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How are landscape complexity and vegetation structure related across an agricultural frontier in the subtropical Chaco, NW Argentina?

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ABSTRACT

Human-driven alteration of the Chaco strongly affects ecological patterns and associated processes at all spatial scales. To understand these modifications, sufficient methods for describing and quantifying high levels of landscape complexity caused by human activities in the region are urgently needed. Most methods involve the use of passive remote sensors, which capture complexity in only two dimensions (2D). A common 2D approach has been to calculate landscape metrics, such as Shannon's Landscape Diversity Index. But, it is not clear what aspects of three dimensional (3D) vegetation structure are being captured by these metrics. 3D structure is known to be as important as or more important than 2D structure in determining landscape patterns of biodiversity of many groups of organisms. In addition, studies have used a limited number of coarsely defined land-cover classes to calculate metrics. Our question was: how is vegetation structure related to remote sensing attributes in an agricultural frontier in the subtropical dry Chaco, NW Argentina? A secondary question was to explore the relationships between traditional landscape metrics and the semivariogram, a geostatistical tool used to describe 2D complexity. We described landscape complexity from the panchromatic QuickBird band and measured vegetation structure in 22-1 ha plots across an agricultural frontier in the subtropical dry Chaco, northern Argentina. A total of 2683 individual trees in 51 plant species and 21 families were measured in the field and 25,665 points were recorded to estimate foliage height diversity. Four landscape complexity groups were identified by a two-way cluster analysis using the 2D metrics. Four vegetation variables differed significantly among the 2D complexity groups: the standard deviation of the Enhanced Vegetation Index, the coefficient of variation of density per transect (CV density), mean tree diameter (DBH), and foliage height diversity (FHD). Largest patch index and semivariogram range were negatively related to CV density, mean DBH and FHD, while semivariogram sill, mean shape index, landscape shape index and number of patches were positively related to all three vegetation variables. Landscape metrics were not related to tree species diversity or density as previously shown, probably as a result of structural similarity among the dominant tree species in the Chaco biome.

1. Introduction

Human-driven changes of landscapes are affecting biodiversity patterns and associated ecological processes at all spatial scales (MacDougall et al., 2013). Landscape complexity, broadly defined as the number, arrangement, and scaling relationships of key elements of ecosystem structure (Gustafson, 1998; Lovett et al., 2006), mediates changes in biodiversity patterns and associated processes. The mechanisms of this mediation are variable and include species' movement (Huffaker, 1958), changes in productivity and biomass (Daufresne and Loreau, 2001), and changes in food web structure (Bellisario et al., 2012). To understand the consequences of human-driven changes, methods for describing and quantifying landscape complexity are urgently needed.

Different methods to quantify changes in landscape complexity have been developed in the last decades (Lovett et al., 2006; Wu, 2013). Most of these methods involve the use of passive remote sensors which capture complexity in two dimensions (2D) (Hyde et al., 2006) and the calculation of landscape metrics to quantify 2D complexity, such as Shannon's Landscape Diversity Index (SDI)

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(Gustafson, 1998). These metrics reveal how landscape complexity affects processes occurring at species-, food web-, and ecosystem-scales (Kupfer, 2012), though most studies involving their calculation were interested in examining their behavior through time (Uuemaa et al., 2009) or were limited to a few coarsely defined land-cover classes such as forests. Alternatively, complexity can be described in three dimensions (3D). LIDAR (LIght Detection And Ranging) technology has been used successfully to capture vegetation 3D complexity (Lefsky et al., 2002) but the high costs of this technology still limit its application in most parts of the world (Selkowitz et al., 2012). In the absence of LIDAR and given that anthropogenic and natural disturbances affect habitats sometimes in a subtle manner we need to combine remote sensing and field data in order to identify what aspects of complexity are being modified by human activities (Pisek and Oliphant, 2013). But there are not enough field studies to confidently calibrate the information yielded by most remote sensors (Hall et al., 2011). In addition, studies quantifying 2D landscape complexity do not clearly link pattern to processes (Li and Wu, 2004; Cushman et al., 2008); thus we are not able to clearly interpret metrics. One way of interpreting the link between patterns and processes is examining what aspect of the 3D vegetation is being captured by landscape metrics.

