Chaparral Vegetation Reflectance and its Potential Utility for Assessment of Fire Hazard*

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ABSTRACT: Current methods for assessment of ignition potential often fail to alert wildland managers to the severity of drought-induced fire hazard at remote locations and over large geographic areas. After the severe fires of 1988 in the western United States, the need was heightened for improved fire hazard assessment techniques. Chaparral vegetation is particularly receptive to recurring drought-related episodes of extreme fire hazard and was thus chosen for study here. Demonstrated herein is that chaparral vegetation has considerably different reflecting properties at different levels of drought stress. As such, remote sensing may have utility for fire hazard assessment in this vegetation type.

INTRODUCTION

DROUGHT COMMONLY LEADS TO WATER STRESS and increases the dead-to-live biomass ratio of woody plants (Kramer and Kozlowski, 1979). Together, these two factors decrease the amount of energy required to ignite plant crowns, making them more flammable (Cohen, 1989). Currently, the primary means of assessing fire hazard is by field observation of dead fuels and laboratory analysis of water stress in collected live branch foliage (Brown *et al.*, 1982; Norum and Miller, 1984). However, hazard assessments based on these sampling techniques are limited to the relatively small geographic areas where data were collected. After the number of severe fires that burned all over the western United States in the summer of 1988, it is clear that improved fire hazard monitoring techniques are needed. Remote sensing technology, when incorporated into current assessment schemes, may help to facilitate efficient and effective assessments of drought-induced fire hazard over large geographic areas.

Leaves commonly account for a large proportion of the vegetation biomass visible to a remote sensor. Hence, a major thrust of research in remote sensing of the manifestations of drought stress in live vegetation has been the evaluation of leaf reflectance-water stress relationships. However, two basic problems exist with this approach. First, reflectance variation associated with changes in leaf water stress may be small relative to naturally occurring spectral variation among leaves at the same level of water stress (Cohen, 1990a and 1990b; Pierce *et al.*, 1990). The second problem is that a woody plant canopy consists of numerous vegetative components, not just leaves, and that background materials contribute to the spectral response (Colwell, 1974).

Given the questionable applicabiltiy of leaf reflectance-water stress relationships to plant canopies, techniques that evaluate manifestations of drought stress in whole plant crowns, or communities, are needed for remote sensing of fire hazard. Such techniques must capitalize on changes in live to dead biomass ratio. They also have to address other related factors that are often associated with drought stress, including changes in leaf area and orientation and percent ground cover (Colwell, 1974; Curran, 1981; Pierce *et al.*, 1990).

Research has indicated that drought can be remotely sensed because of the combined effects of the manifestations of drought on canopy reflectance (Tucker *et al.*, 1975; Jackson and Ezra, 1985; Everitt and Nixon, 1986; Collier, 1989). With these manifestations in mind, the potential utility of multispectral data for drought-induced crown fire hazard assessment was investigated here. A chaparral ecosystem was chosen for study because it commonly undergoes dramatic annual changes in level of drought stress and associated crown fire hazard. It also is a difficult ecosystem to evaluate with traditional technologies. The analysis was done using reflectance spectra of numerous scene components (plant parts and soil background materials) that contribute to canopy-level spectral responses.

MATERIALS AND METHODS

Samples of various scene components were collected in the field under a range of drought conditions (Table 1). All materials came from a south facing slope at Tanbark Flats in the San Dimas Experimental Forest of the San Gabriel Mountains in southern California. The materials were bagged and iced before being transported to the Jet Propulsion Laboratory where reflectance spectra of the samples were obtained. The three species represented in the samples, *Ceanothus crassifolius* Torr. (ceanothus), *Salvia mellifera* Greene. (black sage), and *Adenostoma fasciculatum* Hook. & Arn. (chamise), dominated the site. Data presented in Cohen (1989) indicate that drought stress was low at the beginning of this experiment (February, 1988). Drought stress subsequently became progressively more severe, and by the end of the experiment (August, 1988) it was extremely high.

A Beckman UV-5240 spectrophotometer was used to measure hemispheric diffuse reflectance over the wavelength range from 0.4 to 2.5 μm. The instrument was equipped with an integrating sphere and halon reference standard. Reflectance was measured and recorded every 0.001 μm in the region from 0.4 to 0.8 μm and every 0.004 μm in the 0.8 to 2.5 μm region.

