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Assessment of sagebrush cover using remote sensing at multiple spatial and temporal scales

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ABSTRACT

Rangelands occupy a large portion of the Earth's land surface and provide many ecosystem services to human populations around the world. Increasingly, however, the ability of rangelands to continue providing these services is challenged by anthropogenic influence. There is an urgent need to monitor changes in rangelands through time and across large geographic areas. Current field-based methods used to assess and monitor rangelands are limited because of their inability to account for spatial and temporal variation. An alternative approach is presented to assess rangelands using high resolution imagery as enhanced ground samples and multi-spatial remote sensing imagery to quickly, cheaply, and effectively map basic land cover components. High-resolution, ground-based natural color vertical photography captures, in space and time, percent cover of vegetative and abiotic components at the plot level. This imagery maintains a visual history of percent cover allowing other investigators the ability to repeat the observation or use other sampling techniques to extract improved or additional information. These plot-based measures are then linked to airborne or satellite acquired imagery allowing for extrapolation of ground measurements across large landscapes. Linking plot-based measures to remotely sensed imagery can allow for documentation of change across the past 30 years utilizing Landsat imagery. Our process was applied to a sagebrush-steppe landscape in northern Utah with promising results. Extrapolation of percent vegetation cover data extracted from ground-based natural color vertical photography to 1 m resolution Ikonos imagery using regression tree analysis resulted in an overall R^2 value of 0.81 while an extrapolation to 30 m Landsat Thematic Mapper resulted in an R^2 of 0.90 using a 5-fold cross-validation. A comparison between independently acquired ground measurements from multiple time intervals showed a moderately strong correlation of $R^2 = 0.65$ for Landsat Thematic Mapper. This technique has great potential to place land cover change and rangeland health in a contextual perspective that has not been available before. In this way, past management practices can be evaluated for their effectiveness in altering basic cover components of rangelands. With this hindsight, improved management prescriptions can be developed providing a valuable tool in assessing public land grazing allotments for renewal or habitat quality for sensitive wildlife species like greater sage-grouse.

1. Introduction

Rangelands are widely distributed and occupy a large portion of the world's available land. Estimated global land area of rangelands varies widely from as little as 30% to nearly 70% based on the definition of rangelands (Lund, 2007; Breckenridge et al., 2008; Food and Agriculture Organization of the United Nations, 2009). Nonetheless, rangelands support almost one-third of the global human population, store about half of the global terrestrial carbon, support 50% of the world's livestock, and contain over one-third of the biodiversity hot spots (James et al., 2013). The monitoring and assessment of rangelands is thus of critical importance.

Monitoring of rangelands, however, is complicated by the high degree of spatial and temporal variation in vegetation and soil. To provide meaningful information about rangelands requires an evaluation across large landscapes and over extended periods of time (Booth and Tueller, 2003; Palmer and Fortescue, 2003; Washington-Allen et al., 2006). Moreover, semi-arid and arid rangelands are significantly influenced by the quantity and timing

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of precipitation creating extreme inter-annual variation (Noy-Mier, 1973; Sharp et al., 1990). Evaluating rangelands and their response to specific management (e.g., grazing) can therefore be difficult (Pickup et al., 1998; Blanco et al., 2009). Traditional field-based monitoring is usually insufficient to accurately assess ecological status or to detect important changes across large geographic areas outside of the plot extent (National Research Council, 1994; Donahue, 2000). Increasing the number of traditional ground-based monitoring plots across large spatial and temporal scales is often prohibitively expensive and still has limited evaluative capabilities (Friedel et al., 1993; Bastin et al., 1993; West, 1999).

The inadequacies of traditional ground-based sampling for rangeland assessment could be the reason that the largest rangeland management entity in the United States, the United State Department of Interior – Bureau of Land Management (USDI-BLM), has only inventoried an average of 0.6% of its national land holdings annually (~113 million ha) from 1998 to 2007, resulting in 5.4% being inventoried over this time period (USDI-BLM, 2012). Often, land-use plans are renewed without formal assessment of rangelands as required by the National Environmental Protection Act (NEPA). Most grazing allotment renewals in the past few decades have been completed via a "grazing rider" attached to the Department of Interior's Appropriation Bill. This renewal process keeps in place the terms and conditions of previous allotment management plans without assessing whether "Standards and Guidelines" of rangeland health are satisfied. This lack of feedback limits the ability of land managers to improve knowledge of the systems' ecology and to respond adaptively (Boyd and Svejcar, 2009).

The application of remote sensing technology to rangeland assessment has the potential to remove some of these limitations. While coarse resolution remote sensing technology cannot, directly identify plant species, it has had success in determining percent ground cover using vegetation indices like the normalized difference vegetation index (NDVI) at coarse resolution like 30 m Landsat imagery. Percent ground cover is not, in itself, an indicator of range condition, but when assessed over large landscapes and over long time periods, the patterns of percent ground cover change caused by management action can be separated from changes due to climatic variability, soils, or geomorphology (Pickup et al., 1994, 1998).

