COMPARISON OF AVIRIS AND EO-1 HYPERION FOR CLASSIFICATION AND MAPPING OF INVASIVE LEAFY SPURGE IN THEODORE ROOSEVELT NATIONAL PARK

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1. Introduction

Invasive species are rapidly becoming a threat to the world's biota. In the United States alone, non-native species are causing environmental damage and economic losses estimated to exceed $100 billion per year (Pimentel *et al*., 2000). Morse *et al*. (1995) estimate that approximately 5,000 plant species that have escaped from cultivation have subsequently invaded natural ecosystems in the United States. One of these species, leafy spurge (*Euphorbia esula* L.), entered North America from Eurasia in 1829 (Council for Agricultural Science and Technology (CAST), 2000). Some years later, during the Homestead Period, it found its way into North Dakota and subsequently has spread throughout the upper Midwest and northern Rocky Mountain States, causing estimated annual losses of revenue in excess of $200 million. Leafy spurge causes severe ecosystem degradation due to its aggressive growth relative to that of native flora, its ability to invade non-infested habitats, and its persistence once established. It forms nearly monotypic stands and has the capacity to alter ecological processes and visitor perceptions of Theodore Roosevelt National Park and the surrounding region (Trammell, 1994).

Control of leafy spurge infestations has become a primary resources management issue at Theodore Roosevelt National Park, resulting in years of research to develop efficient and cost effective methods for detection, mapping and monitoring of this plant (Anderson, *et al*., 1997, O'Neill *et al*., 2000, and Root and Wickland, 2001).

2. Study area description

Theodore Roosevelt National Park (Fig. 1) was established April 25, 1947. The park consists of three separate units totaling 70,416.39 acres of which 245 acres are directly linked in historical significance to the life of Theodore Roosevelt. Management is directed toward protection and interpretation of the badlands ecosystems surrounding the Little Missouri River and the cultural resources resulting from human habitation of the area. Approximately 42 percent of the park has been designated as a wilderness. Local variations in geology, soil and topography along the Little Missouri River have created an abrupt scenic contrast to the gently rolling panorama of the northern Great Plains. Sandstones, siltstones, and clays interspersed with beds of lignite -- some of which have burned, baking the overlaying clays into bright pink to deep purple "scoria" -- have been sculptured into a landscape of seemingly infinite variety. The badlands formations are rich in fossils of Paleocene forests and swamp life including petrified trunks of giant Metasequoia and remains of ancient alligators. Under the influence of today's climate, the park is mantled by a rich and diverse mosaic of plant communities that provide habitats for an equally diverse variety of animal life.

Approximately 500 species of vascular plants are found in the park. While the majority of plants are typical of those found in the rolling plains of the Missouri Plateau, species of the southwestern desert and Great Basin regions, as

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Figure 1. Location of study area. The South Unit of Theodore Roosevelt National Park is situated immediately north of Medora, ND, bordering Interstate Highway 94.

well as from the boreal forests are represented here. Of these, 59 species are not native to the park's total flora. The most invasive exotic with the greatest potential for damage to native plant communities is leafy spurge.

Leafy spurge is found throughout the park in all habitat types, although it prefers streambeds, drainages, and wooded draws. The plant was first discovered in the park on Knutson Creek, migrating east along the drainage from an established National Grasslands infestation. From just a few plants in the late-1960s, the infestation spread to an estimated 10 ha by 1970. During the next twenty years, sporadic attempts at containment and eradication with herbicides were limited to manual ground spraying in rugged terrain while the infestation increased dramatically. In the late 1980s, the park embarked on an aggressive eradication campaign in cooperation with the United States Department of Agriculture (USDA) Agricultural Research Service (ARS), Animal and Plant Health Inspection Service (APHIS) and North Dakota State University. An integrated approach utilizing helicopter-based herbicide application, ground spraying and release of host-specific insect species (biological control) was adopted and remains in use to date.

Biological control insectories located in North Dakota and Montana provided increasing numbers of insects for release in the park beginning in 1994. By the late 1990s, more than 2000 insect release sites had been established, forming a dense network of insectories throughout the infestation. Recently, the park has seen landscape-scale reduction in leafy spurge infestation as the insect network coalesces; however, leafy spurge still infests an estimated 10 percent of the land base. To effectively monitor the infestation and improve the application of controls, state-of-the-art remotely sensed data are needed at frequent intervals to quantify areas of reduction/eradication and identify remaining infestations.

