USING AVIRIS IMAGERY TO MAP INVASIVE PLANTS ON RANGELANDS: LEAFY SPURGE IN NORTHEASTERN WYOMING

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1.0 INTRODUCTION

Invasions of exotic organisms have been proposed as one of the largest components of global environmental change, second only to habitat destruction (Vitousek et al. 1996). Leafy spurge, *Euphorbia esula* L. (sensu lato), is only one of hundreds of successful exotic plant species that have invaded North America. It is an adventive, perennial weed that infests approximately 1.2 million hectares of land in North America (Lajeuness et al. 1999). Its distribution includes the northern Great Plains of the U.S. and the prairie provinces of Canada (DeLoach 1997). It often forms dense stands that displace native vegetation and useful forage plants on rangelands and in riparian habitats. Infestations of leafy spurge destroy the quality of grazing lands for cattle and horses (Hein and Miller 1992), degrade the forage base and structure of wildlife habitat (Trammell and Butler 1995), decrease plant diversity (Belcher and Wilson 1989), and reduce land value (Leistritz et al. 1992).

Using remotely sensed data to map leafy spurge would provide a valuable tool for documenting leafy spurge distribution and infestation levels over larger regional areas. Differentiation of individual green plant species can be problematic because all green plants have similar spectral characteristics. Leafy spurge is a good candidate for detection via remote sensing because the distinctive yellow-green color of its bracts is spectrally unique when compared to the co-occurring green vegetation (Everitt et al. 1995). Because spectral detail is necessary for differentiating similar materials, high spectral resolution data is the most appropriate data for mapping individual plant species with a high level of accuracy and precision (Clark et al. 1995). Imaging spectrometers, or hyperspectral sensors, provide remotely sensed data in which each pixel in the image has a detailed set of reflectance values that allow interpretation of the pixel's spectrum. From its spectrum two primary characteristics can be identified, the physical materials of which the pixel is composed on the ground, and a quantitative estimate of their abundances. By using spectral mixture analysis to model each pixel spectrum as a linear combination of a finite number of spectrally distinct signatures or "endmembers," subpixel estimates of endmember abundance can be obtained (Adams et al. 1985, Smith et al. 1990). The main goal of this research was to map leafy spurge from hyperspectral imagery using spectral mixture analysis to obtain sub-pixel estimates of leafy spurge cover. This was compared to ground estimates of leafy spurge cover to assess the ability of hyperspectral remote sensing data to estimate leafy spurge cover.

2.0 METHODS

2.1 RESEARCH AREA

The study area for this research is in Crook County in northeastern Wyoming, on the northwestern edge of the Black Hills, a small mountain range that extends from northeastern Wyoming southeast into western South Dakota. It consists of approximately 65 square-kilometers of private land about 8 kilometers west of Devils Tower National Monument (DTNM). The land is used extensively for livestock grazing (cattle and sheep) with some areas of dryland farming and hay production.

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The vegetation of the study area is a mosaic of ponderosa pine (*Pinus ponderosa*) communities, grasslands, sagebrush-grasslands, and pine-juniper (*Juniperus scopulorum*) woodlands. Riparian areas are characterized by willow (*Salix* spp.) and plains cottonwood (*Populus deltoides*) communities, with bur oak (*Quercus macrocarpa*) and green ash (*Fraxinus pennsylvania*) commonly occurring in draws. Elevations in the study area range from 1219 m along the Belle Fourche River to 1584 m at Missouri Buttes along the northern border of the study area. The average annual precipitation is 442 mm. Leafy spurge is very well established in most of the study area.

2.2 ACQUISITION AND ATMOSPHERIC CORRECTION OF AVIRIS IMAGERY

Airborne Visible / Infrared Imaging Spectrometer (AVIRIS) imagery was acquired over the study area in northeastern Wyoming on July 6, 1999. The imagery was from a NASA ER-2 aircraft flown at an altitude of 20 km with each pixel representing a ground area of approximately 20 x 20 m (Green et al. 1998). Each AVIRIS scene was first radiometrically corrected by the Jet Propulsion Laboratory. It was atmospherically corrected to apparent surface reflectance using Version 3.1 of the ATmosphere REMoval Program, or ATREM (Gao et al. 1993, Goetz et al. 1997). Due to the limited range of field spectroradiometer data (350 – 1050 nm) and to absorption artifacts in the corrected AVIRIS data, a spectral subsample of the AVIRIS data was taken. AVIRIS bands 6 through 68 (418 – 1000 nm) were used in the final analysis. A visual comparison of AVIRIS reflectance spectra with ground reflectance spectra (Fig. 1) showed very good correspondence; therefore, we did not perform further image correction.

