Using Hyperspectral Data to Assess Forest Structure

By Susan L. Ustin and Antonio Trabucco

More accurate maps of forest composition will result from the new hyperspectral instruments, which read the abundance and distribution of woody biomass and standing litter by picking up slight variations in pigment, water content, and soil properties. Such information allows direct inferences about physical processes rather than requiring managers to make statistical associations. Although more difficult to analyze and interpret than multispectral images, these data will raise the level of accuracy for making forest management decisions.

Hyperspectral imaging sensors (HSI) are among the most advanced remote sensing technologies. These instruments measure many narrow-wavelength adjacent spectral bands and create a laboratory-like spectrum for each pixel. Up to now, these instruments have been available only on airplanes, but NASA will launch the first satellite with HSI, Hyperion, in September 2000. Three joint-venture commercial-government hyperspectral satellites are planned beginning in 2001; they will measure 150 to 200 spectral channels in the 0.40- to 2.50-mm region (visible and reflected infrared radiation) at spatial resolutions of 30 meters or better.

At least 15 HSI airborne instruments are operating in the United States today. Data from NASA's 224-band airborne visible infrared imaging spectrometer (AVIRIS) have been available from the Jet Propulsion Laboratory for the past decade. This instrument provides the benchmark against which other HSI sensors are compared. The laboratory website (http://aviris.makalu.jpl.nasa.gov) has a searchable archive of more than 3,000 datasets, including about 1,000 datasets acquired at 5-meter pixel resolution; single-band quick-look images can be previewed on line.

Strengths and Limitations

HSI instruments improve maps of forest composition by better characterizing the reflectance spectra of tree species and provide data about the abundance and distribution of woody biomass and standing litter. Variations in biochemical properties related to pigment composition, water content, and soil and litter properties are quantifiable. These new types of information permit direct inferences about physical processes rather than statistical associations, increasing accuracy of interpretations and conclusions.

The principal drawback to HSI data is that they require more skill and knowledge to analyze and interpret than multispectral images. However, commercial software programs are available that have advanced analysis procedures designed for HSI data, reducing this limitation. And the computing requirements for memory, storage, and speed that once drove the cost of data analysis are no longer prohibitive.

Applications in Forestry

We have selected the southern part of the Gifford Pinchot National Forest in Washington, on the western slopes of the Cascade Range, to illustrate issues facing forest management and ways in which hyperspectral imagery can assist

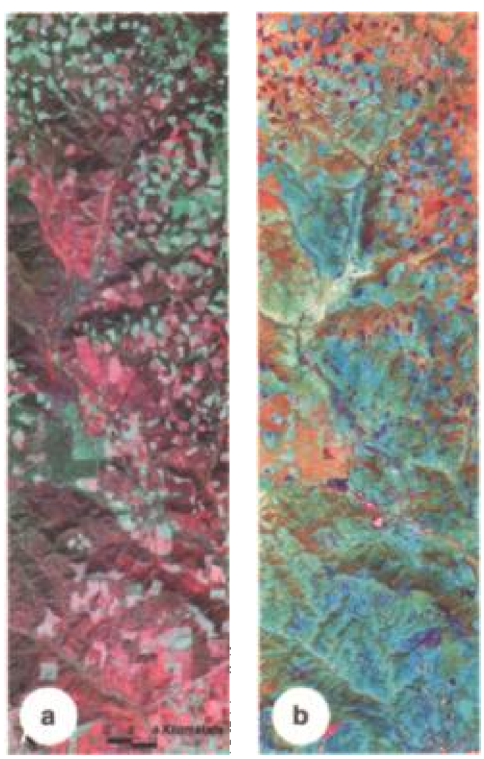

Figure 1. **Hyperspectral image data of 1,300 square kilometers of the Gifford Pinchot National Forest, Washington. The forests of the region are fragmented from land-use practices and are in various stages of recovery.**

a. **A false color near-infrared composite.**

b. **A false color composite of mature conifers (red), herbaceous cover and young trees (green), and shade (blue).**

