

SPECTRAL CHARACTERIZATION OF SUSPECTED ACID DEPOSITION DAMAGE IN RED SPRUCE (*PICEA RUBENS*) STANDS FROM VERMONT

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ABSTRACT

In an attempt to demonstrate the utility of remote sensing systems to monitor sites of suspected acid rain deposition damage, intensive field activities, coupled with aircraft overflights, were centered on red spruce stands in Vermont during August and September of 1984. Remote sensing data were acquired using the Airborne Imaging Spectrometer, Thematic Mapper Simulator, Barnes Model 12-1000 Modular Multiband Radiometer and Spectron Engineering Spectrometer (the former two flown on the NASA C-130; the latter two on a Bell UH-1B Iroquois Helicopter). Field spectral data were acquired during the week of the August overflights using a high spectral resolution spectrometer and two broad-band radiometers. Preliminary analyses of these data indicate a number of spectral differences in vegetation between high and low damage sites. Some of these differences are subtle, and are observable only with high spectral resolution sensors; others are less subtle and are observable using broad-band sensors.

INTRODUCTION

Since 1965, red spruce (*Picea rubens* Sarg.) has shown a marked decline in vigor in the high elevation spruce-fir forests of northeastern United States (Siccama, et al., 1982; Vogelmann, et al., 1985). Other members of the montane forest, including sugar maple (*Acer saccharum* Marsh.), mountain maple (*A. spicatum* Lam.), striped maple (*A. pensylvanicum* L.), white birch (*Betula papyrifera* Marsh. var. *cordifolia* (Regel) Fern.) and balsam fir (*Abies balsamea* (L.) Mill.) have experienced less dramatic declines throughout this time period (Vogelmann, et al., 1985). Although the specific cause of the forest decline has been disputed, there is mounting evidence that high inputs of air pollutants into high elevation forests are a significant factor.

Camels Hump Mountain, located in the Green Mountains of northern Vermont, was chosen as a study area for the current investigation because of (a) the presence of an extensive data base (Siccama, 1974), (b) the marked vegetational damage symptoms apparent, especially in red spruce (Siccama, et al., 1982; Vogelmann, et al., 1985), and (c) the influx of high levels of air pollutants into the region (Scherbatskoy and Bliss, 1984). In addition, Mount Ascutney, located in the Taconic Mountains of southeastern Vermont, and sites in Ripton, Vermont were included in the study.

The overall objective of this study is to correlate various levels of forest decline (presumably caused or exacerbated by the influx of pollutants into the high elevation ecosystem) with remote sensing data. Some specific goals are as follows: (a) determine what levels of forest

damage can be detected using spectral data; (b) determine which remote sensing systems are most useful/appropriate for continuing study of the problem; (c) determine the feasibility of using remote sensing to monitor forests through time, and d) determine if spectral data will provide insight into the nature of the forest decline (e.g. heavy metal stress, water stress).

MATERIALS AND METHODS

Study Sites: A total of 12 spruce stands, including seven from Camels Hump Mountain, three from Mount Ascutney, and two from Ripton are included in this study. These represent a gradient from low to high levels of damage. A "high damage" site and a "medium damage" site on Camels Hump and a "low damage" site from Ripton were selected for more extensive study using Scholander pressure bombs and portable field spectrometers and radiometers.

Damage Level Evaluation: Percentage red spruce and balsam fir damage and mortality estimates were calculated separately at each site. Damage estimates were based upon the amount of red spruce foliar damage (i.e. percentage of needles missing from the live crown) visually apparent.

Field Measurements: Field spectral data were acquired from clipped sunlit branches with needles from a high damage site and a low damage site using the Visible/Infrared Intelligent Spectrometer (VIRIS). This is a high spectral resolution sensor with spectral coverage from 0.4 to 2.5 microns. Simultaneous with field spectral data acquisition, xylem water column tension was measured using Scholander pressure bombs.

Aircraft Data Collection: The sensors onboard the C-130 included the JPL Airborne Imaging Spectrometer (AIS), the NS-001 Thematic Mapper Simulator (TMS) and aerial photographic cameras. Study sites on Camels Hump Mountain and Mount Ascutney were flown on August 17, 1984 about 4.8 km above the ground. Sites were reflown on September 8, 1984 due to a malfunction of the AIS instrument during the earlier overflight. AIS data were acquired using the "tree mode", with spectral coverage ranging from approximately 0.9 to 2.1 microns.

On August 17, 1984, a Bell UH-1B Iroquois helicopter was used to collect spectral data over four sites on Camels Hump. The instrument package onboard included a Spectron Engineering spectrometer (SE-590), a Barnes Model 12-1000 MMR radiometer, and various cameras.