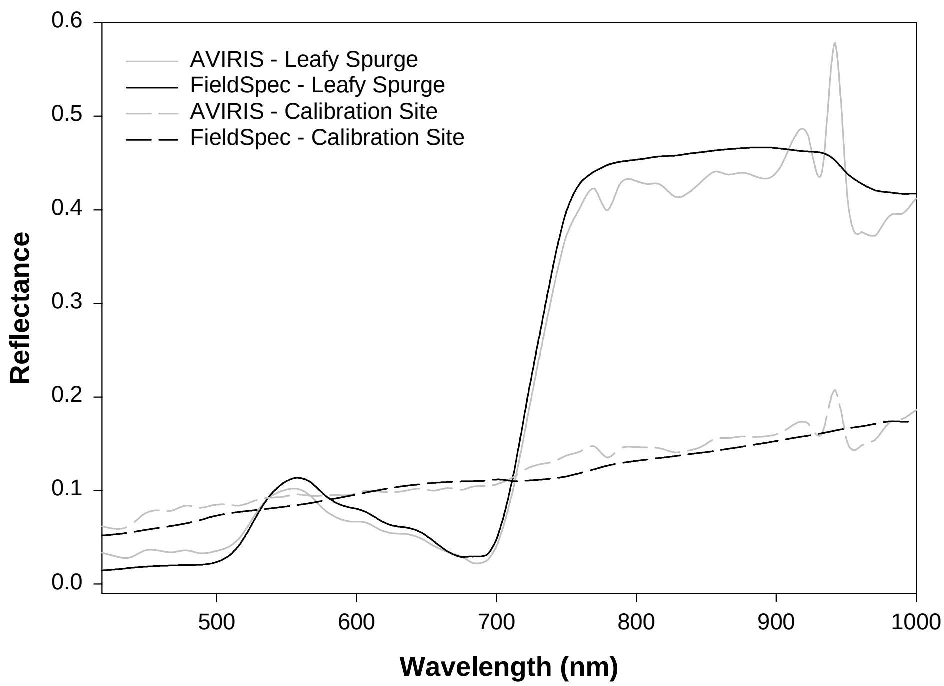

Figure 1. Correspondence of corrected Airborne Visible / Infrared Imaging Spectrometer (AVIRIS) data with averaged field spectroradiometer data.

2.3 FIELD SPECTRORADIOMETRY

Field spectroradiometer data were collected in late June 1999 about two weeks before the AVIRIS data acquisition between 10:00 am and 2:00 pm on a clear, sunny day similar to the weather and sky conditions on the day of the AVIRIS overflight. Field reflectance spectra were acquired using an Analytical Spectral Devices, Inc. (ASD, Boulder, Colorado) FieldSpec UV/VNIR Spectroradiometer. It was not possible to collect field spectroradiometer data on the day of the AVIRIS overflight due to the unavailability of the ASD spectroradiometer.

The ASD FieldSpec UV/VNIR acquires continuous spectra from 350 nm to 1050 nm. Dark current (property of the detector) and white reference (Spectralon panel) corrections were made approximately every 2-3 minutes. Each spectrum acquired in the field consisted of 25 individual measurements taken consecutively and averaged by the

FieldSpec. Measurements were acquired using the bare tip of the fiber optic cable, which had a 25 degree field of view (FOV). All measurements were made with the optic tip about 1.3 m above the target material resulting in a FOV diameter of about 0.50 m.

The final spectrum for each material in the field was calculated through postprocessing, which consisted of examining sets of 10 of the averaged field spectra, removing any extreme outliers, and averaging the remaining spectra. All field spectra were resampled to match the wavelengths and bandpass of the AVIRIS data, based on the 1999 wavelength calibration file supplied by JPL.