3. Previous leafy spurge mapping efforts

In 1993, the U.S. Department of Agriculture Agricultural Research Service flew 10,000 scale low-altitude aerial photography over the South Unit of Theodore Roosevelt National Park, mapping the leafy spurge infestation using visual photo interpretation processes (Anderson *et al*., 1997). Seven hundred twenty five ha of leafy spurge were digitized, georeferenced and imported into a geographic information system (GIS). Using this base of spatial information, map products were generated that allowed park managers to more efficiently gather and direct resources toward infestation control (National Park Service, 1992 and Redente, 1993). In 1998 the South Unit of the park was reflown, and an updated leafy spurge map was created, again by manual photointerpretation. In Figure 2 the level of infestation by 1993 is illustrated in yellow, with additional infestations from 1993 to 1998 mapped in red. Because different photointerpreters were used in 1998, the areas of infestation are more generalized, giving the impression of greater spread than may have actually occurred.

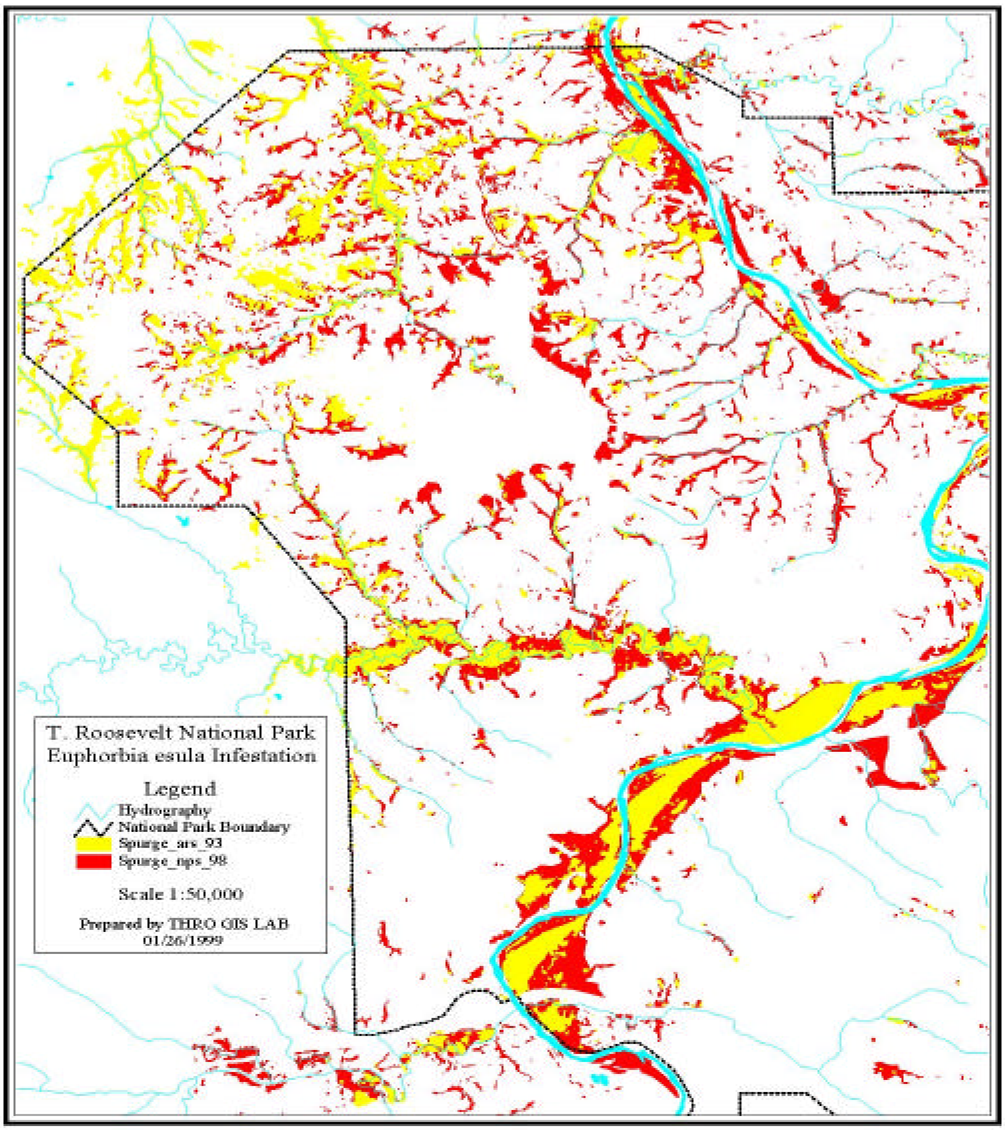

Figure 2. Manually interpreted aerial photo maps of leafy spurge illustrating infestation levels in 1993 (yellow), and 1998 (red).

For this reason, a variety of digital remote sensing techniques have been examined since 1998 with the aim of achieving more quantitative and consistent analysis of leafy spurge spread over time.

4. Data Acquisition

Testing of state-of-the art remote sensing technology for detection and mapping of leafy spurge at Theodore Roosevelt National Park began in 1998 as part of a cooperative demonstration project between the National Aeronautics and Space Administration (NASA) and the United States Department of Interior. (DOI). Within the NASA/DOI Hyperspectral Technical Transfer Project (Root and Wickland, 2001), high altitude Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data were collected over the South Unit of the park in July, 1999. Preliminary analysis of these data demonstrated that leafy spurge could be identified and mapped (O'Neill *et al*., 2000).

Examination of the potential for mapping leafy spurge from a space-based platform was supported by NASA in 1999 with the incorporation of leafy spurge mapping research into the Earth Observing-1 (EO-1) science validation program. EO-1 Hyperion data were obtained over the extreme western part of the South Unit of Theodore Roosevelt National Park on May 21, July 6, and Sept. 24 of 2001, along with a second high altitude AVIRIS mission on June 21, 2001 for comparison purposes. Because leafy spurge was close to full bract development in early July, the 07/06/02 Hyperion data set was selected for in-depth analysis because fully developed bracts produce a uniform greenish-yellow canopy, making infestations visibly stand out from surrounding native vegetation.

