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Estimating sagebrush cover in semi-arid environments using Landsat Thematic Mapper data

Ramesh Sivanpillai [a,*], Steven D. Prager [b], Thomas O. Storey [b]

[a] Wyoming Geographic Information Science Center, University of Wyoming, 1000 E University Avenue, Laramie, WY 82071, USA
[b] Department of Geography, University of Wyoming, Laramie, WY 82071, USA

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ABSTRACT

Sagebrush ecosystems of the western US provide important habitat for several ungulate and vertebrate species. As a consequence of energy development, these ecosystems in Wyoming have been subjected to a variety of anthropogenic disturbances. Land managers require methodology that will allow them to consistently catalog sagebrush ecosystems and evaluate potential impact of proposed anthropogenic activities. This study addresses the utility of remotely sensed and ancillary geospatial data to estimate sagebrush cover using ordinal logistic regression. We demonstrate statistically significant prediction of ordinal sagebrush cover categories using spectral ($\chi^2 = 113$; $p < 0.0001$) and transformed indices ($\chi^2 = 117$; $p < 0.0001$). Both Landsat spectral bands (*c*-value = 0.88) and transformed indices (*c*-value = 0.89) can distinguish sites with closed, moderate and open cover sagebrush cover categories from no cover. The techniques described in this study can be used for estimating categories of sagebrush cover in arid ecosystems.

1. Introduction

Sagebrush ecosystems are a component of the broader semi-arid ecosystems in the Western US and serve as important habitat for a variety of wildlife species ranging from sage grouse (*Centrocerus urophasianus*) (Connelly et al., 2004) to mule deer (*Odocoileus hemionus*) (Sawyer et al., 2006). Changes to sagebrush affect the fauna that are dependent on this vegetation for forage and other needs (Sawyer et al., 2006). Recent disturbances associated with natural gas energy extraction activities in western Wyoming have affected, and will continue to affect, the sagebrush communities (Sawyer et al., 2006). In the face of the continuing energy development in sagebrush ecosystems, land management agencies must balance the permitting of new energy extraction activities and subsidiary activities such as road construction with the conservation of habitats, foraging and breeding areas. Given the vast geographic extent of these ecosystems, methods employing remotely sensed and other geospatial data represent a potentially cost-effective approach for characterizing the spatial distribution of sagebrush ecosystems (Seefeldt and Booth, 2004; Underwood et al., 2007). Maps characterizing sagebrush canopy cover (as a continuous variable) are valuable for management purposes, however generating such maps often requires intensive field surveys, high-resolution remotely sensed imagery, a variety of post-processing algorithms and ancillary geospatial data.

Alternatively, sagebrush canopy cover may be mapped on a categorical basis. When such categories are designed to coincide with the categories relevant to the land management process, the utility of such maps is maximized. Connelly et al. (2000, 2004) discuss several categories of sage cover with direct relevance to sage grouse management. From these reports, we identify four categories of sagebrush cover with direct relevance to land management activities: 0–5% (no cover), 6–15% (open cover), 16–25% (moderate cover), and >25% (closed canopy). The shift from continuous data to ordinal categories eliminates a linear relationship and thus it follows that logistic regression may be more suitable than a linear model. Additionally, updating categorical information is potentially less expensive given the difference in sampling requirements relative to maps with sagebrush cover as a continuous variable.

Regardless of whether working with ordinal or continuous data, mapping vegetation in semi-arid environments using remotely sensed data poses a variety of challenges (Frank and Tweddale, 2006). Factors such as sparse vegetation, multiple species with similar characteristics, and considerable bare ground are common to these environments (Tueller, 1987). One approach frequently used to improve the accuracy of mapping vegetation distribution is through the use of vegetation indices (e.g., the Normalized Difference Vegetation Index (NDVI)) derived from transforming the spectral values recorded by the sensors. NDVI as well as other

* Corresponding author. Tel.: +1 307 766 2721; fax: +1 307 766 2744.
E-mail address: sivan@uwyo.edu (R. Sivanpillai).

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indices such as the Greenness Condition Index (GCI), Vegetation Condition Index (VCI), Mid-IR/Red Reflectance Index (MIRI), and tasseled cap brightness (TC_B), are commonly used for highlighting relevant vegetation and landscape characteristics. GCI is a ratio that combines information from Landsat spectral bands 3 and 4 and VCI ratio combines information from bands 7 and 4. MIRI is a normalized ratio that also combines information from bands 7 and 4. Unlike NDVI, GCI, VCI, and MIRI, that only combine information from two Landsat bands, TC_B is derived from a linear combination of six Landsat bands and separates the landscape features based on their relative brightness. While there are numerous other indices that have been used to map vegetation condition, a comprehensive review of these indices is beyond the scope of this article. For a broader perspective, Jenson (2004) and Campbell (2007) describe the origin and applications of indices derived from Landsat and other remotely sensed data.

Another strategy often used to address the challenges of remote sensing in arid environments is the incorporation of ancillary data into the classification process. Information such as elevation, slope and aspect has been shown to improve the accuracy of mapping sagebrush distribution; surface topography affects sagebrush distribution by influencing wind exposure and, in turn snow distribution, soil moisture, and soil temperature (Liu et al., 2003; Osumi et al., 2003). Similarly, Burke et al. (1989) demonstrate that topographic factors serve as vegetation controls in sagebrush steppe in Wyoming. Given the above challenges of remote sensing in semi-arid areas and the role of topographic factors in influencing vegetation, there exists the possibility that ancillary data reflecting these landscape controls may supplement spectral information when delineating sagebrush.

