COMPARISON OF AVIRIS AND MULTISPECTRAL REMOTE SENSING FOR DETECTION OF LEAFY SPURGE

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1.0 Introduction

Leafy spurge (*Euphorbia esula* L.) is a noxious perennial weed that infests approximately 2 million hectares of land in North America and causes severe economic impacts (Anderson et al. 2003). Biologically-based integrated pest management is practical for the control of leafy spurge (Anderson et al. 2003). What is now required is methodology to locate and monitor existing plant populations of leafy spurge as part of the integrated pest management.

Remote sensing has been successfully used to locate and monitor leafy spurge distribution because the unique coloration of the flower bracts (Everitt et al. 1995; Anderson et al. 1996; Ustin et al. 2004). Parker Williams and Hunt (2002) showed that the hyperspectral technique, Mixture Tuned Matched Filtering (Boardman 1998), accurately estimated the amount of leafy spurge cover. Furthermore, Parker Williams and Hunt (2004) showed that classification of leafy spurge presence/absence was 95% accurate. As shown in Figure 1, it is the reflectance from the flower bracts in the yellow-green region of the spectrum, due to an approximately 1:1 chlorophyll-carotenoid ratio, that allows the flowering shoots of leafy spurge to be distinguished from co-occurring species with hyperspectral imagery (Hunt et al. 2004). In northeastern Wyoming, determination of the presence or absence of leafy spurge, while flowering, was 95.2 % accurate with hyperspectral imagery (Parker Williams and Hunt, in press). However, the non-flowering shoots of leafy spurge have a similar reflectance spectrum as other vegetation (Parker Williams and Hunt 2004).

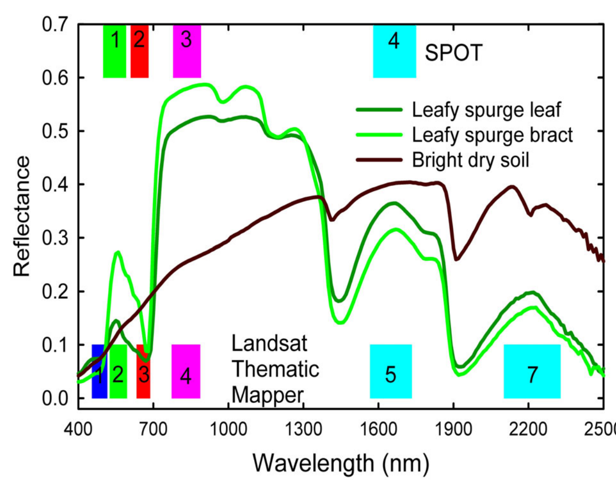

Figure 1. Spectrum of dry soil, leafy spurge leaves, and flower bracts. Shown along the top and bottom are the wavelength intervals of Landsat Thematic Mapper and SPOT 4 sensors.

Hyperspectral imagery would be ideal to map the distribution and abundance of leafy spurge, except the area covered is small, the data are not routinely available at the period of peak flowering. Two multispectral sensors on satellite platforms are the Enhanced Thematic Mapper Plus (ETM+) onboard the Landsat 7 satellite and the Système Pour d'Observation de la Terre (SPOT) 4 sensor/satellite (Fig. 1). Landsat ETM+ has bands in the visible (400–700 nm), near-infrared (700–1100 nm), and shortwave-infrared wavelengths (1100–2500 nm) with a pixel size of 900 m^2 (Fig. 1). Landsat ETM+ also has bands in the thermal

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infrared (band 6), and a panchromatic (band 8). SPOT 4 has four bands with a pixel size of 400 m^2 (Fig. 1). The advantages of multispectral imagery are that these data are routinely available, and there are extensive software packages for handling the data, and expertise with the data are widely available. With the green and red bands, the distinctive yellow-green color of the flower bracts should be detectable, hence the objectives of this study are to compare the ability of Landsat 7 ETM+ and SPOT 4 to AVIRIS for the detection of leafy spurge.