Two spatially and spectrally homogenous ground calibration sites were used in this study including a large gravel natural gas pumping station compound and the boulder field surrounding the base of Devils Tower. Each ground calibration site was characterized using the ASD FieldSpec Spectroradiometer along a series of transects with measurements being taken approximately every 5 meters using the same methods described previously.

2.4 GROUND DATA COLLECTION OF LEAFY SPURGE COVER

During 1999, the same year the AVIRIS data were acquired, extensive ground data collection was performed on field vegetation plots. Data were collected during the 2 weeks prior to and the 2 weeks following the AVIRIS flight. The ground plots were part of a concurrent study that documented leafy spurge percent cover in detail (Parker Williams 2001). The 67 circular vegetation plots had a radius of 23 meters and were located within areas of leafy spurge infestation. Each plot's location was recorded using a selective availability encoded Rockwell Precision Federal Global Positioning System (GPS) unit (Rockwell International Corporation, Cedar Rapids, Iowa) and digital orthophotoquads. These locations were transferred onto the AVIRIS imagery from a digital orthophoto quad with an estimated positional error of 1 pixel. It has been shown that positional error results in conservative bias of image assessments (Verbyla and Hammond 1995); therefore, the unavoidable positional error introduced into this assessment would result in lower, or conservative, correspondence between AVIRIS and ground estimates of leafy spurge cover.

Each plot was also classified on the ground into three different topographical position types, riparian, draw, or upland, and into two different vegetation types, woodland or prairie. Leafy spurge cover was estimated using broad cover classes (0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%) for five, randomly located 1-by-2-meter subplots. The mid-point value of the cover class was recorded as the leafy spurge cover for that sub-plot. Sub-plot values were then averaged to obtain an estimate of leafy spurge cover for the plot.

2.5 IMAGE PROCESSING AND ANALYSIS

The purpose of this research was to map and document leafy spurge using clear, repeatable methodology. With this goal in mind, it was unnecessary to spend time and resources trying to account for and classify all other materials and vegetation in the imagery. Therefore, Mixture Tuned Matched Filtering (MTMF) a specialized type of spectral mixture analysis was used. MTMF performs a "partial" unmixing by only finding the abundances of a few user-defined endmembers and not requiring that all image endmembers be identified (Harsanyi and Chang 1994).

With the goal of isolating and identifying the leafy spurge endmember, the AVIRIS reflectance image was used as input into the minimum noise fraction (MNF) transformation (Green et al. 1988, Lee et al. 1990). The first twelve MNF transforms were carried forward in the analysis. Eigenvalues decreased and noise increased substantially after MNF transform twelve. To identify potential endmembers in the AVIRIS imagery, the 12 MNF transforms were used as input into a Pixel Purity Index (PPI) analysis (Boardman et al. 1995). A relatively high number of iterations (3,000) and a high PPI threshold value (5) were used to eliminate large numbers of pixels and to emphasize the unique pixels. The output of "pure" pixels from the PPI procedure was examined using multidimensional visualization software (RSI 1999). Pixels were interactively clustered and grouped based on their spatial relationship to each other and upon examination of their spectral signatures. All groups of pixels that did not contain a vegetation component as identified by their spectral signatures were removed from the multidimensional plot space, allowing finer discrimination of different vegetation pixels. The spectral signatures of each remaining pixel group were systematically compared to the resampled field spectra. The average spectral signature of a tightly clustered group of pixels matched the field spectra for leafy spurge. Leafy spurge's unique color in the visible (green to red wavelengths) and NIR wavelength regions was sufficient to differentiate it from other green vegetation. The leafy spurge endmember was used as the endmember of interest in a Mixture Tuned Matched Filtering (MTMF) analysis. This procedure was performed on two AVIRIS scenes (approximately 11 km x 9 km) acquired over the study area.

In order to assess the variation between remotely-sensed and ground-measured cover of leafy spurge, data were stratified by both topographic position (riparian, draw, or upland) and vegetation type (woodland or prairie). The draw and riparian strata were combined due to a small sample size of riparian sites in the AVIRIS imagery. The relationships between MTMF estimates of sub-pixel leafy spurge abundance and ground estimates of leafy spurge cover were examined using simple linear regression analysis for all sites and for sites in each strata.