See Rock, et al. (1985) for more discussion regarding the above procedures/instrumentation.

RESULTS AND DISCUSSION

Damage Level Evaluation: Spruce stands showed marked differences in levels of foliar damage (see Rock, et al., 1985, for numerical estimates of damage). At Camels Hump, percentage mortality closely paralleled damage values, ranging from 0.6 to 31.1%. The damage levels for the Camels Hump sites are highly correlated with elevation ($r^2=0.90$), with the most damaged sites located at relatively high elevations, and the least damaged sites located at relatively low elevations.

Balsam fir damage also showed marked differences in levels of damage (see Rock, et al., 1985). There is a good correlation between fir damage and spruce damage ($r^2=0.88$)--those sites with the highest spruce damage values also have the highest fir damage values; those sites with the lowest spruce damage values also have the lowest fir damage values.

Spectral Data: VIRIS and SE590: Field spectral curves from representative spruce samples from high and low damage sites (acquired by the VIRIS) indicate the following: 1) A slightly reduced absorption at approximately 0.68 microns characterizes spectral curves from the high damage site. 2) The chlorophyll absorption maximum located at about 0.67 to 0.68 microns is at a slightly shorter wavelength for the high damage site (i.e., the "blue shift"). 3) Spectra from the high damage site have a reduced reflectance along the NIR plateau. 4) Ratios of the amplitudes of spectral reflectance maxima between near 1.26 and 1.65 microns are different for the two sites (see below).

Helicopter SE-590 data from a high damage site and a medium damage site independently confirmed the reduced absorption and the "blue shift" of the chlorophyll absorption feature at 0.68 microns for vegetation at the more highly damaged site. However, in contrast to the field spectral data, helicopter-acquired spectra from the more highly damaged site had an increased reflectance along the NIR plateau. This apparent discrepancy is thought to be a function of the increased presence of highly reflective broadleaved species which invade the high damage sites as the canopy becomes more open.

The above information indicates that broad-band sensors such as TM/TMS are most appropriate for detecting certain vegetative spectral differences between sites of different damage levels. However, high spectral resolution sensors such as AVIRIS will be needed to detect the subtle shift to shorter wavelengths in the chlorophyll absorption feature (0.68 microns) in stressed vegetation.

TMS Data--Use in Estimation of Water Stress: The relative heights of spectral reflectance maxima near 1.26 and 1.65 microns provide an accurate indication of leaf water content (Rohde and Olson, 1971; Goetz, et al., 1983). The ratio of the the 1.65 micron reflectance divided by the 1.26 micron reflectance is herein referred to as the Moisture Stress Index (MSI). As vegetation dries, this ratio increases and approaches 1.0.

NS-001 TMS bands 6 and 5 contain the 1.65 and 1.26 micron regions, respectively. Thus, TMS 6/5 ratios are the broad-band equivalent of the MSI ratios. TMS 6/5 ratios were obtained from approximately 100 pixels at each of the seven Camels Hump sites using the September data set. Suspected rocky and/or deciduous areas were excluded from this analysis, such that comparisons are among mostly coniferous areas. Results from this analysis indicate that TMS 6/5 ratios correlate well with site damage values ($r^2=0.90$ --as damage increases, site 6/5 ratios also increase (see Figure 1)).

AIS Data Analysis: AIS data were acquired from four study sites from Camels Hump and two from Mount Ascutney. As expected, spectra from coniferous areas had markedly lower DN values than those from deciduous areas (see Figure 2). No obvious spectral differences were seen between high damage and low damage sites. Attempts to atmospherically

correct the data using a program developed by Jerry Solomon (JPL) did not appear to work since it dramatically decreased the already low coniferous DN values such that interpretation of spectra became difficult.