2.0 Methods

2.1 Study Area

The area for this study was the TEAM Leafy Spurge site near Devils Tower National Monument in Crook County, Wyoming, USA (Parker Williams and Hunt, 2002, 2004). The site was between 44.4 to 44.6° North latitude and 104.6 to 104.9° West longitude. Elevations range from 1219 m along the Bell-Fourche River to 1584 m at the Missouri Buttes. The vegetation in the study area is a mosaic of conifer woodlands, northern mixed-grass prairie, and riparian zones with deciduous shrubs and trees. Leafy spurge is well established throughout the study area.

The period of flowering in 1999 began in late June and lasted until mid July. All of the ground data collection occurred during this period (Parker Williams and Hunt, 2002, 2004). Two sets of plots were established in the study area using a 1991 Landsat 5 Thematic Mapper image to cover adequately the different vegetation types. The first set were circular plots (46 m diameter) used for determining cover of flowering leafy spurge (Parker Williams and Hunt, 2002). The second set were rectangular plots (50 m by 50 m) used for classification accuracy (Parker Williams and Hunt, 2004). Because all plots in the first set had some leafy spurge, we combined these plots with the second set to increase the number of points for accuracy assessment (Fig. 2).

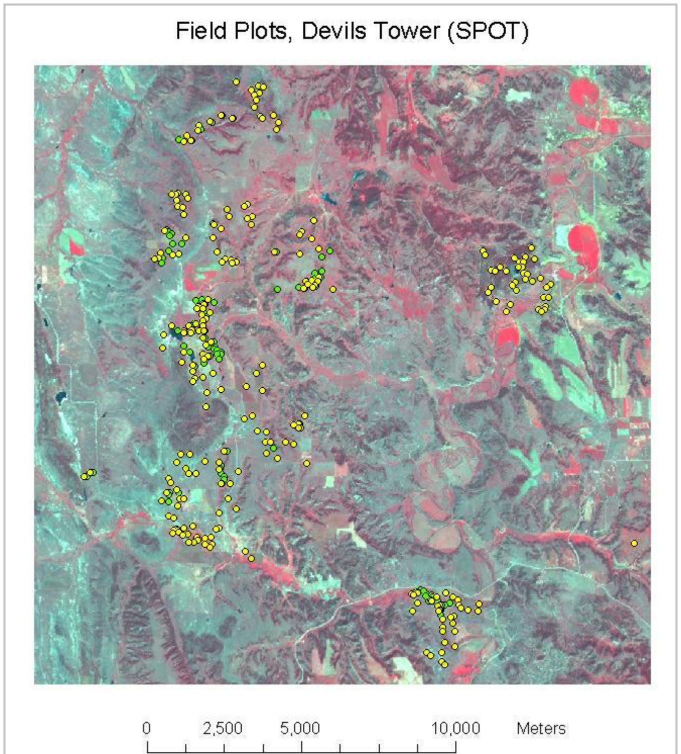

Figure 2. SPOT image with plots.

2.2 Image Analysis and Vegetation Indices

A Landsat 7 ETM+ image (path 35 row 29) acquired on July 8, 1999 was obtained from the United States Geological Survey EROS Data Center. The study area was on the extreme eastern boundary of the ETM+ image. A SPOT 4 image centered on Devils Tower was acquired on July 11, 2000, a year after data collection (Fig. 2). The Landsat 7 ETM+ image was georegistered to the SPOT image. The residual mean square error (RMSE) of the Landsat image to the SPOT image was 22 m.

The Airborne Visible Infrared Imaging Spectrometer (AVIRIS) was flown at high altitude over the study site on July 6, 1999 (Parker Williams and Hunt 2002). The AVIRIS data were atmospherically corrected using the ATREM 3.1 program (Gao et al. 1999). The atmospherically-corrected reflectances were smoothed using the spectral reflectances of a large talus field at the base of Devils Tower, which was measured using an ASD Fieldspec UV/VNIR spectroradiometer (Analytical Spectral Devices, Inc. Boulder, Colo.). The image files did not have a geometric lookup table, therefore the three AVIRIS flight lines (11 scenes total) were georegistered to the SPOT image. The RMSE between the AVIRIS and SPOT images was 26 m.