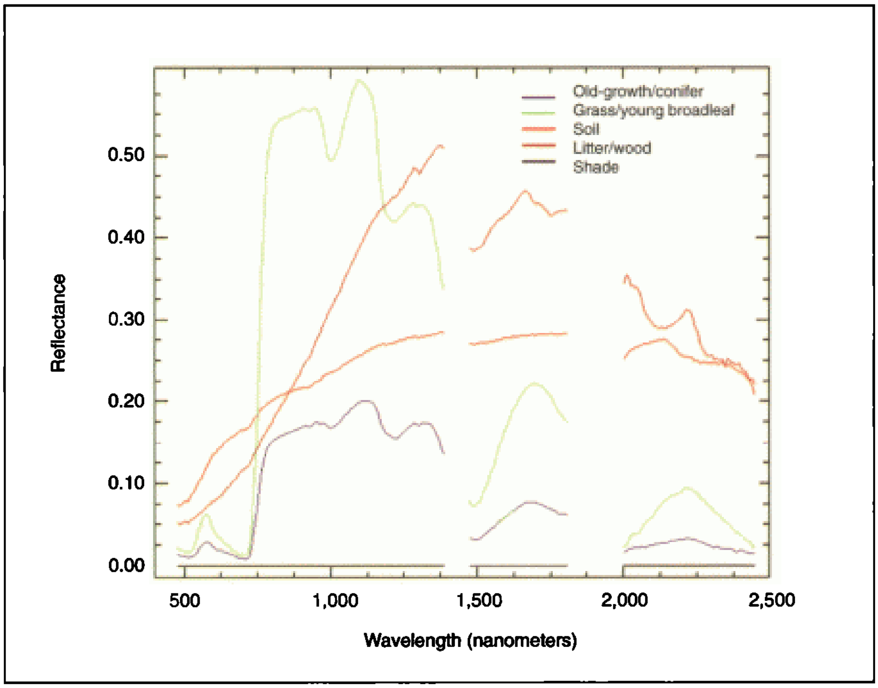

***Figure 2.* Spectral signatures used as reference for the linear mixture analysis of AVIRIS data.**

these management decisions. AVIRIS was acquired on June 14, 1996, at 20-meter pixel resolution. *Figure 1a* is a false-color composite that shows vegetated areas in shades of red. The extensive patchiness of the region is caused by complex regional vegetation patterns and recent logging. A significant compositional change is evident from the top of the scene, just south of Mount St. Helens, to the bottom, at the Columbia River. Broadleaf vegetation and sapling-stage young conifer stands are red and brown, apparently indicating greater vegetation cover.

The green L-shaped region left of the Wind River (which traverses the middle of the image from upper left toward lower right) is an old-growth forest in the T.T. Munger Experimental Forest. Here, trees are as old as 500 years. Maximum tree height is 65 meters with 1,740 trees per square hectare, and biomass of 890 megagrams per hectare, compared with the mean Northwest forest biomass of 150 megagrams per hectare. Clearly, mature forests have spectral responses that are not well represented in traditional infrared photography. This is a result of the complex vertical distribution of the canopy, which produces strong shadows, and the standing litter and branches in the canopy; both make the area dark in the infrared.

Figure 1b uses a transformation of all the spectral bands to estimate the composition of land cover by first characterizing the spectral types representing shade (blue), herbaceous and young forests (green), and old-growth forest vegetation (red) and then estimating the proportion of each in every pixel. The relative proportions of these spectral types are expressed as the tone and hue of the image, with intermediate colors indicating mixtures.

Figure 2 shows reflectance spectra for the four cover types and shade that were used in the AVIRIS mixture analysis. These pixel spectra were extracted from sites of bare soil, old-growth forest canopy, and the canopy of seedlings and herbaceous cover in the Forest Service nursery, south of the mature forest (diagonal red stripes on the false color image, and turquoise on the mixture fractions in *figure 1*), and plant litter, bark, and wood.

Soil, old-growth forest canopy, and plant litter have similar magnitudes of reflectance in the near-infrared (700 to 850 nanometers), making them difficult to separate. When the full spectrum is used for classification, however, these materials are distinct. Herbaceous vegetation and young forest canopies have higher reflectance across the spectrum than old-growth forest canopies. In the green spectral region (around 550 nanometers), young trees have higher reflectance and a steeper negative slope toward the red spectral region (650 nanometers). In the near-infrared, young trees are brighter and the water absorption bands at 950 and 1,180 nanometers are deeper. The overall brightness in the spectral regions between water absorption bands declines to a greater extent across the infrared. The convex shape of plant litter reflectance from 400 to 1,500 nanometers and the features in the shortwave infrared (1,500 to 2,500 nanometers) are due to absorption by structural carbon compounds. Such features are nearly absent in bare soils without a layer of surface litter. The residual organic matter in the soil is observed in the convex shape of the 400- to 550-nanometer region and in the smaller absorption bands in the 2,000- to 2,500-nanometer region. Thus, the three basic materials have markedly different distributions as land cover conditions change. Because all pixels contain these data, the information derived from AVIRIS data is much richer than that from multispectral sensors.