This study investigates the utility of Landsat for mapping sage in a manner suitable for management purposes. To accomplish this objective, this study evaluates the utility of transformed indices and ancillary data such as elevation, slope, and aspect in addition to the spectral values recorded by the Landsat satellite sensor (Thematic Mapper) for discerning ordinal categories of sagebrush canopy coverage. The ordinal approach is in keeping with the sage densities identified in a variety of research reports detailing management strategies for a variety of sage obligates (Connelly et al., 2000, 2004). Remotely sensed and ancillary data are used as independent variables in an ordinal logistic regression model with a dependent variable comprised of four categories, each encompassing a range of sagebrush cover percentages. Logistic regression models are widely used when analyzing the relationship between categorical dependent variables and remotely sensed data (Pasher et al., 2007; Waser et al., 2008; Wulder et al., 2006). If combinations of Landsat and ancillary data are able to distinguish the management related ordination of closed canopy (>25%), moderate (>15–25%) and low (>5–15%) sagebrush cover from no (0–5%) sagebrush cover, then land management agencies could use this methodology to characterize habitat value in areas slated for potential energy recovery activities. Maps depicting relative abundance of sagebrush could provide valuable information to land management agencies for identifying areas for habitat conservation and habitat reclamation in western Wyoming and throughout the western US.

2. Materials and methods

2.1. Study area

The Pinedale Anticline Project Area (PAPA) is a large (80 000 ha), semi-arid, sagebrush steppe ecosystem located in the upper Green River Basin of western Wyoming, approximately 5 km southwest of Pinedale (Fig. 1). The United States Department

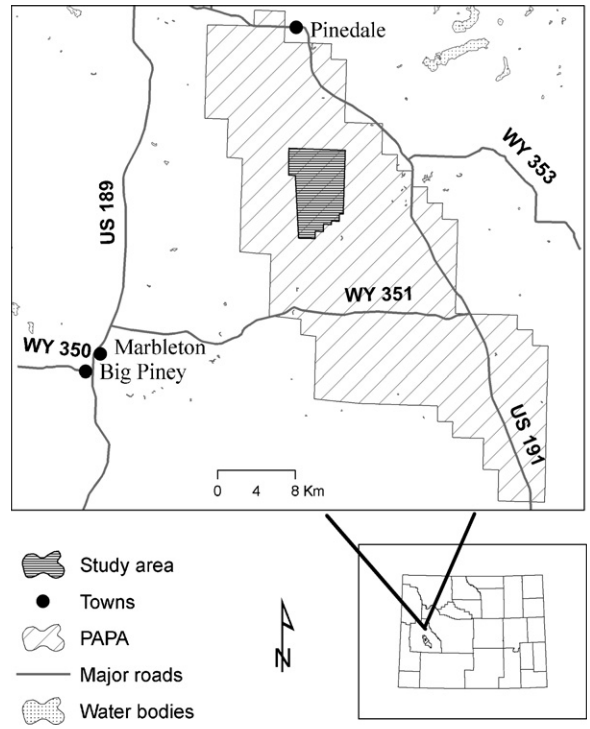

Fig. 1. The study area was located south of Pinedale, Wyoming. The study area is part of the 'Mesa' area within the Pinedale Anticline Project Area, and is bounded by the Green River on the west and the New Fork River on the north, south, and east.

of Interior–Bureau of Land Management (BLM) manages approximately 80% of PAPA and the vegetation is dominated by Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) with portions of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) located throughout the bottoms of draws (Ingelfinger and Anderson, 2004). The state of Wyoming owns 5% of the surface and the remaining 15% is privately held (Sawyer et al., 2006). The PAPA contains significant gas reserves, is winter range for several thousand migratory mule deer and is also home to a variety of agricultural uses (Sawyer et al., 2006). Beginning in 2000, BLM approved the construction of 700 producing well pads, 645 km of pipeline and 444 km of roads to develop a natural gas field in this region. This study focuses on the most disturbed portion of the PAPA, generally referred to as, "the Mesa" (Sawyer et al., 2004); the impact of energy development on wildlife is a particularly important issue at this location. The sagebrush ecosystems present in the Mesa are crucial to sage grouse and mule deer (BLM, 2006; Connelly et al., 2000, 2004; Homer et al., 1993; Ingelfinger and Anderson, 2004; Sawyer et al., 2006; Spidso, 2005).

2.2. Remotely sensed and surface topographic data

A Landsat Thematic Mapper image (WRS2 path 37; row 30) acquired on 17 June 2006 was obtained from the USGS-EROS Data Center, Sioux Falls, SD. This image had 3 visible and 3 infrared bands (Table 1) and its projection parameters were UTM (zone 12) and NAD 83 (GRS80), with a ground pixel resolution of 30 m. Several transformed indices were derived from these six original Landsat bands (Table 2). Quickbird imagery acquired in summer 2004 was obtained from BLM state office in Cheyenne, Wyoming. These images contained 4 spectral bands (1 infrared and 3 visible) and were in the same map projection and coordinate system as the Landsat image, with a ground pixel resolution of 2.4 m. The spatial