A single reflectance spectrum yielded over 800 data points. Thus, some form of data compression was required. To compress the data, reflectance values at wavelengths that matched the midpoints of the Landsat Thematic Mapper (TM) reflectance bands were extracted from all spectra. These values were then combined with the TM Tasseled Cap equivalent transformation matrix for reflectance factor data (Crist, 1985). Values were obtained only for the first three orthogonal axes of the transformation for each component spectrum. These three axes are called Brightness, Greenness, and Wetness, repectively (Crist *et al.*, 1986).

Examination of the pre-transformed scene component spectra revealed that certain components had similar spectral characteristics. Furthermore, those with similar characteristics also are commonly most abundant and/or should be most visible to a remote sensor at the same general level of drought stress. This suggested the component spectra could be grouped and, thus, their interpretation in Tasseled Cap data space simplified.

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TABLE 1. NUMBER OF SAMPLES AND SAMPLE DATES* OF SCENE COMPONENTS COLLECTED.

Scene Component	Ceanothus	Black Sage	Chamise
green leaves	9a 9c 12d 7e 7f	6a 5c 6d	9a 10c 13d 14e 4f
emerging stems	4a	4a	3b
flower buds		3a	3b
new fruits	6b		
new flowers	6a	5b	3c
chlorotic leaves	7e 3f	8e 3f	4f
lower leaf surface	9c		
dried flowers			3e
dried fruits		6d	
older live stems	12b	9b	9b
dead stems	3a	3b	3d
humus soil layer	3f		
exposed soil	3f		

*Date: a, 23 February; b, 27 March; c, 10 May; d, 19 June; e, 14 July; f, 7 August.

All components were assigned to one of five groups, named Green Leaves (healthy green leaves of all three species), Other Green Components (all emerging woody stems, flower buds, and newly formed fruiting bodies), Flowers (all new flowers), Mature Components (chlorotic leaves, persistent dried flowers, mature fruiting bodies, older live stems, and the lower surface of ceanothus leaves), and Soil and Litter (erect and fallen dead stems, soil humus, and exposed soil). Spectra of the lower leaf surface of ceanothus were collected because this surface has a silvery white color and faces the sky (and thus a sensor) when moderate to severe levels of drought stress occur.

Members of the Green Leaves, Other Green Components, and Flowers groups commonly are in maximum abundance and contribute most to the spectral response of the ecosystem at the same, generally low level of drought stress. The Mature Components group is the most diverse spectrally, but can be expected to contribute most to the scene spectral response at the same, generally moderate level of drought stress. The Soil and Litter group consists of scene components most likely to have their greatest contribution to the scene spectral response during severe stress and fire hazard conditions.

Once the individual scene component spectra were grouped, what remained was to evaluate whether the spectral properties of groups were statistically separable. Only then can it be determined if chaparral vegetation reflectance is likely to change temporally with drought stress by an amount sufficient to permit remote sensing of those changes from aircraft or satellite sensors. To accomplish this, canonical discriminant functions (Afifi and Clark, 1984) were calculated for the defined groups in three-dimensional Tasseled Cap space.

RESULTS AND DISCUSSION

Figure 1 shows mean reflectance spectra of new ceanothus leaves collected at different times of the year. As illustrated, mean temporal spectral changes of new ceanothus leaves were small and in no consistent direction. The largest changes occurred in the near-infrared plateau, but even there, observations of individual spectra revealed that there was considerable variation from leaf to leaf at the same drought stress level (Cohen, 1990a and 1990b). New leaves of all three species under study exhibited similar spectral properties, providing the impetus for placing their spectra in the same group.

The first three sampling dates for old ceanothus leaves provided mean reflectance spectra with no more temporal change than the spectra for new leaves (Figure 2). The last two sampling dates represent severely stressed chlorotic and browning leaves, respectively. For these dates, the mean reflectance spectra for old leaves changed dramatically in the visible and near-infrared regions. Only for the brown leaves of the last sampling date did reflectance change by much in the water absorption region. Similar observations were made on leaves of the other two species. Comparison of Figures 1 and 2 illustrates the logic for placing the old green leaf spectra in the Green Leaves group and the yellow and browning leaf spectra in the Mature Components group.

