Remote Sensing of Environment 121 (2012) 516–526

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Image texture as a remotely sensed measure of vegetation structure

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ARTICLE INFO

Article history:
Received 25 March 2011
Received in revised form 4 January 2012
Accepted 8 January 2012
Available online 5 March 2012

Keywords:
Band 4
Foliage-height diversity
Horizontal vegetation structure
Image texture
Infrared air photo
Landsat
NDVI
Wildlife habitat

ABSTRACT

Ecologists commonly collect data on vegetation structure, which is an important attribute for characterizing habitat. However, measuring vegetation structure across large areas is logistically difficult. Our goal was to evaluate the degree to which sample-point pixel values and image texture of remotely sensed data are associated with vegetation structure in a North American grassland–savanna–woodland mosaic. In the summers of 2008–2009 we collected vegetation structure measurements at 193 sample points from which we calculated foliage-height diversity and horizontal vegetation structure at Fort McCoy Military Installation, Wisconsin, USA. We also calculated sample-point pixel values and first- and second-order image texture measures, from two remotely sensed data sources: an infrared air photo (1-m resolution) and a Landsat TM satellite image (30-m resolution). We regressed foliage-height diversity against, and correlated horizontal vegetation structure with, sample-point pixel values and texture measures within and among habitats. Within grasslands, savanna, and woodland habitats, sample-point pixel values and image texture measures explained 26–60% of foliage-height diversity. Similarly, within habitats, sample-point pixel values and image texture measures were correlated with 40–70% of the variation of horizontal vegetation structure. Among habitats, the mean of the texture measure 'second-order contrast' from the air photo explained 79% of the variation in foliage-height diversity while 'first-order variance' from the air photo was correlated with 73% of horizontal vegetation structure. Our results suggest that sample-point pixel values and image texture measures calculated from remotely sensed data capture components of foliage-height diversity and horizontal vegetation structure within and among grassland, savanna, and woodland habitats. Vegetation structure, which is a key component of animal habitat, can thus be mapped using remotely sensed data.

1. Introduction

Vegetation structure is an important attribute of wildlife habitat quality (Cody, 1981, 1985; MacArthur & MacArthur, 1961; Morrison et al., 2006; Nudds, 1977) and vegetation structure characteristics partition animal species both within and among habitats (Hutto, 1985; Rotenberry & Wiens, 1980; Wiens & Rotenberry, 1981). Throughout their lives, animals make habitat selection decisions at multiple scales (Morrison et al., 2006). For example, at broad scales, landbirds select habitat types with strongly different structural characteristics, such as a grassland or woodland (Cody, 1985). At fine scales, differences in vertical and horizontal vegetation structure are strongly associated with nest placement (Martin, 1993), and foraging site selection during migration (Hutto, 1985) and the breeding season (Robinson & Holmes, 1984). Thus, in the half century since MacArthur and MacArthur (1961) put forth their hypothesis that vegetation structure influences avian diversity, this relationship has become a central tenet of wildlife habitat selection theory (Morrison et al., 2006; Tews et al., 2004).

The measure *foliage-height diversity*, (MacArthur & MacArthur, 1961), or derivations of this measure, are commonly used to characterize vegetation structure. Foliage-height diversity quantifies vertical heterogeneity in vegetation structure at a given point. Furthermore, multiple measures of foliage-height diversity can be used jointly to derive an index of horizontal vegetation structure depicting the variation in canopy heights within a habitat patch (Wiens & Rotenberry, 1981). Similar indices of heterogeneity in horizontal vegetation structure such as cover-board measurements are linked with habitat density and patchiness (Nudds, 1977), which are useful descriptors for wildlife occurrence (McShea, 2000). Foliage-height diversity is a flexible measure that can describe avian habitat in ecosystems from sparse grasslands (Patterson & Best, 1996; Rotenberry & Wiens, 1980; Wiens & Rotenberry, 1981), to patchy deserts (Pidgeon et al., 2001), and dense forests (Estades, 1997; Karr & Roth, 1971). In addition, foliage-height diversity can characterize habitat for tropical mammal communities (August, 1983), ant biodiversity in grazed and ungrazed habitats (Bestelmeyer & Wiens, 2001), spider communities (Greenstone, 1984), and insect diversity (Murdoch et al., 1972; Southwood et al., 1979). However, while foliage-height diversity is a

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doi:10.1016/j.rse.2012.01.003

key measure for describing wildlife habitat, it is labor intensive to collect and consequently is mainly limited to small scale studies. Therefore, ecologists need efficient methods for characterizing foliage-height diversity, and its derived measures, at a sufficiently fine grain yet broad extent to be useful for management and conservation applications.

Remotely sensed data are powerful for characterizing habitat at broad extents, for example to describe landscape configuration (Kerr & Ostrovsky, 2003; Turner et al., 2001) and for assessing biodiversity (Gillespie et al., 2008; Laurent et al., 2005; Roughgarden et al., 1991; Turner et al., 2003). Broad scale land cover classifications are useful predictors of wildlife occurrence (Anderson, 1976; Thuiller et al., 2004; Venier et al., 2004). Indices derived from remotely sensed data sources, such as the normalized difference vegetation index (NDVI), which is a proxy for vegetative cover and productivity, are associated with patterns of wildlife species richness (Bailey et al., 2004; Seto et al., 2004; St-Louis et al., 2009), and habitat suitability at broad spatial extents (Naugle et al., 1999). Additionally, Light Detection and Ranging (LiDAR) can characterize vegetation heights at smaller spatial resolutions, which are positively associated with animal distributions (Vierling et al., 2008), occurrence (Seavy et al., 2009), diversity (Clawges et al., 2008; Goetz et al., 2007; Lesak et al., 2011), and habitat quality (Goetz et al., 2010; Hinsley et al., 2006). However, among the remote sensing data that are used to characterize wildlife habitat, LiDAR and Synthetic Aperture Radar (SAR) are the only products from which foliage-height diversity can be mapped (Bergen et al., 2009; Clawges et al., 2008). Unfortunately though, while SAR data are widely available, LiDAR data are not. Furthermore, there are limited image archives for LiDAR, in contrast to satellite imagery (e.g., Landsat TM), thus it is not possible to analyze change in vegetation structure over time.