3.0 RESULTS AND DISCUSSION

3.1 FIELD SPECTRORADIOMETRY

Field spectroradiometer data collected in the study area showed that the reflectance spectrum of leafy spurge differed from other types of common green vegetation (Fig. 2). It was easily differentiated based primarily on values in the 500-700 nm wavelength region. Leafy spurge was consistently brighter than other vegetation between 500 and 650 nm. It also differed from other vegetation in the shape and magnitude of the characteristic chlorophyll absorption features between 550-685 nm.

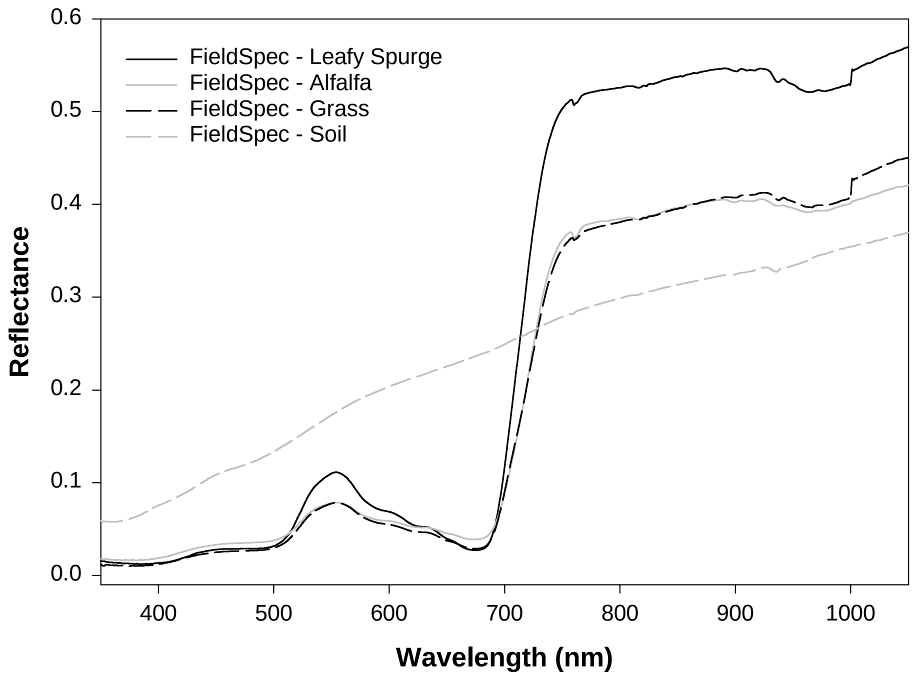

Figure 2. Comparison of averaged field spectra for vegetation and soils.

3.2 MIXTURE TUNED MATCHED FILTERING FRACTION IMAGES

The output from the mixture tuned matched filtering (MTMF) analysis was a fraction image with values for each pixel representing the relative sub-pixel abundance of leafy spurge, and an infeasibility image with values ranging from 1-12. Pixels with a high fraction value and a low infeasibility value (< 6) had a high percent cover of leafy spurge, while those with high infeasibility values were not classified as leafy spurge. All ground sites used for the MTMF comparison were located in leafy spurge infestations, and all of these sites were classified as leafy spurge in the analysis.

Overall performance of the MTMF for estimating percent cover of leafy spurge for all sites was good (Fig. 3, $r^2 = 0.69$). A definite linear relationship exists between the MTMF fraction and the ground cover estimate. The ability to discriminate leafy spurge and achieve good estimates of canopy cover may be due to the unique growth habit and color of the bracts, which are closely packed and oriented upwards, forming a dense uniform canopy that reduces shadows and de-emphasizes the contribution of green leaves to the reflectance spectrum.