Originally a SPOT image was acquired on July 9, 1999, but the selected gains were set too low, hence band 3 (near-infrared) was saturated over vegetation for much of the image. About one-third of the plots with leafy spurge were used for release sites of *Aphthonia* species flea beetles in 1999 (Parker Williams, 2001), and the flea beetles may have reduced the amount of cover of flowering leafy spurge somewhat for the SPOT 4 image.

Bands 1 through 4 of the Landsat ETM+ image and bands 1 through 3 of the SPOT 4 image (Fig. 1) were atmospherically corrected using an empirical line approach using the average reflectance spectrum of the talus field and a dark pixel subtraction. The shortwave-infrared bands were atmospherically corrected using the talus-field reflectances from the AVIRIS image.

A standard technique with multispectral imagery is the use of vegetation indices. Based on the spectral differences of leafy spurge leaves and flower bracts, several indices were tested with the AVIRIS, ETM+ and SPOT 4 data. The first index was the Normalized Difference Vegetation Index (NDVI):

$$NDVI = (NIR - Red)/(NIR + Red) \tag{1}$$

where NIR was AVIRIS band 54 (855 nm), ETM+ band 4 or SPOT 4 band 3, and Red was AVIRIS band 31 (665 nm), ETM+ band 3 or SPOT 4 band 2 (Fig. 1). The second index was the Green Normalized Difference Vegetation Index (GNDVI):

$$GNDVI = (NIR - Green)/(NIR + Green) \tag{2}$$

where Green was AVIRIS band 20 (556 nm), ETM+ band 2 or SPOT 4 band 1 and the NIR band was defined in Equation 1. The third index was the Green:Red reflectance ratio (G:R):

$$G{:}R = Green/Red \tag{3}$$

where the green and red bands were defined in Equations 2 and 1, respectively.

Various methods of classification were tried on the AVIRIS, ETM+, and SPOT images. Supervised methods used large fields of leafy spurge near Devils Tower National Monument for a flowering leafy spurge signature, vegetation pixels with no spurge were selected based on the ground data. Other land cover classes (rocks, soils, crops, forest, water, roads, etc.) were added as needed. The spectral signature for flowering leafy spurge for the Spectral Angle Mapper

(SAM) method was obtained from the same fields as the supervised classification. One-sample Z-tests were used to test if the kappa-hat statistic were significantly different from zero and two-sample Z-tests were used to test if two classifications were significantly different (Congalton and Green 1999).

2.3 Canopy Reflectance Modeling

The Scattering by Arbitrarily Inclined Leaves (SAIL) model was designed to predict canopy reflectance for various leaf area indices (LAI) and measured leaf reflectances and transmittances (Verhoef, 1984). A graphical user interface for the Microsoft Windows operating system was programmed in Visual Basic and is available from the corresponding author.

The soil, leaf and flower bract reflectance spectra (Fig. 1) were used as inputs to the SAIL model. Grass and forb reflectance and transmittance spectra were obtained from measurements on *Poa pratenesis* L. (Kentucky bluegrass) and *Taxiarium officialis* L. (dandilions), respectively made with an ASD FieldSpec Pro FR spectroradiometer and LICOR LI-1800-12 integrating sphere (Lincoln, Nebraska). Leafy-spurge flowers and leaves, and forb leaves, were assumed to have a typical planophile (horizontal) leaf distribution, and grass leaves were assumed to have a typical erectophile (vertical) leaf distribution. The SAIL model was run for various combinations of leaf area index (LAI), forb cover, grass cover, leaf cover of leafy spurge, and flower cover of leafy spurge. Leaves of forbs, grass, and leafy spurge were placed in a lower canopy layer, and flowers of leafy spurge (when present) were placed in the top canopy layer.

3.0 Results and Discussion

3.1 Vegetation Indices

All of the vegetation indices were significantly, but not strongly, correlated ($P < 0.05$) with the measured cover of flowering leafy spurge for the prairie cover type. The slopes of vegetation indices versus spurge cover were not significantly different from zero for the woodland cover type (data not shown). The G:R reflectance ratio was the best correlated index for the AVIRIS image ($R^2 = 0.23$, Fig. 3), the ETM+ image ($R^2 = 0.24$, Fig. 4), and the SPOT 4 image ($R^2 = 0.26$, Fig. 5). The R^2 were 0.12, 0.16, and 0.19 for NDVI and spurge cover for the AVIRIS, ETM+, and SPOT 4 images, respectively (data not shown). Finally for the GNDVI, the R^2 were 0.05, 0.12, and 0.19, respectively. We tried other band combinations using AVIRIS data, particularly using band 25 (606 nm) and we did not find a better index than G:R for detecting flowering leafy spurge.