5. Data pre-processing and calibration to surface reflectance

The EO-1 Hyperion data, collected on 07/06/01, were corrected to radiance (Level 1) at NASA Goddard Space Flight Center. The radiance corrected data, initially in hierarchical data format (HDF), were then sent to the USGS Rocky Mountain Mapping Center and previewed for spatial and spectral data integrity.

At the time of EO-1 data collection on 07/06/01, field crews used two ASD-FR spectrometers to gather several hundred ground spectra over a pre-selected calibration site at the estimated time of satellite overpass. The site was a 1 ha. level asphalt parking surface with uniform medium reflectance. Consistency of spectral responses between the two spectrometers was verified by single path measurements through a calibrated mylar sheet. Close agreement of sharp absorption feature responses from both instruments justified merging the spectra.

The mean calibration reflectance spectrum collected from the ground was then corrected for Spectralon panel absorption features, to achieve the best possible approximation of true reflectance. Noise associated with the 1.37 and 1.87 water vapor regions was eliminated using lab-measured spectra from asphalt samples obtained from the parking area. Minor smoothing was also done in the 2.2 to 2.5 micron region where ground instrument signal to noise was at a maximum. The spectrum was then convolved to Hyperion and AVIRIS wavelength and bandpass, and processed in ACORN to ratio the data to surface reflectance. The final edited and smoothed ground spectrum was input into ACORN for Single Spectrum Enhancement (SSE), along with the arithmetic mean of corresponding AVIRIS and Hyperion pixels that were selected after examination of their spectra to assure that they were consistent and positioned fully within the boundaries of the asphalt calibration surface. Because calibration site ground spectra collected at the time of the AVIRIS overflight on 06/21/01 were virtually the same as those collected on 07/06/01, only the 07/06/01 ground spectra were used for calibration of both sensors. Close agreement (+/- 1 percent) between the EO-1 and AVIRIS calibration spectra indicated consistent calibration to surface reflectance enabling direct comparisons between the two sensors.

