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Interpretation of high-resolution imagery for detecting vegetation cover composition change after fuels reduction treatments in woodlands☆

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ABSTRACT

The use of very high resolution (VHR; ground sampling distances < ~5 cm) aerial imagery to estimate site vegetation cover and to detect changes from management has been well documented. However, as the purpose of monitoring is to document change over time, the ability to detect changes from imagery at the same or better level of accuracy and precision as those measured in situ must be assessed for image-based techniques to become reliable tools for ecosystem monitoring. Our objective with this study was to quantify the relationship between field-measured and image-interpreted changes in vegetation and ground cover measured one year apart in a Piñon and Juniper (P–J) woodland in southern Utah, USA. The study area was subject to a variety of fuel removal treatments between 2009 and 2010. We measured changes in plant community composition and ground cover along transects in a control area and three different treatments prior to and following P–J removal. We compared these measurements to vegetation composition and change based on photo-interpretation of ~4 cm ground sampling distance imagery along similar transects. Estimates of cover were similar between field-based and image-interpreted methods in 2009 and 2010 for woody vegetation, no vegetation, herbaceous vegetation, and litter (including woody litter). Image-interpretation slightly overestimated cover for woody vegetation and no-vegetation classes (average difference between methods of 1.34% and 5.85%) and tended to underestimate cover for herbaceous vegetation and litter (average difference of −5.18% and 0.27%), but the differences were significant only for litter cover in 2009. Level of agreement between the field-measurements and image-interpretation was good for woody vegetation and no-vegetation classes (*r* between 0.47 and 0.89), but generally poorer for herbaceous vegetation and litter (*r* between 0.18 and 0.81) likely due to differences in image quality by year and the difficulty in discriminating fine vegetation and litter in imagery. Our results show that image interpretation to detect vegetation changes has utility for monitoring fuels reduction treatments in terms of woody vegetation and no-vegetation classes. The benefits of this technique are that it provides objective and repeatable measurements of site conditions that could be implemented relatively inexpensively and easily without the need for highly specialized software or technical expertise. Perhaps the biggest limitations of image interpretation to monitoring fuels treatments are challenges in estimating litter and herbaceous vegetation cover and the sensitivity of herbaceous cover estimates to image quality and shadowing.

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1. Introduction

Ground cover and plant composition are important ecological indicators used to assess soil and site stability, hydrologic function and biological integrity in rangelands and woodlands (Pyke et al., 2002; Booth and Tueller, 2003). Thus collecting quantitative monitoring data on these indicators is important to assess trends of the

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biophysical components of an ecosystem to support land-use management and policy decisions at multiple scales (National Research Council, 1994).

Remote-sensing approaches have been proposed to monitor vegetation cover and composition in rangelands because ground-based sampling is often not economical due to logistical (e.g., inaccessibility) and budget (e.g., cost of field visits) constraints (Booth and Tueller, 2003; Hunt et al., 2003; Washington-Allen et al., 2006). Estimating ground cover from aerial or satellite imagery can, under the right conditions, have advantages including increased speed, flexibility, repeatability, and convenience in the time and place to make measurements (Booth and Tueller, 2003).

Remote-sensing approaches to monitoring include area-wide predictions of cover and composition (Dymond et al., 1992; Marsett et al., 2006; Homer et al., 2012) and deriving estimates for selected sample locations and extrapolating those estimates to a larger area (Hengl et al., 2004; Karl, 2010). Additionally, cover can be estimated from imagery via classification techniques (e.g., Shupe and Marsh, 2004; Bork and Su, 2007; Navulur, 2007), biophysical models (e.g., Running et al., 2004; Schott, 2007), and image interpretation (e.g., Booth et al., 2005a; Booth and Cox, 2008; Duniway et al., 2011; Karl et al., 2012a).

Vegetation cover across landscapes has been estimated with moderate-resolution image products (e.g., Qi et al., 2002; Scanlon et al., 2002; Ramsey et al., 2004; Xiao and Moody, 2005). However, very high-resolution (VHR) imagery (i.e., less than 5 cm ground-sample distance [GSD]) is often necessary to estimate vegetation cover and composition from imagery at site scales because of the importance of distinguishing plant species (or life forms), dead plant material (i.e., litter), and bare ground (Booth and Cox, 2008) and the potential for resolving individual plants, rocks, and other soil surface components such as biologic and physical crusts.