However, while optical satellite data or air photos cannot measure vegetation height directly, remotely sensed image texture may be a good proxy of vegetation structure. Image texture has been used to characterize distributions of landbirds in heterogeneous habitat types including eastern North American deciduous and coniferous forests (Culbert et al., 2009; Hepinstall & Sader, 1997; Tuttle et al., 2006), desert shrublands and grasslands (St-Louis et al., 2006, 2009), and agricultural grassland ecosystems (Bellis et al., 2008), and habitat selection patterns of the endangered mountain bongo (*Tragelaphus eurycerus isaaci*) in east African montane forests (Estes et al., 2008, 2010). Image texture measures the heterogeneity in the tonal values of pixels within a defined area of an image. Image texture data is fine grained, depending on the image resolution, yet broad in extent, a combination of attributes that are desirable for landscape-scale characterization of wildlife habitat.

In addition to its use in characterizing animal distribution patterns, image texture has also been used for characterizing vegetation patterns (Ge et al., 2006) and as input for vegetation classifications, for example in the Canadian Rocky Mountains (Zhang & Franklin, 2002), Canadian coastal forests (Coburn & Roberts, 2004), African grasslands and savannas (Hudak & Wessman, 1998, 2001), and African montane habitats (Estes et al., 2008, 2010). However, to our knowledge, no study has directly evaluated the use of image texture for quantifying vegetation structure as represented by foliage-height diversity. This relationship is important to understand because it is presumably the ability of image texture to measure vegetation structure that underlies its strong correlation with wildlife diversity measures.

Our goal was to evaluate the strength of the relationship of remotely sensed pixel values and image texture measures, calculated from air photos and satellite images, with foliage-height diversity and horizontal vegetation structure that are widely used to characterize wildlife habitat. We conducted this analysis in a North American grassland–savanna–woodland mosaic where the wide range of vegetation structural characteristics provided an appropriate setting for testing these relationships. Our specific objectives were 1) to determine which sample-point pixel value summaries and image texture measures derived from air photos and Landsat TM data were best at characterizing foliage-height diversity and horizontal vegetation structure both within and among habitats and 2) to offer recommendations for using remotely sensed measures of texture in wildlife habitat models.

2. Materials and methods

2.1. Study site

Our study area was the 24, 281 ha Fort McCoy Military Installation, in the Driftless Area of southwestern Wisconsin, USA (Fig. 1). The dominant habitat types at Fort McCoy include grasslands (defined here as less than 5% tree canopy cover), composed of grasses and forbs with intermittent patches of bare ground and low shrub cover; oak savannas (5–50% tree canopy cover with variable shrub cover), and woodlands (>50% tree canopy cover with variable shrub cover, Curtis 1959, Fig. 2). Dominant tree species include black oak (*Quercus velutina*), northern pin oak (*Quercus ellipsoidalis*), bur oak (*Quercus macrocarpa*), jack pine (*Pinus banksiana*), black cherry (*Prunus serotina*), red oak (*Quercus rubra*), and white oak (*Quercus alba*). Dominant shrubs include blueberry (*Vaccinium angustifolium*) and American hazelnut (*Corylus americana*), while dominant grasses include big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*).

Fort McCoy is an operational military installation and approximately 50% of its area is off limits to non-military personnel. Of the remaining area, roughly 16% is grassland, 24% is oak savanna, and 40% is oak woodland. Small patches of cattail marshes, riparian tracts, and bogs make up the remaining 20%. Within these areas, a stratified random sampling design was used to select points for ground based foliage-height diversity quantification and image texture calculation. Three habitat types, grassland, oak savanna (hereafter savanna), and oak woodland (hereafter woodland) were classified using an infrared air photo and a digital raster graphic map depicting land cover types.

Polygons encompassing patches of the three focal habitat types were manually digitized. Within the digitized polygons, 400 random sample points were generated using Hawth's Tools extension (Beyer, 2004) in ArcGIS 9.1 (ESRI, Redlands, California, USA, 2006). Reflectance of roads or other non-vegetative areas (i.e., buildings) can influence texture calculations, so all sample points that were within 150 m of a paved road or human structures were removed from consideration. Sample points that were located within 150 m of marginal roads (i.e., non-paved, single vehicle tracts) were included in this analysis because marginal roads were similar in their effect on image texture to naturally occurring bare areas. From this set, sample points that were surrounded by at least 100 m of one habitat type, and that were separated from other sample points by at least 300 m, were retained. This resulted in a total of 193 sample points, with 49 sample points in grassland, 84 in savanna, and 60 in woodland (Fig. 1).

2.2. Foliage-height diversity field measurements

Foliage-height diversity was measured, following the methods of Martin et al. (1997), at each sample point once from mid-June to late July in 2008 or 2009, which corresponded to the peak growing season for vegetation at our study area. Mean temperatures from March 1 to August 15, which corresponded to the time frame ranging from the early spring thaw to the duration of our foliage-height diversity sampling, were not significantly different between 2008 (10.94 °C) and 2009 (11.23° C, $t_{167} = -0.60$, $p = 0.55$). Similarly, mean precipitation of 2008 (log transformed, 0.35 mm) and 2009