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An approach for characterizing the distribution of shrubland ecosystem components as continuous fields as part of NLCD

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A B S T R A C T

Characterizing and quantifying distributions of shrubland ecosystem components is one of the major challenges for monitoring shrubland vegetation cover change across the United States. A new approach has been developed to quantify shrubland components as fractional products within National Land Cover Database (NLCD). This approach uses remote sensing data and regression tree models to estimate the fractional cover of shrubland ecosystem components. The approach consists of three major steps: field data collection, high resolution estimates of shrubland ecosystem components using WorldView-2 imagery, and coarse resolution estimates of these components across larger areas using Landsat imagery. This research seeks to explore this method to quantify shrubland ecosystem components as continuous fields in regions that contain wide-ranging shrubland ecosystems. Fractional cover of four shrubland ecosystem components, including bare ground, herbaceous, litter, and shrub, as well as shrub heights, were delineated in three ecological regions in Arizona, Florida, and Texas. Results show that estimates for most components have relatively small normalized root mean square errors and significant correlations with validation data in both Arizona and Texas. The distribution patterns of shrub height also show relatively high accuracies in these two areas. The fractional cover estimates of shrubland components, except for litter, are not well represented in the Florida site. The research results suggest that this method provides good potential to effectively characterize shrubland ecosystem conditions over perennial shrubland although it is less effective in transitional shrubland. The fractional cover of shrub components as continuous elements could offer valuable information to quantify biomass and help improve thematic land cover classification in arid and semiarid areas.

1. Introduction

Shrubland ecosystems provide critical habitat for many wildlife species and are important for sustaining a variety of landscape functions and ecosystem services in arid and semiarid areas in the western United States (Perfors et al., 2003; Davies et al., 2006; Anderson and McCuistion, 2008). Shrubland ecosystems also serve as a sensitive proxy for revealing the impacts of environmental variability on the biological diversity and ecological conditions of arid and semiarid areas. The spatial extent and density of shrubland ecosystems are also critical to influence surface soil moisture for land surface energy and water balance.

Many recent changes have occurred in arid and semiarid ecosystems throughout the western United States, including diminishing vegetation cover and degradation of sagebrush the most abundant shrubland ecosystem (Connelly et al., 2004; Schroeder et al., 2004). For example, the quality and quantity of sagebrush ecosystems have steadily declined and the speed of the deterioration has accelerated in recent decades (Berlow et al., 2002). Many of these changes have been attributed primarily to human activities (Davies et al., 2007). For example, recent natural gas energy extraction activities in western Wyoming in the United States have significantly impacted sagebrush communities in the region (Walston et al., 2009) and will continue to have impacts as such activities continue. Invasive species such as cheatgrass (*Bromus tectorum*) also reduced abundance of shrublands (Bradley et al., 2006). Climate presents another important driver of change in shrubland ecosystems (Brown et al., 1997; Munson et al., 2011). Most shrubland components in semiarid lands are vulnerable to climate variations, especially to precipitation changes, because of low soil moisture content (Reynolds et al., 1999; Weltzin et al., 2003). Moreover, variations in precipitation strongly influence arid and semiarid land plant composition and dynamics (Branson et al., 1976; Cook and Irwin,

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1992; Pelaez et al., 1994; Ehleringer et al., 1999; Reynolds et al., 2000). A recent study using image change analysis showed that bare ground had a net increase at a rate of 0.7% and sagebrush canopy cover had a net decline at a rate of 2.7% between 1988 and 2006 in the southwestern part of Wyoming (Xian et al., 2012a). Over 60% of the measured variation was due to gradual changes directly related to climatic perturbations (Xian et al., 2012b). Because water is the most limiting resource in arid and semiarid environments, changes in global or regional climate patterns that usually influence precipitation regimes can bring substantial effects. Given the rates of potential reduction of shrubland ecosystems, coupled with the relatively slow recovery potential of these components, information on ecosystem distribution and temporal variation is important for evaluating the source and impact of change, the subsequent pattern, the causes of change, and ultimately implementing effective management to address it.

Historically, however, shrubland ecosystem components have not been easily measured. Traditional field-based monitoring methods are generally most useful for observing and recording plant conditions in specific locations (Davies et al., 2006). Field observations are generally confined to short-term field measurements with limited samples. According to the 2001 USGS National Land Cover Database (NLCD) (Homer et al., 2004), shrub canopy accounts for about 21.0% of the total land cover in the conterminous United States. Field-based monitoring methods are woefully inadequate for monitoring such a large expanse. Additionally, for highly heterogeneous shrub ecosystems, different vegetation types such as herbaceous and shrub usually grow close together, making it difficult to quantify true cover amounts of different components using thematic land cover data, leading to large uncertainties for biomass estimates in shrubland. Given the vast geographic extent and the heterogeneous nature of shrubland ecosystems in the United States, an effective and comprehensive method is needed to quantify the density and spatial distribution of shrubland ecosystem components at a national scale. Maps of percent cover of shrubland components, rather than percent shrub cover alone, could provide most useful information for quantifying distributions of and characterizing cover features of shrub ecosystems.