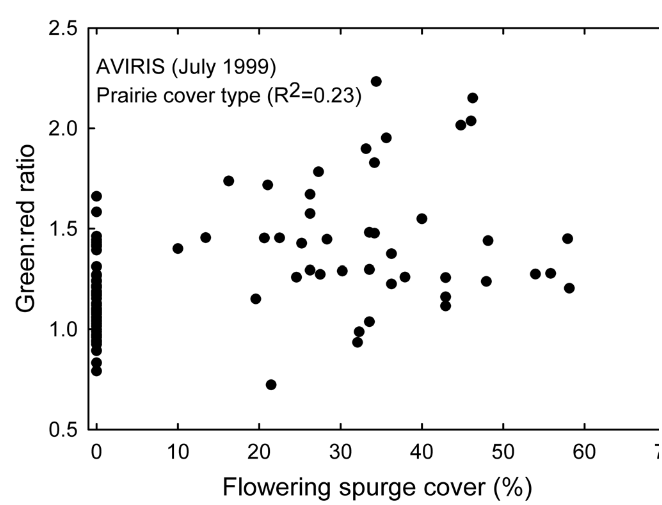

Figure 3. Green:red reflectance ratio from AVIRIS for flowering leafy spurge in prairie cover types.

3.2. Canopy Reflectance Modeling

The SAIL model was used in exploration to determine if another vegetation index to detect flowering leafy spurge was possible. As LAI increases, the spectral reflectance in the near-infrared increases, the spectral reflectance in the red decreases, and the spectral reflectance in the green remains about equal to the spectral reflectance of the soil (Fig. 6). At constant LAI, spectral reflectances in the near-infrared increase with increased cover of leafy-spurge leaves in grass because of the difference between the planophile leafy-spurge and the erectophile grasses (data not shown). At constant LAI, spectral reflectances also increase in the green with increased cover of leafy-spurge leaves and flowers in grass (Fig. 7). The relationship of G:R with increased cover of leafy-spurge flowers generally increased at low LAI for mixtures of leafy spurge in both forbs and grasses (Fig. 8, 9). However, the change in G:R with increased LAI was much more than the change in G:R associated with increased cover of leafy-spurge flowers. From the SAIL model results, there was not a better index than G:R for detecting flowering leafy spurge, but this index performed poorly when LAI was variable.

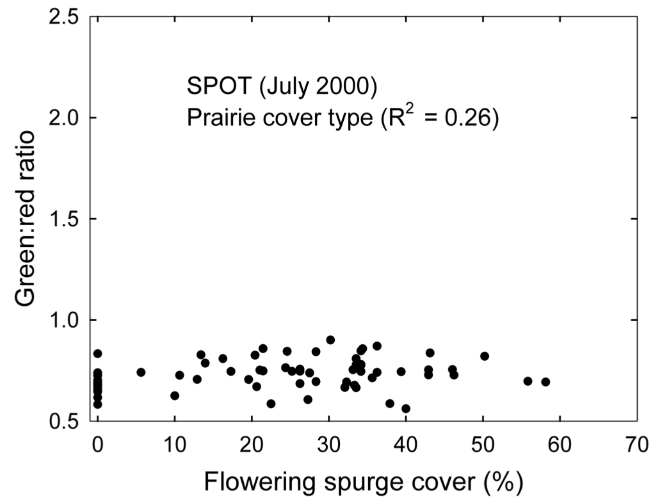

Figure 4. Green:red reflectance ratio from SPOT 4 for flowering leafy spurge in prairie cover types