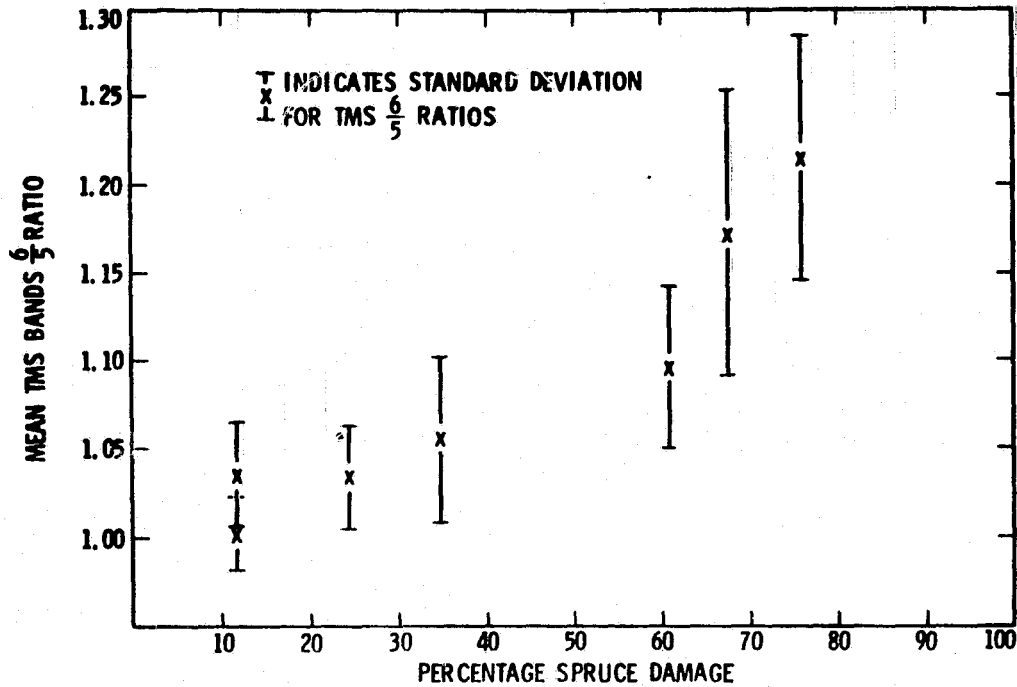


Figure 1. Red spruce damage versus ratios of TMS bands 6/5 for seven sites on Camels Hump Mountain, Vermont.

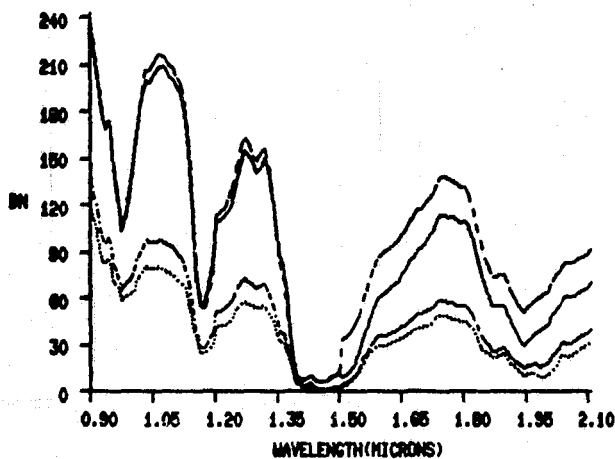


Figure 2. AIS spectra for deciduous areas (top two spectra) versus coniferous areas (bottom two spectra) from Camels Hump Mountain, Vermont. Each spectrum represents an average of 400 pixels.

Using AIS data, MSI values were calculated from spectra of 2x2 pixels from each study site. Results from the four Camels Hump sites were compared with site damage levels and TMS 6/5 ratios (Table 1). The site with the lowest TMS 6/5 ratio (i.e., the one showing the least amount of water stress) also has the lowest MSI value. Similarly, the

site with the highest TMS 6/5 ratio (i.e., the one showing the highest amount of water stress) also has the highest MSI value. However, the two sites with medium low and medium high TMS 6/5 ratios (Camels Hump 2 and 5, respectively) have very similar MSI values. Thus, there is some, but not complete agreement between TMS and AIS results.

Table 1. Comparison of forest damage, TMS 6/5 ratios, and AIS 1.65 micron/1.26 micron (MSI) ratios for four sites from Camels Hump Mountain, Vermont.

SITE	PERCENTAGE SPRUCE DAMAGE	RATIO OF TMS BANDS 6/5	RATIO OF AIS 1.65 μm PEAK DN / 1.26 μm PEAK DN
CAMELS HUMP 1	11.8	1.004 \pm 0.022	0.787 \pm 0.059
CAMELS HUMP 2	11.9	1.036 \pm 0.030	0.819 \pm 0.040
CAMELS HUMP 5	61.2	1.097 \pm 0.047	0.815 \pm 0.029
CAMELS HUMP 7	76.0	1.216 \pm 0.069	0.856 \pm 0.049

AIS data were also analysed using a cross-band correlation analysis. This technique is discussed by Vern Vanderbilt elsewhere in these proceedings. No evidence was found for subtle differences existing between high damage and low damage sites using this method. However, it is felt that this approach will have much potential in detecting subtle spectral differences when they exist in future studies, especially when AIS instrument noise problems become mitigated.

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