6. Comparison of AVIRIS and EO-1 spectra

Figure 3 shows comparisons of 06/21/01 and 07/06/99 AVIRIS and 07/06/01 EO-1 Hyperion spectra over identical ground locations at: the calibration site, the Medora sewage lagoon (low reflectance water), Little Missouri River (turbid water), non-vegetated road fill, a 0.5 ha patch of leafy spurge, and a 4 ha grassland area. All areas clearly show the difference in noise levels of the two instruments, but they also show the consistency of Hyperion in approximating the spectra obtained by AVIRIS. Over highly reflective surfaces there are consistently lower reflectance levels in the 950-1,900 nm range for Hyperion. Although the reasons for this difference are unclear, it may be a result of a small scaling error in the Hyperion calibration or it might indicate variations in Hyperion detector response in this portion of the spectrum.

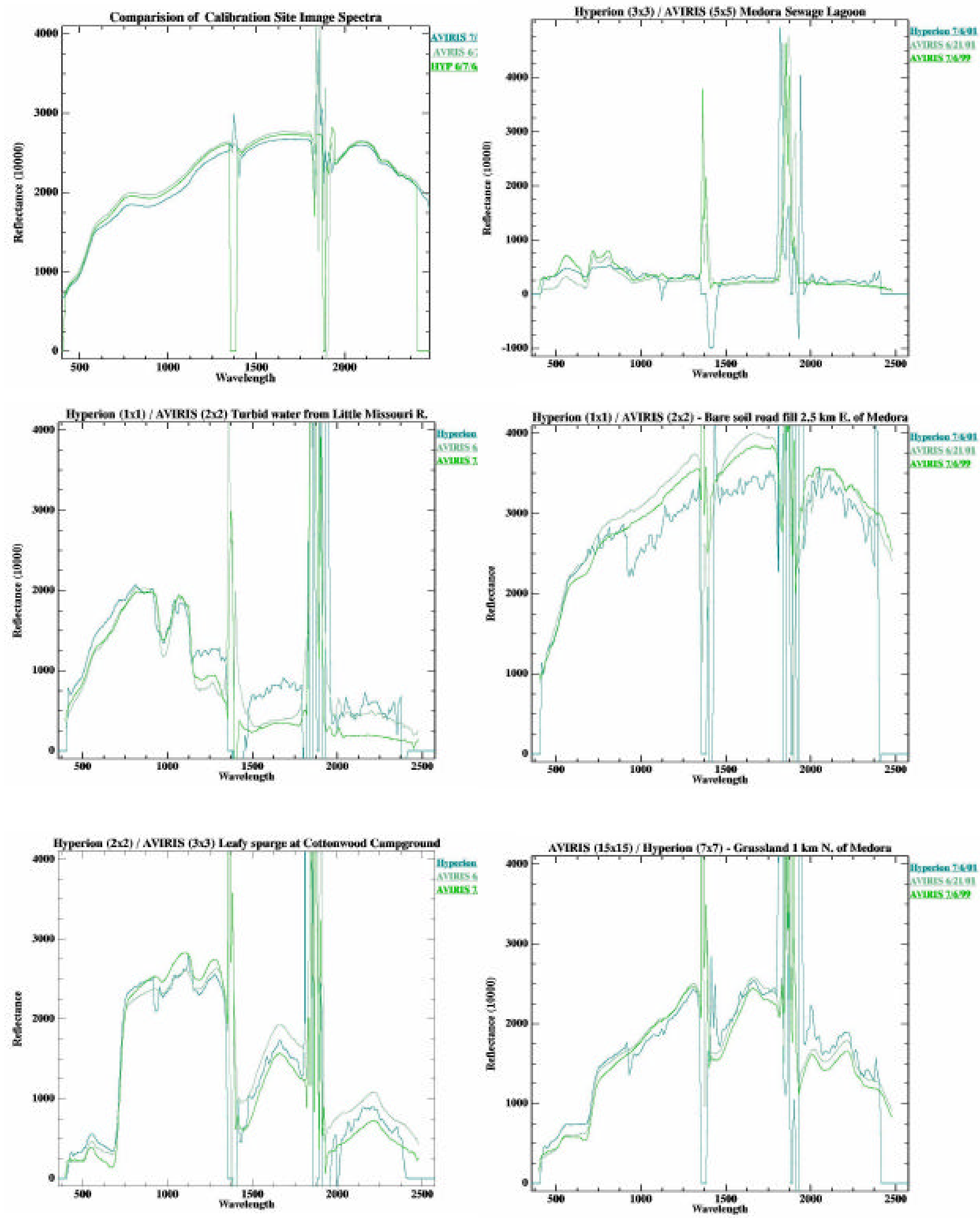

Figure 3. Comparisons of Hyperion (2001) and AVIRIS (1999 and 2001) spectra at selected locations