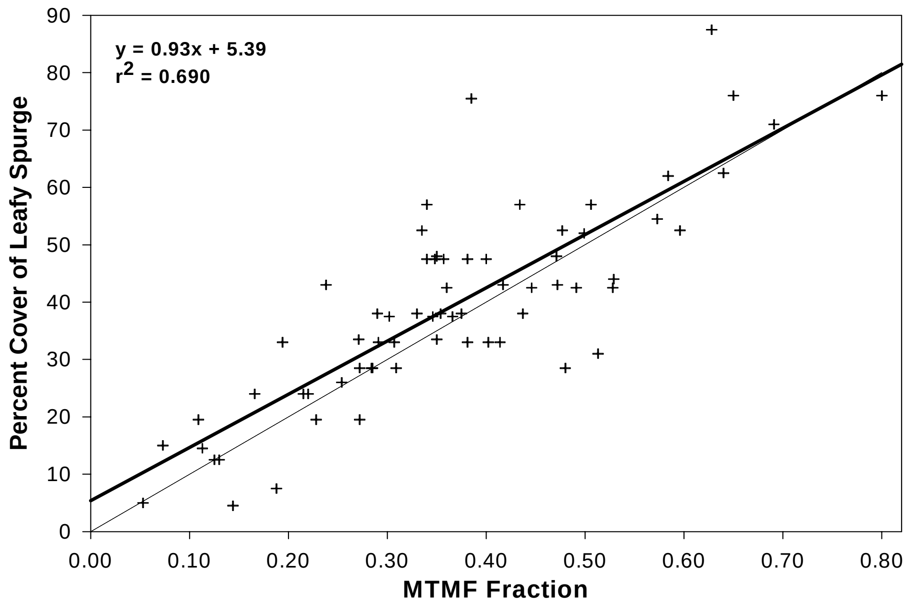

Figure 3. Regression of MTMF fraction values vs. percent canopy cover of leafy spurge from all ground data.

3.3 EFFECT OF TOPOGRAPHIC POSITION AND VEGETATION TYPE

Leafy spurge cover in sites located in draws and riparian areas ($r^2 = 0.72$) was estimated slightly better than those located in upland areas ($r^2 = 0.68$). Cover was also generally higher in draw and riparian sites than in upland sites. The better estimation of cover in draw and riparian sites may be due in part to variability in leafy spurge phenology in upland sites where moisture was less available in late June and July than in more mesic draw and riparian sites. As the summer progresses, leafy spurge bracts lose their distinctive yellow-green color and the plant is not as easily distinguished from other green vegetation.

The MTMF analysis performed very well on sites located in areas of prairie, which included all sites not in the woodland type ($r^2 = 0.79$). In contrast, the MTMF analysis performed poorly in estimating leafy spurge cover in woodland areas ($r^2 = 0.57$). These sites also had the largest variance of any of the types. This may be explained in relation to tree canopy obscuring detection from an aerial perspective and variations in tree canopy cover and view angle between sites. Materials are often obscured by forest canopies, especially when viewed at off-nadir angles. Also, positional error in woodland areas may have a larger effect on image to ground correspondence than in non-wooded prairie. However, the fact that leafy spurge can be detected in woodland areas at all is an encouraging demonstration of MTMF.

4.0 CONCLUSIONS

Mixture tuned matched filtering (MTMF) has been reported as a superior method for detection of materials in hyperspectral imagery. It can outperform spectral mixture modeling and matched filtering, especially in cases of subtle, sub-pixel occurrences (Boardman 1998). It also has the added advantage in cases of mapping individual materials of not requiring identification of all potential endmembers. MTMF performed very well for mapping leafy spurge and estimating leafy spurge canopy cover. Its sensitivity for detecting and estimating leafy spurge were surprising. Leafy spurge has several characteristics that make it an ideal species for detection from remotely sensed data, so caution must be fostered when considering mapping other invasive species using hyperspectral data. Leafy spurge grows in large dominant stands, is a robust plant with a dense canopy, and has a distinctive color for a several week period during the growing season. All of these factors make it easier to map than many other invasive species. Its habit of forming large uniform stands with a dense canopy also ameliorate problems of positional error and non-linear spectral mixing, allowing good prediction. There was also a certain amount of uncertainty in the ground data collection, because it involved estimates using broad cover classes. However, keeping these things in perspective, mapping leafy spurge using hyperspectral remote sensing data is feasible and reasonably accurate for estimating percent cover in broad cover classes. Obviously, mapping leafy spurge under tree canopies is problematic. Although this is one limitation of the method, results demonstrated that in open canopies that have leafy spurge growing in the understory, it dominates the spectral signature sufficiently to be detectable. The techniques presented here could possibly be used for constructing leafy spurge distribution and abundance maps with satellite hyperspectral data for larger regional areas.

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