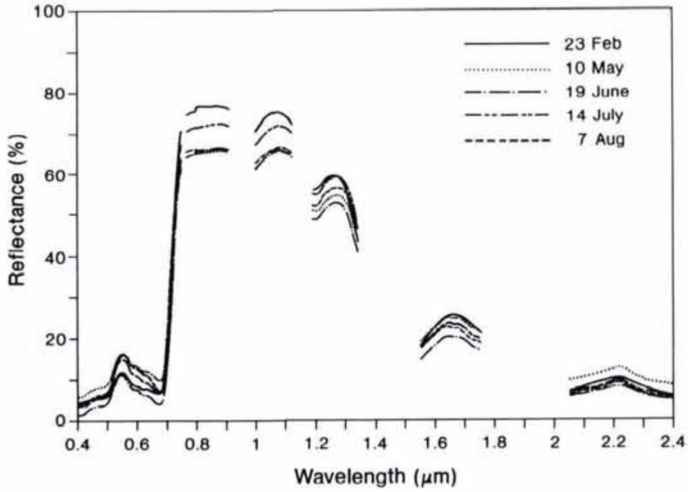

FIG. 1. Mean reflectance spectra for new ceanothus leaves at different times of the year.

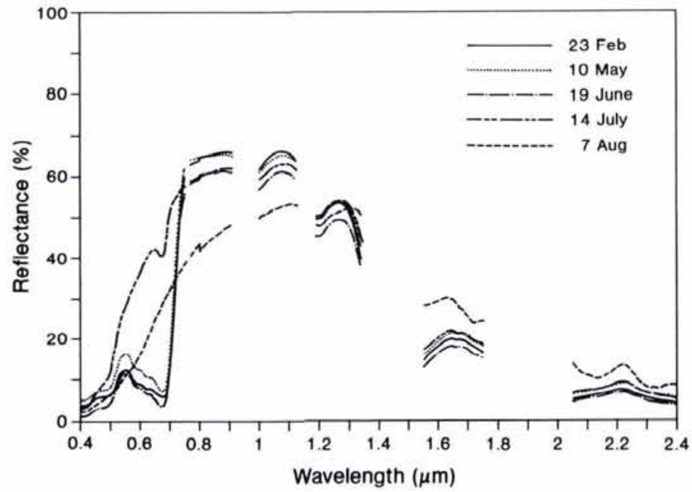

FIG. 2. Mean reflectance spectra for old ceanothus leaves at different times of the year.

Mean reflectance spectra for other components of ceanothus are shown in Figures 3 and 4 to illustrate the logic for placement of these components into their respective groups. The fruiting body spectrum is representative of spectra in the Other Green Components group and the new flower spectrum is representative of the Flowers group. A lower leaf surface spectrum collected with the spectrophotometer (Mature Components category) also is shown. Mean spectra for ceanothus dead stems and for bare mineral soil and the humus soil layer found underneath the plant canopy have similar spectral properties, and were all assinged to the Soil and Litter group. Live stems have spectral properties similar to those of the Mature Components group.

The mean locations of the five groups were in different portions of Tasseled Cap space (Table 2). However, when consid-

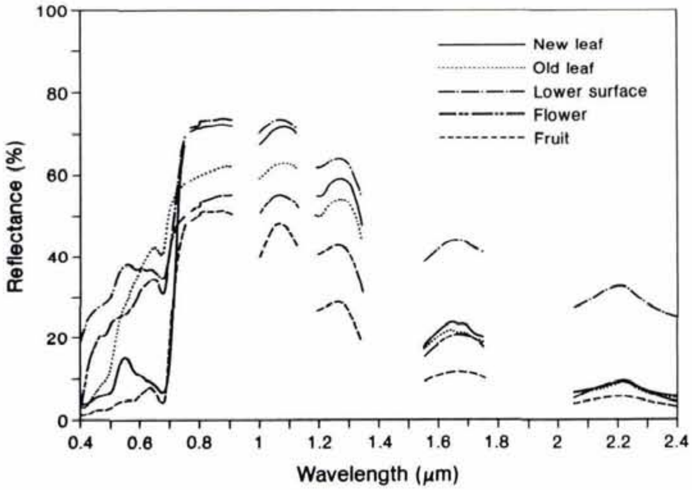

FIG. 3. Mean reflectance spectra for various components of ceanothus shrubs: healthy new leaves, old browning leaves, lower surface of new leaves, new flowers, and fruiting bodies.