7. Collection of vegetation spectra and verification data from the ground

Throughout the course of this study ground spectra were collected at multiple sites representing varying densities of leafy spurge ranging from 25 to100 percent crown cover, and locations representing native grasses and shrubs within the park. Each measured site was delineated by global positioning system (GPS) measurements and entered into the park's GIS database. Spectrometer measurements at each site were collected in a dynamic mode to provide a mean spectrum with both a low signal to noise ratio and good spatial variation within the site. Numbers of individual spectra collected at each site were usually in excess of 200, with a minimum of 50. Mylar panels were used to document the spectral calibration of each spectrometer used in the study to assure uniformity of spectra.

During the summer of 2001, field crews at Theodore Roosevelt National Park trained in vegetation identification and global positioning system field procedures conducted detailed ground surveys of major leafy spurge infestation areas. Using a sampling scheme of 32 by 32 m grid cells, percent cover of leafy spurge, along with up to 28 other vegetation types were recorded in several areas containing extensive leafy spurge infestations (National Park Service, 2001). These data were gathered to characterize both presence and density of leafy spurge in spatial context with associated native vegetation. A second field survey was conducted for three consecutive growing seasons from 1999 through 2001 to monitor responses of leafy spurge to chemical and biological control measures. This project entailed collection of data from a total of 550 3 m by 5 m plots to geographically document presence/absence of leafy spurge, and to produce detailed estimates of crown cover (via stem counts) and biomass for leafy spurge and associated native vegetation types. Plots containing leafy spurge were a combination of known bio-control measure locations and stratified random samples from areas previously mapped as leafy spurge (Anderson, et al., 1997). Plots not containing leafy spurge were randomly selected from a buffer zone extending 250 meters in all directions from previously mapped leafy spurge infestations (Anderson, et al., 1997). Ground data obtained from the first of these surveys were used for determining classification training inputs and setting of thresholds. Data from the second survey will be used to perform accuracy assessments on the classifications developed from both the Hyperion and AVIRIS imagery.

Leaf-level spectral measurements were also carried out for biochemical analysis of leaf chlorophyll concentrations through SPAD-502 chlorophyll meter readings (Minolta Camera Co., Ltd., Japan) and leaf reflectance and transmittance. Leaf and bract optical measurements were acquired from leafy spurge samples collected at different locations in order to use reflectance and transmittance for red edge characterization and modeling leafy spurge canopy reflectance as a function of different densities.

Single leaf reflectance and transmittance measurements were acquired on all leaves and bracts using a Li-Cor 1800-12 Integrating Sphere apparatus coupled by a GER-2600 spectrometer yielding a 0.5 nm sampling interval and 2.5 nm spectral resolution in the 340-2500 nm range. Measurements were collected with the integrated sphere following the methodology described in the manual of the Li-Cor 1800-12 system in which five signal measurements are required: transmittance signal, reflectance signal, reflectance internal standard, reflectance external reference, and dark measurements.