Figure 3 shows an enlarged block of the experimental forest and surrounding lands. The four images illustrate how differences in the composition can be inferred from HSI data. *Figure 3a* is a composite of litter, old-growth forest canopy, and soil. The other composite images show combinations of three spectral types: two kinds of vegetation (herbaceous cover and young trees, and old-growth forest), plus litter or wood *(fig. 3b)*, soil *(fig. 3c)*, or shadow *(fig. 3d)*.

By displaying the spectral types in different combinations, greater resolution of the composition of this complex forest region is possible. For example, the location of clearcuts is evident on all images, but the apparent soil and litter composition of the patches and the spatial distribution of the younger growth depend on which combination is displayed. Likewise, the riparian vegetation along the Wind River (travers-

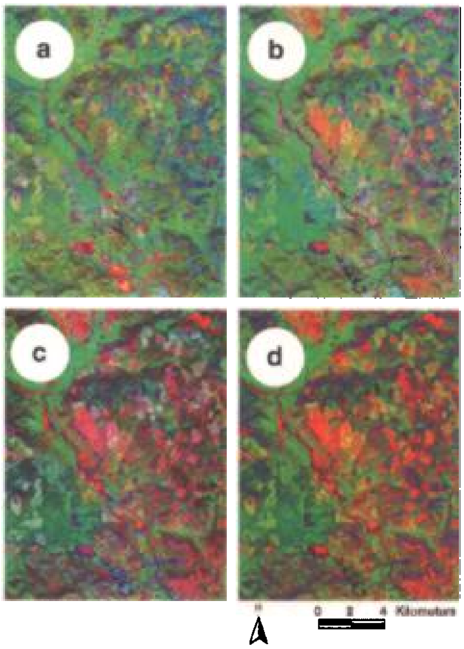

***Figure 3.* Four representations of site conditions in the Wind River Valley, Washington.**

***a.* Litter (blue), old-growth forest canopy (green), and soil (red).**

***b.* Herbaceous cover and young trees (red), old-growth forest (green), and litter or wood (blue).**

***c.* Herbaceous cover and young trees (red), old-growth forest (green), and soil (blue).**

***d.* Herbaceous cover and young trees (red), old-growth forest (green), and shadow (blue).**

ing from upper left to lower right) is more heterogeneous in *figure 3b*. Beetle damage to the old-growth forest (upper left edge of the L-shaped patch) is most evident in *figure 3a* because the areas have higher litter and soil fractions.

There are many quantitative ways to further evaluate differences in the color images and extract more information about the structure and biochemical condition of the forests. For example, the spectral types can be used to classify forest communities to create a detailed land cover map.

Because the gradient in land cover types runs north to south, it is possible to identify more spectral types when smaller subsets are analyzed independently. For example, there are at least two distinct types of litter: the one shown in *figure 2*, representing woody debris and bark, and another associated with dry grass leaf litter. The spatial distribution of canopy water content can be quantified from the depth of the water absorption features, providing information about sites with high leaf area index values and areas of canopy water stress.

One can also zoom in on a smaller region to determine the potential for soil erosion and the integrity of streambanks based on the presence of bare soils adjacent to streams. Soil erosion processes can be examined in greater detail when the images are registered to a digital elevation model and soils database. Similarly, gap size, gap structure, and forest heterogeneity can be characterized for wildlife habitat. Lastly, images taken at different times can be compared to reveal change.

Susan L. Ustin (e-mail: susan@cstars.ucdavis.edu) is associate professor of resource science, and Antonio Trabucco is postgraduate research scientist, Center for Spatial Technologies and Remote Sensing, Department of Land, Air, and Water Resources, University of California, One Shields Avenue, Davis, CA 95616-8671.