Pixel Unmixing for Hyperspectral Measurement of Foliar Chemistry in Pacific Northwest Coastal Forests

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Abstract – Studies for the detection and mapping of variation in foliar chemistry have concentrated on the correlation of wavelength specific reflection and concentrations of foliar pigments and nutrients either through ground-based radiometric measurements or airborne data. The advantage of the former is that the scene components can be effectively controlled so that a relatively simple reflectance model can be constructed and end members extracted. In the case of using airborne data, however, the influence of scene components that mask, or subdue, the reflectance-chemical signal, may dominate. This has led to the development of methodologies for which the various scene components can readily be isolated and accounted. Pixel unmixing to isolate canopy reflectance from other scene components has long been used in the assessment of foliar characteristics and processes. Unfortunately the traditional methods of unmixing rely on distinct spectral signatures from the various scene components. This paper details a method developed to isolate the scene components when they are not spectrally dissimilar.

INTRODUCTION

One of the proxy indicators of environmental variability has been found to be the chemical composition of foliage. The more obvious chemical constituents are the pigments (chlorophyll a, chlorophyll b, and carotenoids) and nutrients (nitrogen, carbon).

Previous work with the remote sensing of foliar chemistry has fallen into two categories: the assessment of reflectance at first the leaf and second canopy scales. The work carried out at the leaf scale involves the use of foliage harvested and assessed through the use of either laboratory or field spectrometers ([1]; [2]). Alternatively, spectrometer measurements taken from aircraft or satellites are used to assess the characteristics at the canopy scales ([3]; [4]).

Remotely sensed airborne and satellite data are relatively coarse. Implicit in this concept is the fact that each pixel (especially when the pixel resolution is greater than the reflective objects in this case trees) contains multiple reflective elements. This may include understory or background reflectance such as vegetative ground cover or exposed soil, and shadow. As we are concerned with only the upper canopy chemistry it is important that we separate the various reflective components. The process selected for this project is commonly known as pixel unmixing, ([5]). Much of the previous work in unmixing has been carried out in semiarid regions where the reflective differences between the green vegetation, soil background, and shadow are unique and easily separable. In our situation, in the Pacific Northwest, we must employ a more complex strategy in that the background reflectance is commonly not soil, but rather other green vegetation. This renders the process of separating out these various components much more problematic.

The technique of pixel unmixing as it is generally applied assumes a linear regression model to separate the reflective components, termed end members. The technique relies on the analyst to identify the spectra of "pure" reflectors. These spectra are subsequently used within a multiple regression to estimate the contribution of each reflector for each pixel.

$$DN_b = \sum_{i=1}^{n} F_i DN_{i,b} + E_b \; and \; \sum_{i=1}^{n} F_i = 1$$

The model is that DN_b is equal to the sum over the number of bands of $(F_i)(DN_{ib})$ plus E_b. DN_{ib} is the data number for a pixel; F_i is the fraction of the end member i; DN_b is the relative reflectance for each end member of band b; and E_b is the error associated with each end member. If F_i is normalized, the sum of F_i will equal unity (1.0). The results of applying this analysis are a series of images, one for each end member.

Normally, to define each of the end members, reference spectra defining each of the reflective components are acquired. Where possible this involves the collection of spectra in the field from each of the identified reflective elements. In many cases, however, this may not be the best approach as it assumes that there is a linear relationship between a small sample collected in the field and that measured from an aircraft or satellite platform. The alternative is to find "pure" reflectors from the imagery from which representative spectra can be extracted for each of the end members. In situations where pixels cover moderate resolutions (20 meters or greater), the opportunities to define "pure" reflectors are few. Rather, pixels tend to be composed of a number of reflectors (hence the need for the spectral unmixing in the first place). When we apply spectral unmixing to areas where the reflective differences of the various components are subtler, for example in the Pacific

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North West forests, the problem of end member definition becomes more difficult.

METHODS

To address this problem we developed a methodology to separate the crown from understory reflectance. To achieve this an initial identification of crown versus other reflectance was necessary. This was carried out through the use of a stem mapping approach ([6]). The method was applied to a one meter digital orthophoto. Once the stems were mapped, they were grouped into 20 meter pixels and densities recalculated on a stems/hectare basis. The stem density image was co-registered with a corresponding AVIRIS scene. AVIRIS data were chosen for the initial analyses as this sensor imaged a spectrally contiguous data cube from 390 nm to 2450 nm in 10 nm bands.