8. Preliminary classification analyses

Minimum noise fraction (MNF) principal components analyses were performed on the 1999 and 2001 AVIRIS and 2001 Hyperion, surface reflectance data to reduce overall data dimensionality Both years of AVIRIS data yielded approximately 30 useable components compared to 10 from Hyperion. The spectral angle mapper (SAM) algorithm was applied to selected components of each set of imagery that gave clear visual indications of known leafy spurge infestations. Two leafy spurge infestations that had been observed on the ground were selected for training areas. Both were approximately 100 m square, and represented high-(50%) and moderate-(35%) crown cover. Pixels representing these areas were located in the Hyperion imagery by visual interpretation and comparison of image spectra with mean ground spectra obtained from these sites. The Spectral Angle Mapper (SAM) classification algorithm in the Environment for Visualizing Images (ENVI) was then used to generate a rule image for the high- and moderate- density training areas. Gray-scale density values on the rule image represent spectral angle values, with smaller angles (i.e., darker areas) indicating closer matches to the reference spectrum. The two rule images were then added to each other, producing an integrated rule image (Figure 4). This image was then georeferenced and visually compared with the GPS field survey data and polygons from photo interpreted leafy spurge maps created with 1993 aerial photographs. Using these visual comparisons, digital values on the summed rule image were thresholded to produce a leafy spurge occurrence map (Figure 5). Determination of the threshold value was based on interactive contrast stretching of the rule image to match low spectral angle values with GPS ground surveyed areas (National Park Service, 2001) and previous photo-interpreted mapping boundaries of leafy spurge (Anderson *et al*., 1997). An optimal threshold value would result in a classification where there is a balance

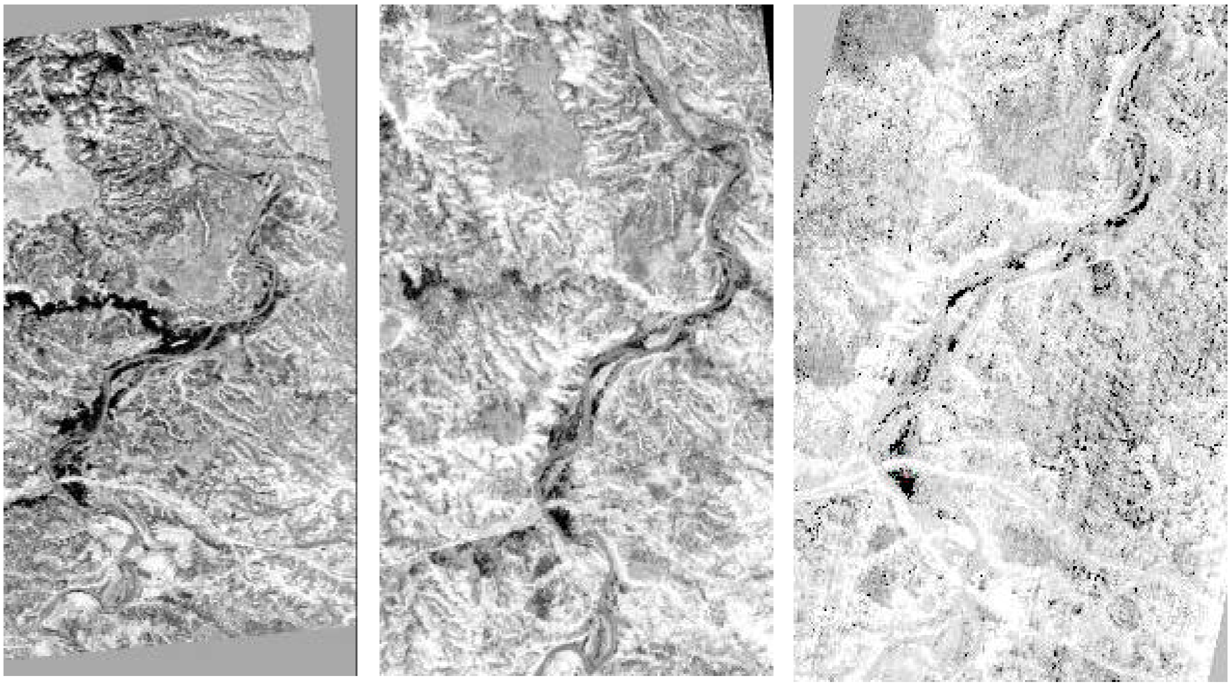

Figure 4. Summed spectral angle mapper rule images from 1999 AVIRIS (left), 2001 AVIRIS (middle), and 2001 Hyperion (right). Note the absence of leafy spurge in the lower Knudsen Creek drainage (center of image) in the 2001 images, resulting from chemical control measures taken in late 1999.