Using remote sensing technology, Homer et al. (2012) mapped percent cover of basic vegetative components over big sagebrush (*Artemisia* sp.) landscapes of the western United States. They used regression tree analysis on multi-scale imagery with three nested spatial scales including traditional on-the-ground field sampling, Quickbird 2.4 m imagery, and Landsat 30 m imagery to predict percent cover. Additionally, NDVIs were created from Quickbird and Landsat imagery to predict cover. To assess the accuracy of the multi-scale and NDVI predictions, correlation coefficients were determined using a linear regression of the predicted values against independent ground-based vegetation measurements. The correlation coefficients of the nested multi-scale predictions were $R^2 = 0.51$ for Quickbird imagery and $R^2 = 0.26$ for Landsat imagery. The Quickbird and Landsat NDVI predictions were $R^2 = 0.18$ and $R^2 = 0.09$, respectively. These results, while promising for very large scale assessment and planning, are not precise enough on a scale to support local adaptive resource management.

The need for cost effective assessments of rangeland with high spatial resolution and improved accuracy for management applications has stimulated research in the use of high-resolution photography for rangeland assessment. High resolution, nadir photography can serve as a realistic ground plot. It is information rich, understandable to a broad base of people, and the unanalyzed information can be archived for future use. This ability to revisit imagery that documents actual field conditions at the time of collection is not possible through conventional field data collection techniques. Archived field plot imagery can therefore be reviewed by many observers at later times using potentially improved or multiple techniques to record land cover. High resolution imagery, less than 1 cm, is being used by a number of researchers (e.g., Breckenridge et al., 2011; Cagney et al., 2011; Karl et al., 2012; Mirik and Ansley, 2012). Results to date are mixed, but strong correlation coefficients of $R^2 = \sim 0.90$ have been observed for bare ground. Using high resolution imagery, Pilliod and Arkle (2013) found that photography-based grid point intercept (GPI) in Great Basin plant communities was strongly correlated to line point intercept (LPI) but it was 20–25 times more efficient, identified 23% more plant species, and was more precise in determining percent cover. Furthermore, they found that GPI could precisely estimate cover of basic vegetation components when they exceeded 5–13% while LPI cover estimates had to exceed 10–30% cover for equal precision. Detecting change when percent cover is low is very important in arid lands where land cover is typically sparse.

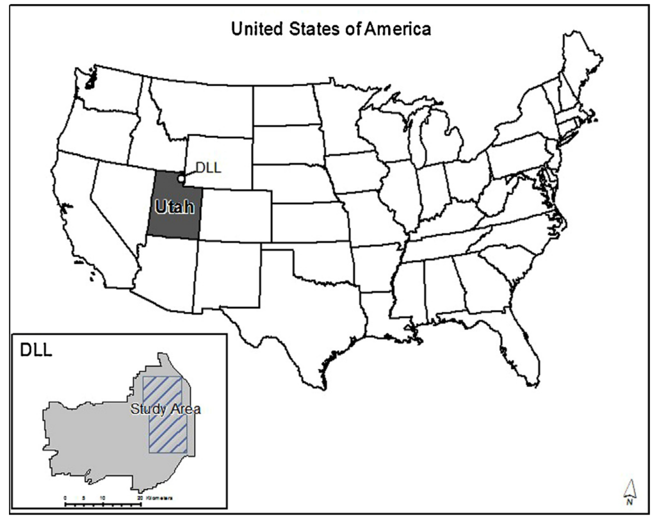

Fig. 1. Study area location in relation to the United States, Utah, and Deseret Land and Livestock (DLL). The actual study area is bounded north to south by 41.439° N and 41.258° N and east to west by 111.057° W and 111.195° W.

The method presented in this paper integrates the use of high resolution photography as enhanced ground samples and as a training dataset for multiple scales of remotely sensed imagery. It models the percent cover of bare ground, shrub, and herbaceous vegetation cover across big sagebrush (*Artemisia* sp.) landscapes in the western United States. It can provide information on sagebrush dominated rangelands at spatial scales from millimeters to kilometers, across multiple years. We show that this method maps commonly used and functionally important cover types with considerable success and increased precision.

2. Methods

2.1. Study area

The study area is part of the 20,263 ha Deseret Land and Livestock (DLL) ranch in Rich County, UT, USA (Fig. 1) in the Middle Rocky Mountains physiographic region. The ranch ranges in elevation from 1928 to 2270 m. Annual precipitation has ranged from 11 cm to 40 cm with an average of 24 cm since 1897. Temperatures during this same period averaged a low of −18 °C in January and a high of 28 °C in July (Western Regional Climate Center, 1986). Dominant landcover types include short sagebrush (*A. nova* and *A. arbuscula*) and big sagebrush (*A. tridentata*). Where big sagebrush communities had been treated (mechanical, fire, or herbicide), crested wheatgrass (*Agropyron desertorum*) was dominant. The