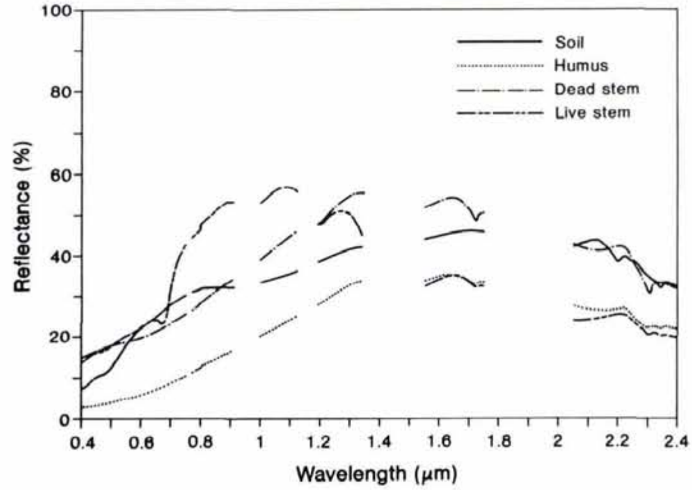

FIG. 4. Mean reflectance for ceanothus dead stems, old live stems, and bare mineral soil and the soil humus layer found beneath the shrub canopy.

ering the spread of the data, one can see that there was some overlap between the groups (Figure 5). This overlap was relatively insignificant for some groups and substantial for others, as indicated by the discriminant analysis. Member spectra from both the Flowers and the Soil and Litter groups were all correctly classified. Only 87.4 percent of the Green Leaves members were correctly classified, with the remainder being classified as Other Green Components. As these groups were relatively closely spaced in transformed data space and can be expected to have their maximum influence at the same, low level of crown fire hazard, this does not suggest a potential problem. Likewise, 21.7 percent of the Other Green Components were classified as Green Leaves, with only 73.9 percent classified correctly. The remaining 4.4 percent were classified as Flowers, another group having its maximum influence at a low level of fire hazard. The group with the largest percentage of misclassified members was the Mature Components group. Only 58.9 percent were correctly classified, with 4.1, 8.2, 13.7, and 15.1 percent classified as members of the Green Leaves, Other Green Components, Flowers, and Soil and Litter groups, respectively. These misclassifications are understandable, as the Mature Components group consisted of members having the least similarity in spectral characteristics. However, it indicates that some difficulty can be expected in remote sensing of fire hazard in a chaparral ecosystem.

Within the context of the TM Tasseled Cap, several similarities exist between the component spectra used here and the TM data of Crist and Cicone (1984). The primary likeness is that both data sets occupy generally the same areas of transformed data space and, thus, give the appearance of a tasseled cap (Figure 5). Furthermore, the Soil and Litter group exhibits little variation along the Greenness axis in the Plane of Vegetation and Transition Zone, having most of its variation in the Plane of Soils. For this group, Brightness and Wetness are inversely related, along what Crist and Cicone (1984) described as the principal direction of moisture variation in the Plane of Soils. The Green Leaves group distributes itself along a principal direction in the Plane of Vegetation that was originally called the "Green Fold" by Kauth and Thomas (1976).

Crist *et al.* (1986) describe how an agricultural field "traverses" through Tasseled Cap space during an annual cycle from bare soil, to crop maturity, to senescence, and back again to bare soil. With this description as a model, the similarities between the data set used here and the one of Crist and Cicone (1984) permit insight into how a given location in the chaparral landscape might traverse through Tasseled Cap space with annual changes in fire hazard.

At the end of the annual drought in early to late fall, there is a period of relatively severe fire hazard. At this time, spectral data from the landscape should be the closest it gets to the location of the Soil and Litter group. This is because many leaves drop from the plants, leaving leaf area at its lowest in the yearly cycle, and exposing much of the soil and dead fuel to the sensor. Once the rainy season begins, the vegetation responds rapidly with new growth and a profusion of flowers. Increased green leaf area should bring the landscape closer to the Green Leaves group, while the abundance of flowers should bring it closer to the Flowers group. Toward the end of the rainy season, when fire hazard is at its lowest, many of the annual plants begin to cure and the flowers begin to die. During this time, the dead to live biomass ratio is increasing with a related increase in fire hazard, and the landscape should move through

TABLE 2. GROUP DIGITAL NUMBER MEANS AND STANDARD DEVIATIONS OF THE MEANS (PARENTHESES) ALONG THE THREE PRIMARY AXES OF THEMATIC MAPPER TASSELED CAP SPACE.