Vegetation cover and composition in rangelands has been successfully estimated from VHR imagery using both automated image classification techniques (Fensham and Fairfax, 2003a; Laliberte et al., 2006, 2010; Luscier et al., 2006) and manual image interpretation (Booth and Tueller, 2003; Seefeldt and Booth, 2006; Moffet, 2009). Duniway et al. (2011) and Knapp et al. (1990) showed that image interpretation to measure rangeland ground cover and community composition was repeatable among independent observers. Karl et al. (2012b) used interpretation of VHR imagery to classify vegetated and non-vegetated areas and calculate vegetation canopy gaps consistent with field measurements.

Several studies have examined the ability to detect changes in rangelands from VHR imagery due to management. Booth and Cox (2008) used detected livestock stocking rate differences in short-grass prairie using 1 mm GSD imagery. In a separate study, Booth and Cox (2009) used VHR imagery ranging from 1 mm to 20 mm GSD to assess oil and gas pipeline reclamation in Wyoming. Both of these studies, however, compared different areas within the same image acquisition campaign (i.e., the same time period). Few studies correlating image-interpretation to field-based estimates have looked at detecting changes in rangelands over multiple dates of imagery.

As the purpose of monitoring is to assess change over time, the ability to accurately detect changes from imagery commensurate with changes measured in situ must be assessed. Two studies typify approaches to detecting change with VHR imagery using automated classification techniques. Zerger et al. (2012) looked at a 6-month time series of images taken every 90 minutes from a nadir-pointing ground camera (1 m^2 field of view [FOV], 0.55 mm GSD) and estimated ground cover (classified into live vegetation, attached litter, detached litter, and bare ground). They saw high temporal agreement between image and field measurements for live vegetation and bare ground classes, but found poor agreement for litter classes that were difficult to discriminate in the imagery. Bennett et al. (2000) also evaluated a time series of very-high resolution ground images (1 m^2 FOV, 2 mm GSD) to assess changes in total vegetation cover in seven images over a two-year span. They were able to detect ground cover changes from classified images consistently over time and among treatments using field measures of biomass. Both of these studies used ground-based cameras with small FOV and GSD. Thus there is need to examine the concordance of field- and image-measured vegetation change at landscape scales using aerial imagery.

Since the early 2000s extensive fuel reduction treatments have been implemented across hundreds of thousands of hectares of Piñon and Juniper (P–J) woodlands and rangelands with encroaching P–J. The goal of the national fuels program is to reduce the risk of wildland fire while restoring forests and rangeland ecosystems to a more historical structure, function, and diversity (http://nationalatlas.gov/mld/firplnp.html). Funding for monitoring the effects of fuels reduction treatments, however, is limited. Following this, there is a clear need to develop treatment-monitoring approaches that: are economically feasible within limited fuels budgets, require limited expertise, and may be implemented by staff with limited training in high resolution imagery analysis. Our objective was to assess agreement between field-measured and image-interpreted changes in vegetation and ground cover taken one year apart in a P–J ecological site in southern Utah, USA that was subject to an extensive fuel (woody vegetation) removal treatment.

2. Materials and methods

2.1. Study area

This study was conducted within the Colorado Plateau region of southeastern Utah on Shay Mesa (37.9858°N, 109.5575°W), on an Upland Shallow Loam P–J ecological site (Site ID: R035XY315UT, U.S.D.A. Soil Conservation Service, 1991), approximately 31 ha in size (Fig. 1). At an elevation of 2237 m, Shay Mesa is located approximately 45 km northeast of Monticello, UT, USA. The mean annual precipitation is 317 mm and follows a bimodal distribution with monsoonal rains in the summer and snow in the winter. The mean annual maximum and minimum temperatures are 18.2 °C and 3.0 °C, respectively (http://www.prism.oregonstate.edu, Accessed 22 March, 2013).

Shay Mesa was chained to remove trees and shrubs and seeded in 1959 but has since undergone rapid recolonization by two needle piñon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* (Torr.) Little), which were the primary overstory species. Other common native plants found within the study site included mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle), broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britton & Rusby), Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult.) Barkworth), and blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths).

2.2. Vegetation treatments

In the summer of 2009, a fuel reduction vegetation treatment was conducted to reduce risk of catastrophic wildfire and restore the historic vegetation structure and diversity. Three methods were used to determine which best promoted native understory species growth while preventing exotic grass establishment and minimizing soil erosion: mechanical P–J mastication (M), lopping of P–J with the slash collected in piles then burned (P), and lopping of P–J with the slash scattered and followed by a broadcast burn (B). An additional area was left untreated to serve as a control site (C) (Fig. 1).