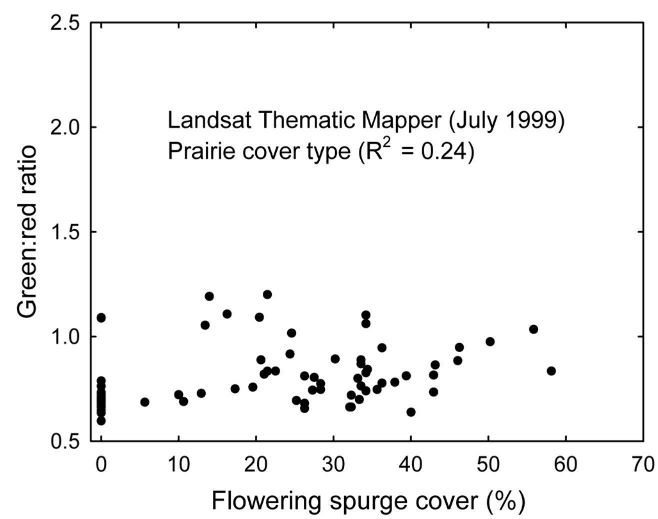

Figure 5. Green:red reflectance ratio from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for flowering leafy spurge in prairie cover types.

3.3 Classification

The best method of supervised classification was minimum distance (Table 1). The classifications for Landsat ETM+, SPOT 4, and AVIRIS were all significantly better than chance ($P < 0.05$), and there were no significant differences among the three types of imagery in detecting flowering leafy spurge (Table 1). On the other hand, SAM classification using the Landsat ETM+ and SPOT 4 images were not better than chance, whereas the AVIRIS image did have a significantly better detection rate of flowering leafy spurge (Table 2). The threshold angle for a match with SAM was reduced from 0.1 radians (the default value) to 0.05 radians, because use of the larger threshold would have included most of the non-forest, vegetated pixels as leafy spurge present.

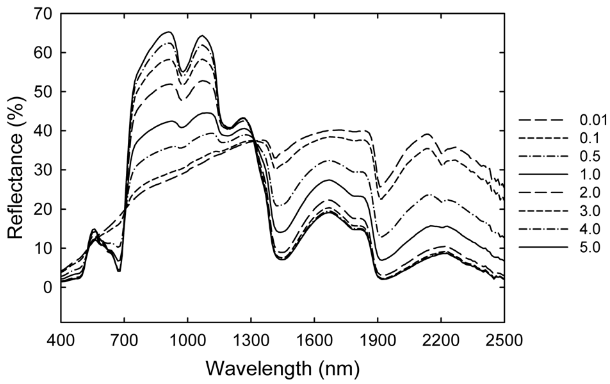

Figure 6. Canopy spectral reflectance from the SAIL model at various leaf area index (LAI) for a mixture of 50% grass, 25% leafy-spurge leaves, and 25% leafy-spurge flowers.

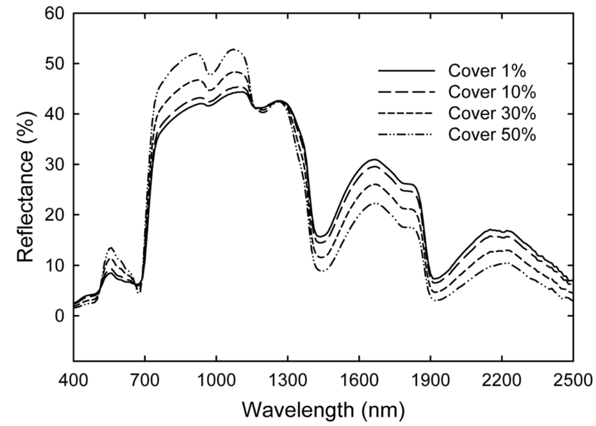

Figure 7. Canopy spectral reflectance from the SAIL model at various total cover of leafy-spurge flowers and leaves in grass. Total LAI was 1 m^2/m^2 and leafy-spurge leaf cover was set equal to flower cover, so 50% total cover is 25% flowers and 25% leaves.

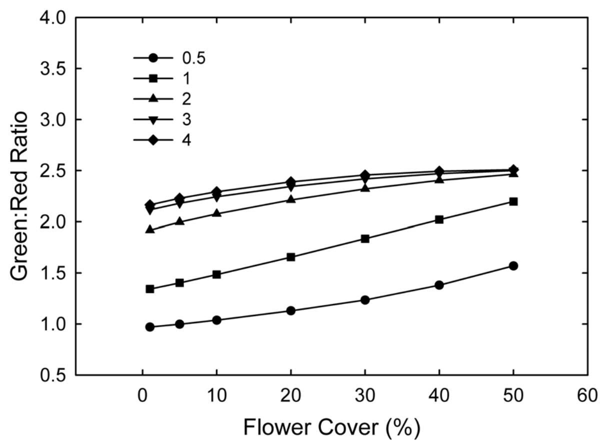

Figure 8. Green:red reflectance ratio from the SAIL model at various LAI and leafy-spurge cover in forbs.

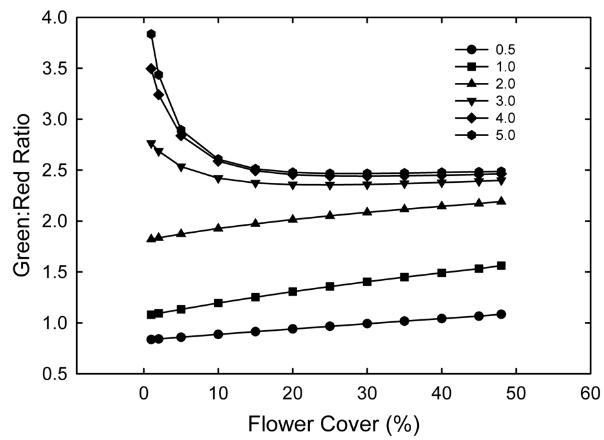

Figure 9. Green:red reflectance ratio from the SAIL model at various LAI and leafy-spurge cover in grass.

These results are not nearly as good as reported before with mixture-tuned matched filtering (Parker Williams and Hunt 2002, 2004). One reason may be due the geometric correction of the AVIRIS imagery (Peleg and Anderson 2002). Parker Williams (2001) located each plot using digital orthophotos, and did not georegister the images. We performed a standard hyperspectral data reduction and a mixture-tuned matched filtering analysis for the AVIRIS mosaic and found the overall accuracy was 75% (data not shown), similar to the results with SAM (Table 2).

4.0 Conclusions

These results show there is little predictive power using vegetation indices to estimate the amount of leafy spurge, even with AVIRIS, when there are variations of LAI across the landscape. Furthermore, we did not find a "best band" that would optimize performance of multispectral sensors, even though flowering leafy spurge has bright, distinctive yellow-green bracts. Supervised classification techniques did not perform well, even with a large number of bands available to separate different classes of vegetation. Thus, applying multispectral techniques to hyperspectral imagery did not increase the ability of remote sensing to detect leafy spurge. We show here that hyperspectral techniques making use of the entire reflectance spectrum (the Spectral Angle Mapper), work far better with hyperspectal data for detection of flowering leafy spurge compared to multispectral data. Underwood et al. (2003) also showed that hyperspectral techniques applied to AVIRIS data worked well for detection of two other non-native plants, iceplant (*Carpobrotus edulis*) and jubata grass (*Cortaderia jubata*). Therefore, hyperspectral analyses are required to bring out the power of hyperspectral data for remote sensing.

Table 1. Presence/absence of leafy spurge using Minimum Distance Supervised Classification.

Sensor		Ground Data		
		Present	Absent	Accuracy
Landsat 7 ETM+	Present	54	30	
	Absent	60	102	63 % *
SPOT 4	Present	68	35	
	Absent	46	97	67 % *
AVIRIS	Present	63	27	
	Absent	51	105	68 % *

* Significant at $P < 0.05$

Table 2. Classification of presence/absence of leafy spurge using the Spectral Angle Mapper with threshold of 0.05 radians.

Sensor		Ground Data		
		Present	Absent	Accuracy
Landsat 7 ETM+	Present	8	8	
	Absent	106	124	54 %
SPOT 4	Present	22	32	
	Absent	92	100	50 %
AVIRIS	Present	83	33	
	Absent	31	99	74 % *

* Significant at $P < 0.05$

5.0 References

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