Spectra corresponding to a wide range of stand densities were extracted from the AVIRIS data. A plot of a few of these is presented in Figure 1. One point becomes strikingly clear when viewing Figure 1: there is a positive correlation between stem density and reflectance. This is especially noticeable in the near and mid infrared range (700 to 1400 nm). In the visible portion of the spectrum (400 to 700nm) this relationship is not as apparent. This relationship is better illustrated in Figure 2 where the reflectance vs. stem densities for 990 nm is plotted.

When examining Figure 2, we see that there are two groupings of points: one representing samples from stem densities greater than 180 stems/ha, and a second for densities lower than 180 stems/ha. The grouping for the higher stem densities is characterized by a relatively small variance in reflectance and a flat slope. The other grouping has a greater variance and a steep slope. The first group of points is, therefore, interpreted as closed canopy where the reflectance is influenced by crown foliage and shadows. The second grouping is open canopy where differing degrees of canopy, understory reflectance, as well as shadow contribute to the overall pixel reflectance.

The goal of defining these two groups was to develop a technique to extract an end member representing the canopy contribution to the reflectance registered by each pixel. To achieve this, two end members were required: the canopy and the understory. Reflectance values corresponding to closed canopy were defined by averaging the reflectance values for those points with stem densities greater than 180 stems/ha. For undergrowth reflectance a best-fit line was derived. The value for the y-intercept, that is 0 stems /ha., was determined for each of the AVIRIS channels. The resultant spectral curves are presented in Figure 3 .

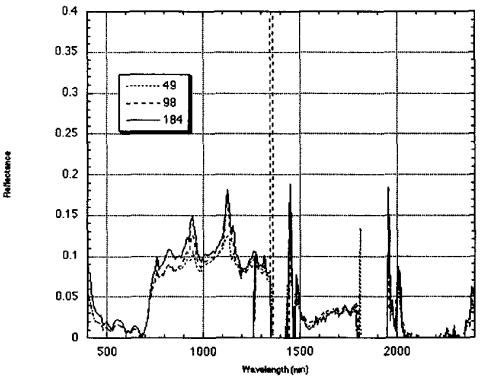

Figure 1 Stem density vs. reflectance

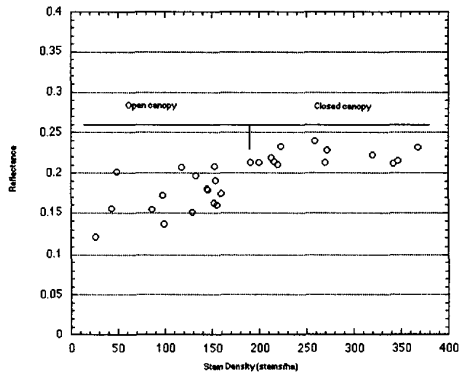

Figure 2 Stem density vs. reflectance for 990nm.

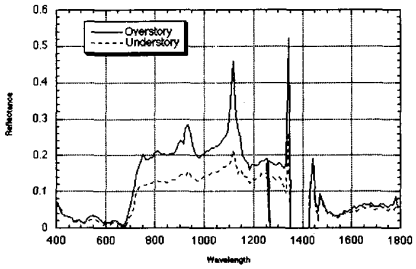

Figure 3 Overstory and understory spectra.

From these spectra two end member images were derived (Figure 4), one for the overstory and the other for the understory proportion of the pixel.

These images were used as additional input into the assessment of foliar chemistry.

CONCLUSIONS

The assessment of canopy chemistry from remotely sensed data requires the separation of canopy reflectance from that of the understory. This is especially challenging in areas where the understory is composed of green vegetation, similar to that of the canopy. A method has been presented that successfully creates separate canopy and understory end members. These end members can subsequently be used as inputs in the assessment of canopy chemistry.

REFERENCES

[1] B. J. Yoder and R. E. Pettigrew-Crosby , *Remote Sensing Environment*, vol. 53, pp. 199-211, 1995.

[2] L. F. Johnson and C. R. Billow, *International Journal of Remote Sensing*, vol. 17, pp. 489-500, 1996.

[3] L. E. Johnson, C. A. Hlavka, and D. L. Peterson, *Remote Sensing of the Environment*, vol. 47, pp. 216-230, 1994.

[4] J. E. Pinzon, S. Ustin, C. M. Casteneda, and M. O. Smith, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, pp. 1913-1926, 1998.

[5] J. B. Adams and M. O. Smith, *Journal of Geophysical Research*, vol. 91, pp. 8098-8112, 1986.

[6] K. O. Niemann, D. G. Goodenough, D. Marceau, and G. Hay, "A Practical Alternative for Fusion of Hyperspectral Data with High Resolution Imagery," Proc. IGARSS'98, pp. 174-176, Seattle, WA, 1998.

Figure 4. Two end members derived for canopy and understory. Upper image is the overstory and the lower image is the understory.