	Group				
Axis	Green Leaves	Other Green Components	Flowers	Mature Components	Soil and Litter
Brightness	54.3 (8.3)	51.2 (12.4)	72.7 (10.7)	66.6 (19.2)	53.3 (14.3)
Greenness	39.6 (6.6)	28.7 (5.8)	12.9 (6.0)	16.2 (7.9)	1.1 (2.2)
Wetness	−17.7 (6.8)	−11.1 (5.6)	−9.6 (8.2)	−32.2 (16.6)	−53.6 (9.5)

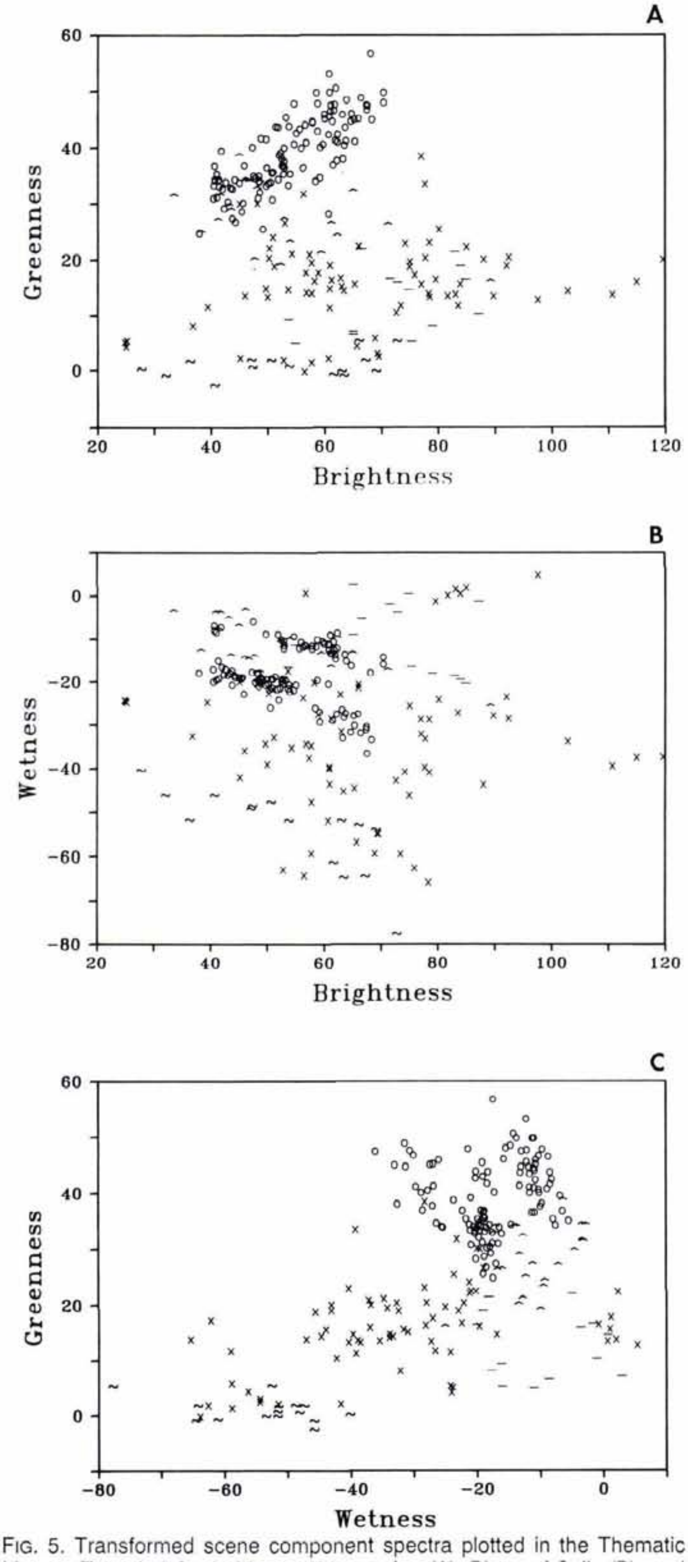

FIG. 5. Transformed scene component spectra plotted in the Thematic Mapper Tasseled Cap's Plane of Vegetation (A), Plane of Soils (B), and Transition Zone (C). Spectra are plotted by group: Green Leaves (o), Other Green Components (∧), Flowers (−), Mature Components (×), and Soil and Litter (~).

the location of the Mature Components group on its way back to somewhere near the Soil and Litter group.

CONCLUSIONS

This experiment illustrated that there is considerable spectral diversity among the many components of common chaparral biomass and related soils. Furthermore, the spectral properties of several components vary temporally. These observations suggest that remotely sensed data may be useful for monitoring drought-related crown fire hazard in a chaparral community. If so, the TM Tasseled Cap should be a useful data transformation with which to conduct fire hazard monitoring. Future research, using a temporal data set collected with aircraft or satellite sensors, is warranted.

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