Linking field data of vegetation structure to landscape complexity as determined from satellite images has shown to be complex (Malhi and Román-Cuesta, 2008) likely because vegetation structure depends on many factors such as plant species identities, species distributions, species life history traits, and disturbance history, among others (Whitmore, 1978). The degree to which each factor can be represented in 2D dimensions will determine how well vegetation structure is represented in satellite images (Broadbent et al., 2008). For example, studies have generally focused on plant species richness and they showed variable and sometimes contradictory relationships with landscape metrics. Kumar et al. (2006) showed that plant species richness was positively related to Simpson's landscape diversity, edge density and interspersion and negatively related to mean patch size; Moser et al. (2002) showed that it was positively related to shape complexity, and Burton and Samuelson (2008) showed that it was positively related to forest cover and largest patch index and negatively related to landscape diversity. Fewer studies have related other aspects of vegetation to landscape metrics (e.g. forest succession stage and crown closure were related to Shannon's landscape diversity (Terzioğlu et al., 2009)). Last, a smaller group of studies have examined vegetation characteristics in relation to semivariograms, a geostatistical tool used to describe 2D complexity from satellite images (Curran, 1988; Costantini et al., 2012). Semivariograms have been used mainly to characterize canopy cover (Cohen et al., 1990; Colombo et al., 2004; Johansen and Phinn, 2006) but it is not clear how they complement with traditional metrics. Because most studies focus on only one or two characteristics of vegetation to relate them to landscape metrics or their description of vegetation is frequently coarse, we still do not understand the generalities of the relationship between vegetation structure and remote sensing data. We need to refine the resolution of both, vegetation and remote sensing data in order to find these generalities. This approach will help us scale up the study of biological patterns and processes from plot to landscape.

Our question in this study was: how is vegetation structure related to remote sensing attributes in an agricultural frontier in the subtropical dry Chaco, NW Argentina? A secondary question was to explore the relationships between traditional landscape metrics and the semivariogram. We collected vegetation data at fine scale and QuickBird data in 22 1 ha-plots including forest, riparian forest, and agricultural fields across the agricultural frontier.

2. Methods

2.1. Study area

This study was conducted in the dry Chaco biome within the Tapia-Trancas watershed located in the province of Tucumán, NW Argentina (26°50′S, 65°20′W, Fig. 1). The dry Chaco, one of the three biomes within the Chaco, shows a continental, warm and subtropical climate with mean annual temperature of 20 °C (18–23 °C) and annual rainfall of 450 mm falling between October and March (Bianchi and Yáñez, 1992). It is characterized by subtropical xerophytic vegetation that includes spiny, small trees and shrubs, some cacti, herbs, epiphytes, and vines (Cabrera, 1976; Vervoost et al., 1981). Dominant tree species include *Schinopsis lorentzii* (Anacardiaceae) and *Aspidosperma quebracho-blanco* (Apocynaceae) whereas dominant shrubs include *Acacia aroma*, *Acacia praecox*, *Prosopis alba* and *Cercidium praecox* (Fabaceae) (Digilio and Legname, 1966).

During the last 40 years the Tapia-Trancas watershed has experienced increasing habitat degradation due to agricultural expansion, deforestation, grazing pressure, and fire (Aizen and Feinsinger, 1994; Grau et al., 2005; Aide et al., 2012). This has resulted in a complex mosaic of forest fragments embedded in a matrix of pastures, corn, sorghum, legume, and soybean fields. Large areas of nearly continuous dry Chaco forest can still be found surrounding the agricultural fields and urban areas are relatively small. As any other ecosystem edge, where particularly high species diversity and complex ecological interactions are found (Fagan et al., 1999), agricultural frontiers in the dry Chaco are a priority for conservation (Brown et al., 2005).

2.2. Image pre-processing

To describe landscape complexity we used a high resolution QuickBird image (2.6 m resolution for multispectral bands and 0.55 m resolution for panchromatic band) collected in November 2007, centered on the study site and covering an area of 10 × 10 km. This period of the year was selected because the rainy season had started and tree crowns were full of leaves. Accordingly, during this period the maximum biological activity occurs (e.g., Monmany and Aide, 2009).

QuickBird multispectral images have four bands (blue [450–520 nm], green [520–600 nm], red [630–690 nm], and near infrared [760–900 nm]) that yield information about differences between soil (blue band) and vegetation and information about different attributes of plant communities (green, red, and near infrared). The QuickBird data was subjected to a series of procedures. First, the red and infrared bands in the multispectral image were enhanced using the Gram-Schmidt Spectral Sharpening module in ENVI 4.8 (Exelis Visual Information Solutions, Boulder, Colorado). Through this pan-sharpening a low spatial resolution band (2.8 m in the multispectral image) is merged with a high-resolution band (the 0.55 m panchromatic band) with resampling to the high-resolution pixel size (Exelis Visual Information Solutions, 2004). The result is an image with the best spectral and spatial resolution possible. Second, the image was converted to top-of-atmosphere spectral radiance and then atmospherically corrected to at-surface spectral reflectance using the QUAC tool in ENVI 4.8.

Once corrected, we used the built-in function in ENVI to calculate the Normalized Difference Vegetation Index (NDVI) and we used Band Math to calculate the Enhanced Vegetation Index (EVI), both derived from combining the red (RED) and infrared (NIR) bands according to the following: