Identification, Classification, and Mapping of Invasive Leafy Spurge Using Hyperion, AVIRIS, and CASI

Ralph Root, Pablo Zarco-Tejada, Carlos Pinilla, Susan Ustin, Raymond Kokaly, Gerry Anderson, and Steve Hager

Invasive vegetative species are a major threat to the world's biota. Some are causing extinction of native species, and their effective management requires rapid discovery and assessment. In the United States, the overall economic loss due to the presence of invasive species is about $138 billion per year. One of these species, leafy spurge, has caused severe ecosystem degradation because of its aggressive growth, its ability to invade non-infested areas, and the difficult task of eradication or control. The economic loss from leafy spurge alone, which is present in more than half of the United States and which thrives in the Northern Great Plains, is estimated at $125 million per year (Figure 1). First introduced into North America in 1829, leafy spurge was introduced into the Theodore Roosevelt National Park in southwest North Dakota in 1966, and has since become a major pest.

Figure 1. Leafy spurge has infested more than half of the United States.

This investigation focused on a 47,000-acre area in the south part of the park. Previous mapping of leafy spurge had consisted of manual interpretation of aerial photography. High-altitude hyperspectral imagery was obtained from NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) in July 1999 and June 2001. Low-altitude AVIRIS imagery was obtained in October 1998. Further tests were done with the high spatial resolution Compact Airborne Spectrographic Imager (CASI) in June 2000 and July 2001.

NASA's EO-1 satellite was launched in November 2000, and several new sets of leafy spurge images were acquired from its Hyperion sensor in May, July, and September 2001. For this investigation, the July 6, 2001, Hyperion dataset was selected for in-depth analysis because the leafy spurge bracts were fully developed and stood out from surrounding native vegetation (Figure 2).

Figure 2. Leafy spurge has a distinctive green-yellow color when fully developed.

Field crews collected ground spectrometer data for a pre-selected calibration site at the estimated time of the satellite overpass. Hyperion data were successfully collected and corrected to radiance Level 1. After image pre-processing, a total of 198 bands out of the original 220 Hyperion bands were retained. This data was calibrated to surface reflectance using Atmospheric CORrection Now (ACORN) software using a radiative transfer model with single-spectrum enhancement that removed atmospheric effects. This was compared with similarly calibrated AVIRIS spectra (Figure 3). The close agreement between the two sets demonstrated consistent calibration to surface reflectance and enabled direct comparisons of the two spectra.

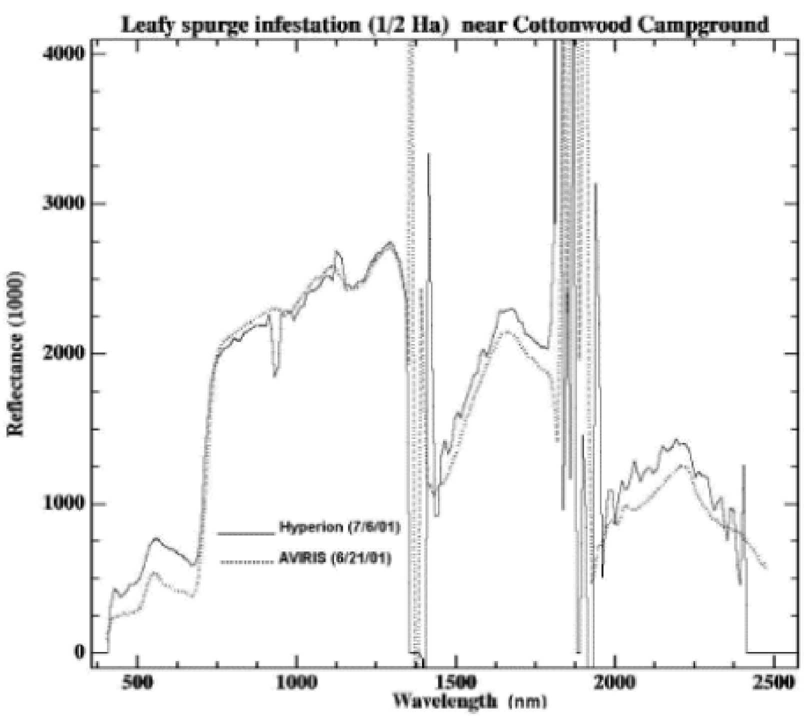

Figure 3. Comparison of Hyperion and AVIRIS spectra for an area of leafy spurge infestation.

Next, a spatial subset of the Hyperion swath was georeferenced and corrected for terrain displacement. This was needed to ensure good spatial agreement between Hyperion and ground data.

For several days before the Hyperion overpass, field crews collected spectra at 10 sites that represented varying densities of leafy spurge and at additional sites representing grasses and shrubs. Also, during the summer, field crews surveyed areas of major infestation to characterize the presence and density of leafy spurge. An additional field study monitored responses of leafy spurge to various control measures over three growing seasons. Red-edge was also characterized by ground spectral measurements and modeling of leafy spurge canopy reflectance.

Three approaches were taken to classify leafy spurge. The first applied a Spectral Angle Mapper (SAM) algorithm to selected principal components, the second (used only on the Hyperion data) utilized red edge spectral parameters, and the third applied a clustering algorithm (isoclass) to all of the Hyperion spectral bands.

In the first approach, noise-whitened principal components analyses using the Minimum Noise Fraction (MNF) transform were applied to separate useable information from noise. The Spectral Angle Mapper (SAM) was then used with training areas selected from the airborne and Hyperion imagery that represented both dense (50%) and moderate (35%) canopy cover. For each of the three sensors (Figure 4), it generated leafy spurge occurrence maps in which the darker areas were the most likely to be leafy spurge, i.e., had the pixels with the smallest spectral angle--the best spectral match. SAM classification results for Hyperion yielded an overall classification accuracy of 63%. A user's accuracy (probability that a pixel identified as leafy spurge actually was leafy spurge) of 82%, and a producer's accuracy (not identifying leafy spurge when it was actually present) of 61% indicated that the SAM was probably underestimating leafy spurge occurrences. On the other hand, results of the SAM classification indicated that leafy spurge could be identified even when mixed with up to 65% of other types of vegetation.

Figure 4. Spectral Angle Mapper images for leafy spurge classification compared: CASI (4 m) (left), AVIRIS (17 m) (center), and Hyperion (30 m).

The second classification approach used red-edge spectral parameters. This technique exploits how vegetation chemistry and canopy structure influence the red-edge spectral region. Results showed an overall classification accuracy of 75% with user's and producer's accuracies for leafy spurge at 83% and 84% respectively. Corresponding accuracies for non-leafy spurge were much lower (53% and 51%) respectively, suggesting a tendency to overestimate leafy spurge occurrences. However, this approach also appeared to be more able to identify smaller infestations.

An unsupervised isoclass clustering algorithm using all Hyperion reflectance bands was also tested, achieving an overall classification of 78.4%, offering a slight improvement over the red-edge classification. This was consistent with the expectation that better results would be achieved when a larger number of spectral bands were available. When simulated Enhanced Thematic Mapper bands were created from Hyperion data, overall isoclass classification results dropped to 75%.

Conclusions:

Different classification methods used in this study demonstrated the feasibility of using hyperspectral satellite data to monitor invasive plant infestations. Both the SAM approach and application of red-edge spectral parameters effectively used the additional spectral information available from Hyperion. The red-edge technique was especially effective in identifying smaller infestations. Isodata classification that used all Hyperion bands yielded the best overall result, with isodata classification of red-edge spectral parameters a close second. Although achieving lower overall results, the SAM classification demonstrated the ability to map leafy spurge when mixed with as much as 65% of other types of vegetation cover. Future improvements in hyperspectral sensors such as improved signal to noise, increased spatial resolution, and greater swath width to increase the coverage area and minimize complexities associated with combining multiple data swaths would further improve results.