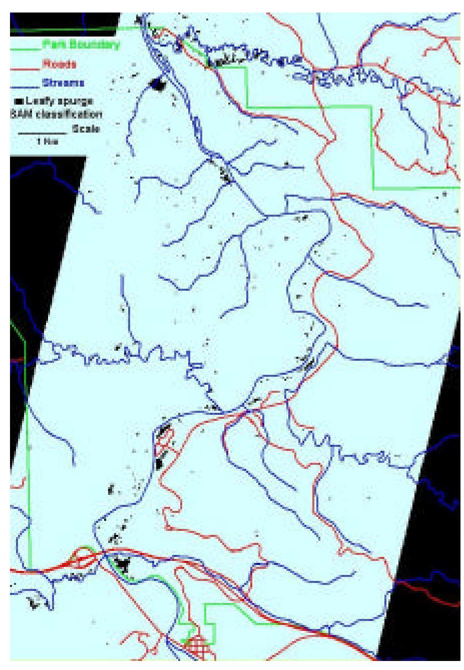

Figure 5. Example of a tightly thresholded spectral angle mapper classification of the 2001 Hyperion data, showing only the closest matches to the reference spectrum (i.e. very low spectral angles). Although other vegetation that might be mis-classified as leafy spurge is virtually eliminated, many less dense infestations and those mixed with other types of vegetation are more likely to be omitted from the classification.

between errors of commission and errors of omission. Further analysis with accuracy assessments using ground verification data is expected to assist in making a final determination of the threshold.

Spectral feature fitting, applied to a continuum-removed version of the chlorophyll absorption zone has been successfully demonstrated for mapping leafy spurge using Compact Airborne Spectrographic Imager (CASI) data calibrated to surface reflectance (Kokaly *et al*., 2001a, 2001b, 2001c). A library of ground spectra, collected from several leafy spurge infestations, was used for reference spectra. Similar analyses of the 1999 and 2001 AVIRIS surface reflectance data using these same library spectra are also expected to produce viable classifications of leafy spurge infestations.

A third approach being investigated is based on the calculation of red edge spectral parameters from hyperspectral data, which are a function of biophysical and biochemical constituents of the vegetation canopy. A method for the classification of land cover has recently been reported which exploits systematic differences in species within the shorter wavelength infrared spectral regions sensitive to foliar chemistry (Martin *et al*., 1998). Zarco-Tejada and Miller (1999) described classification of vegetated land cover based on spectral parameters that characterize the red edge reflectance region, which are responsive to foliar chlorophyll pigment levels. Classification with three red edge spectral parameters, red edge inflection point (λ_p), the wavelength at the reflectance minimum (λ_o), and a shape parameter (σ), as defined by the inverted-gaussian red-edge curve-fit model (Hare *et al*., 1984; Miller *et al.*, 1990; 1991) were carried out with the surface reflectance calibrated Hyperion data. The separation of land cover types and location of leafy spurge patches using this classification method is based on cover-type systematic differences in the variables known to affect red edge spectral parameters: vegetation chlorophyll content, canopy structure, canopy cover, and illumination. Preliminary classifications from the inverted-gaussian red-edge curve-fit model for red-edge spectral parameter calculation, adapted for Hyperion reflectance data also compares favorably with the preliminary results from the first two methods described above.

9. Further research tasks ahead

During the next year finalized classifications developed by the methods described above will be completed and compared by applying accuracy assessments to each technique. In combination with precise georeferencing procedures, classifications for all four AVIRIS flight lines will be merged, producing leafy spurge maps for the entire South Unit of the park. These maps will then be used to quantify the effects of integrated pest control efforts undertaken by the park from 1999 through 2001.

10. Conclusions

AVIRIS has been a central element of four years of imaging spectroscopy research in detection and mapping of invasive leafy spurge at Theodore Roosevelt National Park in southwestern North Dakota. The exceptionally high signal to noise ratios, well-defined system calibrations, and recently improved geospatial positioning capabilities of AVIRIS have provided an excellent reference point for comparison with the Hyperion imager on the orbital side, and CASI on the low altitude aircraft side, for effectiveness of mapping leafy spurge with imaging spectrometers spanning a wide range of spatial resolution. Preliminary results of three different classification techniques indicate that leafy spurge is generally separable from its associated vegetation types. Further research is expected to quantify classification results and explore the potential for generating more regional, multi-flightline maps of leafy spurge infestations that will provide valuable contributions to monitoring and controlling efforts.

11. Acknowledgments

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