). We fitted generalized linear models with different error distributions. Vegetation richness was significantly and directly related to range and entropy (3 × 3 and 5 × 5 windows). Both trees and shrubs, were related to SATVI values and first- and second-order means (3 × 3 and 5 × 5 windows). Moreover, shrub abundance was inversely related to range and entropy (5 × 5 window); and the "other plants" group was inversely related to first- and second-order means in the same window. Variance of the canopy area was directly related to range (5 × 5 window); however, proportion of adults was not related to remote sensing data. Our findings suggest satellite imagery-derived image texture is a valuable tool for management and conservation, and can indicate areas of high plant species richness and abundance of trees and shrubs and help differentiate areas of different canopy sizes in dry *P. flexuosa*-dominated woodlands of Argentina.

1. Introduction

Woodlands around the world have undergone substantial change in the past decades as a result of expanding human populations and economies (Allen et al., 2010). Changes in the quantity and quality of woodlands worldwide affect important global-scale ecosystem services including biodiversity, climate regulation, carbon storage, and water supplies (Hansen et al., 2013). If maintaining woodland ecological integrity is a goal of conservation, then it is necessary to evaluate the condition of this ecosystem using biodiversity indicators that allow quantifying spatial and temporal changes in vegetation (Lawley et al., 2015). This approach could include monitoring indicators of compositional, structural, and functional biodiversity. Compositional indicators include identity attributes, such as species richness, relative abundance, frequency, and proportions of endemic, exotic, threatened and endangered species. Structural indicators, on the other hand, are measures of the three-dimensional arrangement of vegetation, such as density of different plant forms, canopy cover, vegetation biomass, foliage density and layering, distribution of key physical features and ground components (Noss, 1990). Assessing the performance of indicators and their monitoring is a key aspect of management programs and practices (Pyke et al., 2002; Gaitán et al., 2013).

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Indicators of compositional, structure, and biological diversity can be measured using both field- and remotely-based measurements. These two methods have some differences in their spatial and temporal scales of application, costs, expertise required and, importantly, in the different environmental attributes and indicators each can quantify (Lawley et al., 2015). On the one hand, the need to locate site within homogeneous patches of vegetation probably depends on the research questions and scale of the study. According to Oliver (2002) for woodland and open forest vegetation communities in New South Wales (Australia), indicators of vegetation condition are obtained from field-based assessment, such as alpha diversity of native trees, cover of native and exotic species, cover of organic litter, and recruitment of native tree/shrub saplings, among others. However, shortcomings of this method are inconsistencies between different plot sizes, lack of replication and lack of multiple spatial scales. Field-based approaches are thus costly and time consuming, and difficult to implement in remote areas (see review Lawley et al., 2015). On the other hand, remotely sensed data is increasingly recognized for its applicability to ecological research, which includes quantifying and classifying land features, modeling ecosystem functions such as net primary productivity, mapping land cover change, and is used as a proxy for species richness and biodiversity across multiple spatial scales (see review Bradley et al., 2012). The ability of researchers to accurately measure vegetation characteristics using remotely sensed data varies with the sensor (i.e. spatial, spectral and temporal resolutions), background characteristics, and vegetation attributes of individual species such as size, shape, aggregation, phenology and physical structure such as canopy cover (Lawley et al., 2015).

In vegetation science and landscape ecology, remotely sensed images can be processed and classified using image processing software (Palmer et al., 2002). Classification of landscape into discrete units with specific climate, landforms, soils and vegetation provides a foundation for monitoring, conservation and management. Landscape stratification has been practiced worldwide and classifications are refined or updated as more information and data become available (Mücher et al., 2010). However, classification of an image to obtain discrete land cover classes can result in an important loss of information, such as within-class spatial variability in on-the-ground local attributes (e.g., vegetation cover or density). Moreover, another difficulty could be defining boundaries at transition zones between different land cover types (i.e. ecotones), or could involve an expensive process when an extensive ground-truthing survey is necessary to discriminate between different cover types (St-Louis et al., 2006). An alternative that addresses these drawbacks is the use of raw, unclassified imagery (Nagendra, 2001).