Many efforts have been made to characterize spatial distributions of shrubland ecosystem components using both ground observations and remote sensing data. However, most of these studies have focused on either a local or regional scale using either high or moderate resolution remotely sensed data (Ramsey et al., 2004; Seefeldt and Booth, 2004; Stow et al., 2008; Underwood et al., 2007; Hamada et al., 2011). In addition, Landsat has collected globally available data and has provided extensive spatial coverage and moderate spatial resolution data for nearly three decades, offering the potential to better quantify the distribution and variation of terrestrial shrubland ecosystems. More recent work has shown that Landsat data can be effectively used to estimate spatial distributions of shrubland ecosystem components over larger areas (Sivanpillai et al., 2009; Walston et al., 2009). Homer et al. (2012) developed a methodological protocol using QuickBird and Landsat imagery based on sagebrush ecosystems across Wyoming, and Xian et al. (2012a) demonstrated the effectiveness of these prototype products for monitoring abrupt and gradual change. Because of these successes, we proposed an approach of using remote sensing data and regression tree models could be effective for other shrublands in the United States and designed this research to explore performance over different shrubland ecosystems. Because no accurate fractional vegetation estimate of shrubland ecosystems exists for the conterminous United States (CONUS) and because many of these shrub ecosystems face a variety of disturbance factors, developing fractional vegetation estimates for shrubland ecosystems capable of monitoring disturbances is a priority for the NLCD. Hence, a national shrub fractional vegetation prototype product is developed and the product is expected to be incorporated in future versions of the NLCD. In this paper, we summarize prototype research for developing fractional vegetation estimates in CONUS by focusing on four main objectives including (1) developing a strategy of using a field data protocol, high and moderate spatial resolution imagery, and modeling approach; (2) testing the strategic approach to quantify the fractional cover of shrubland ecosystem components, including bare ground, herbaceous, litter, and shrub and shrub height, as continuous field products in different geographic locations across CONUS; (3) generating spatial distribution and structure information of different shrubland ecosystem components in different ecological regions; and (4) evaluating the accuracies of continuous variables for these shrubland components and the practicality of this strategic approach to produce fractional cover of shrubland components as a product of the NLCD.

2. Data and methods

2.1. Study areas

Three study areas located in different ecological regions where shrub cover is one of the dominant land cover types were selected to assess the approach (Fig. 1). Public lands in each study area were targeted for field sample collection. The red dots represent locations where field samples were collected. The locations were chosen based on shrub ecology, analysis of aerial photographs, Landsat imagery, topographic maps, land cover conditions, and availability of public access. Fig. 1 shows general landscape features of the sampling sites in the three areas.

The first study area is within the Arizona/New Mexico Mountains ecoregion (Omernik, 2004) and stretches along the extent of Landsat path 37 and row 36 in the Worldwide Reference System-2 (WRS2) that all paths and rows mentioned in this study are based on. Field data were collected in the Agua Fria National Monument, which is managed by the Bureau of Land Management and encompasses about 287 km^2. The Monument contains many desert and semi-desert ecosystems in a high mesa semi-desert with a mix of grassland and perennial shrubs as the dominant land cover type. The vegetative communities and topographic features are diverse, and a dormant volcano decorates the landscape with a big rocky and basaltic plateau. Elevations range from 655 m above sea level along the Agua Fria Canyon to about 1402 m in the northern hills. This expansive semi-desert mosaic, cut by ribbons of valuable riparian forest, offers one of the most important semi-desert shrub ecosystems in the southwestern United States. Major shrub species in the area include creosote bush (*Larrea tridentata*), bur sage (Ragweed), and mesquite scrub. Cactus including saguaro (*Camegiea gigantea*), cholla, and prickly pear (Opuntia), and trees including pinyon juniper and ponderosa pine (*Pinus ponderosa*), are widespread in the area.

The second study area stretches along the Southern Texas Plains ecoregion and is located in Landsat path 28 and row 40. The Chaparral Wildlife Management area, which encompasses approximately 61 km^2 within the southern part of the Landsat scene, was selected for field sample collection. The management area is composed of scrub-brush rangeland typical of south Texas and perennial shrub cover and grass are the dominant land cover types. The area receives an average of 75 cm of precipitation annually with peaks in April-June and August-October (Nolte et al., 1994). Soils are sandy loams, and topography consists of gently rolling hills interspersed with ephemeral drainage systems. Woody vegetation in the area is dominated by mesquite, whitebrush (*Aloysia gratissima*), blackbrush acacia (*Acacia rigidula*), guayacan (Guaiacum), and prickly pear (Opuntia).