The reflectance of an image could be assessed by using spectral vegetation indices, which allow us to detect green vegetation reflectance and can be calibrated to indicate biomass, vegetation cover, productivity and vegetation types (see review Goirán et al., 2012). The variability in reflectance values among neighboring pixels, caused by horizontal and vertical variability in plants, can be captured by measures of an image texture, which quantify heterogeneity within a defined area of an image as a continuous variable (St-Louis et al., 2006, 2009; Bellis et al., 2008; Wood et al., 2012, 2013; Campos et al., 2015, Campos et al., 2016a,b). Image texture is an image analysis approach that can be applied to remotely sensed images to measure spatial variability in gray tones (e.g., for Digital Aerial Photographs) or reflectance values (from multi-spectral satellite data, Haralick et al., 1973). These indices have been used for characterizing vegetation patterns (Ge et al., 2006) and have been successfully applied to different species and environments to predict occurrence of bird species in grassland (Bellis et al., 2008), desert ecosystem (St-Louis et al., 2006, 2009), grassland, savanna, and woodland (Wood et al., 2012) as well as occurrence of large-sized mammals (*Tragelaphus eurycerus isaaci*, Estes et al., 2008) and small mammals (*Octomys mimax*, Campos et al., 2015). Since remote sensing data represents a powerful tool for deriving quantitative information about diversity, attempts were made to predict species richness by means of spectral heterogeneity. Species richness is a compositional indicator that has been widely used in research, since it is a direct proxy for α-diversity, i.e. the local diversity of a site (see review Rocchini, 2007). NDVI (Normalized Difference Vegetation Index) texture, as opposed to NDVI only, accounted for 65% of the variability in plant species richness in the Canadian Arctic (Gould, 2000) and predicted up to 43% of the variability in hardwood forest leaf area index (LAI) in Canada (Wulder et al., 1998). Moreover, texture of NDVI was the best predictor of bird species richness among all of the measures from individual Landsat TM bands in the Chihuahuan Desert, New Mexico (St-Louis et al., 2009). Identification and monitoring of sites with high species richness within a landscape can provide a basis for future monitoring and an ecological basis for species management and conservation (Rocchini, 2007).

In our research, we assess whether remote sensing data-derived image texture metrics are a good indicator of vegetation composition and structure at different scales, using as case study the dry woodlands of *Prosopis flexuosa* in the Monte Desert of Argentina, a dominant tree and therefore a key species in this ecosystem (Rossi and Villagra, 2003; Cesca et al., 2012). Our objectives were: (1) to quantify on-the-ground vegetation composition and structure using (A) field-based methods and (B) remotely sensed images and analysis techniques; and (2) to evaluate how well the data acquired from remotely sensed imagery estimates field-based measures of vegetation composition and structure in dry woodlands.

2. Methods

2.1. Study area

The study was conducted in Ischigualasto Provincial Park (Fig. 1), San Juan province, Argentina (29°55′ S, 68°05′ W) and its zone of influence. The Park has an area of 62,916 ha and is located in a hyper-arid sector of the Monte Desert, which corresponds to the northern section of Monte of hills and closed basins (Monte de Sierras y Bolsones). Average annual precipitation is 100 mm (Labraga and Villalba, 2009). Temperature is characterized by considerable day/night variations and a wide range throughout the year, (Abraham and Martínez, 2000); mean annual temperature is 22 °C, with a maximum of 45 °C and a minimum of −10 °C (Cortez et al., 2005). The study area is dominated by outcrops of sandstones with varying salt content; moreover, there are areas of fine-textured substrata (sands and clays) where water accumulates after a rainfall event (Márquez et al., 2005). The vegetation is xerophytic due to the low rainfall and high temperatures, with heterogeneous cover that ranges from 5 to 80% (Márquez et al., 2005).

2.2. Field survey

Fieldwork was conducted from August to December of 2016. We selected 40 individuals of *P. flexuosa* about 3 m tall (spaced at least 300 m apart, Fig. 2), and each of them was taken as the center of a 1500 m^2 plot (0.15 ha). For the purpose of our study, we wanted to focus on areas most likely to have one or more individuals of *P. flexuosa*. We therefore located our study plots where we could find trees along roads, which are known to be used for movements of the species' main dispersers (medium and large mammals, Campos et al., 2016a,b). Inside each plot, we ran five 30 m-long transects separated by 10 m, and listed all species of plants in 20 subplots (3 × 2 m, separated by 6 m), as well as recorded the number of individuals of each species. Based on this information, we calculated richness (compositional indicator) and abundance (structural indicator) of plants. To obtain a plot-level measure of richness, we recorded the tally of species across all subplots. To account for variations in the vertical structure of vegetation, we classified plant species into three groups (trees, shrubs, and other plants incl. cacti, grasses and forbs) and we summed up the total number of individuals belonging to each of the three groups across all subplots to