DETECTION OF SPECTRAL EFFECTS IN INDIVIDUAL TREE CROWNS OF METAL-INJECTED TREES USING HIGH-RESOLUTION PUSHBROOM IMAGERY

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ABSTRACT

A field/airborne-sensing experiment has been conducted to investigate the botanical and spectral reflectance response in leaves of selected trees which were inoculated with metal solutions. Four tree species (Balsam fir, Black spruce, Aspen and White birch) were injected with solutions of copper nitrate, nickel nitrate and sodium arsenite ranging in concentration from 250 to 1000 ppm. This injection was followed by frequent optical/botanical sampling during a period of about 10 days; these forest plantation sites were then overflown with an 8 channel MEIS II pushbroom imager with spectral channels at 480, 548, 675, 698, 710, 734, 746, and 776 nm (spectral bandwidths varying from 6.3 to 17.8 nm) and at an altitude of 535 m providing imagery with 38 centimeters spatial resolution. This paper describes the spectral reflectance changes in some representative metal-treated trees with an evaluation of the potential to detect these changes in the airborne imagery.

INTRODUCTION:

Laboratory experiments involving treatment of plants, whether seedlings or excised leaves, with high concentrations of metal ions have provided evidence of the blue shift of the reflectance red edge (Horler et al.,1983a,b,c) as an expected plant response to metal-induced stress. Attempts to observe a similar metal-induced response in natural settings with trees living over mineralized deposits have in the authors' experience been relatively unsuccessful; the literature curiously lacks published reports of ground-supported metal stress responses in natural plant populations subjected to metal stress. One might postulate that in natural populations adaptation processes have occurred making an optical stress response unlikely due solely to the uptake of enhanced levels of metal ions although such a response might be expected under circumstances where additional environmental stress factors (eg. moisture stress, senescence, etc) may enduce spectral reflectance changes in the trees experiencing additional stress conditions.

In the absence of accepted natural test sites for metal-induced stress studies the present experiment was conceived in which mature trees were injected with metal ions, the optical/botanical response was studied temporally and the site was overflown with a multispectral pushbroom imager with sufficent spatial resolution to identify individual tree crowns. The injection experiment was carried out between August 1 and 15, 1986 at the Petawawa National Forestry Institute (PNFI) at Petawawa, Ontario, Canada. PNFI provided

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both natural and plantation vegetation for the experiment. Five sites were selected for tree injections each containing a nearly homogeneous stand of one of four species studied. The four species Balsam fir (Abies balsamea), Black spruce (Picea mariana), Aspen (Populus tremuloides) and White birch (Betula papyrifera) were injected with 500 mls of solution from 250, 500 or 1000 ppm of the metal ions in MES buffer .003M. (2[N- morphaline ethone sulfonic acid). Salts used were $Cu(NO_3)_2.6H_2O$, $NaAsO_2.Ni(NO_3)_2.6H_2O$ and $Zn(NO_3)^2.6H_2O$. This paper reports the preliminary results of the analysis of data obtained for the treatment of Balsam fir.

FIELD SITE DESCRIPTION:

The Balsam fir stand consisting of about 40 trees with DBH values ranging from 50 to 200mm was cleared of underbrush and trees of other species to produce a Balsam fir canopy of both closed and open conditions. Two white 120cm x 120cm panels were placed at each end of the stand to mark the site extremities and to provide ground control points for the image analysis. A base map of the test site (Figure 1) shows the locations of the trees, the diameter class, as an index of crown size, and identification of treated trees.

TREE INJECTION:

Prior experimentation with trees under greenhouse conditions (1985-86) and in nursery trials (1986) had enabled the development of injection techniques which provided effective translocation of soluble metal salts in mature deciduous and coniferous trees. Each tree selected for injection had 3 to 5 equidistant holes (5 mm diametre) depending on size drilled into the sapwood. The drill hole was kept saturated by a stream of water during the preparatory process to prevent cavitation. A plastic disposable pipette tip was then inserted attached through a hose to a covered funnel containing the solution. Uptake in the transpiration stream, except in the case of white birch, was usually completed within 24 hours. Once uptake was complete, the spectral reflectance of excised leaf samples were measured in a field laboratory. Treatment levels and the results of geochemical analysis on excised samples are summarized (Table 1). Typical botanical analysis included chlorophyll a & b concentrations, leaf water deficits, dry weights, pressure bomb measurements and stomatal imprints. Only some of these data are reported here.

SPECTRAL REFLECTANCE MEASUREMENTS:

Detailed laboratory spectral reflectance measurements were made on excised leaves at a portable laboratory the same day samples were collected. Spectral reflectances were obtained with a J-Y grating monochromator between 500 and 900nm at 4nm resolution with a $BaSO_4$ plate as a reference standard. Leaf stacks of both 1st and 2nd year needle clumps were measured separately.

Field spectral reflectance measurements were made with a ten channel radiometer (see Table 3) using comparisons of target radiances with that from a horizontal $BaSO_4$ screen illuminated by the total solar/diffuse irradiance. Spectral reflectance data from selected trees were obtained in situ from the top of ladder on August 14, 1988. The reflected spectral data collected from the $BaSO_4$ screen at three times on the day of the airborne flight permitted an estimate of the surface spectral irradiance corresponding to the airborne image data. In addition, the spectral reflectance of the gravel road (Woermke Road, see Figure 1) was measured to provide a target of known reflectance characteristics.

ACQUISITION OF MEIS IMAGERY:

An airborne 8 channel MEIS II pushbroom imager (see Till et al.,1984) was configured with cylindrical interference filters selected to record the reflective characterisitics of the forested canopy; the system optical/spectral parameters are summarized in Table 3. The Balsam fir site was overflown twice, on August 9th and 29th, 1986. The August 9th flight at an altitude of 535m and an azimuth of 130^{o} provided imagery with a 40^{o} full swath width at a 38cm ground resolution.

RED EDGE ANALYSIS OF AIRBORNE IMAGERY:

Digital data from the MEIS II sensor was calibrated through the use of field data. Airborne digital count spectra of Woermke Rd. compared to the estimated spectral radiance at the time of the overflight (computed from the measured gravel road spectral reflectance and the measured incident total spectral irradiance at ground level) provided a radiance calibration of the MEIS II sensor. The measured ground level total spectral irradiance then allowed the conversion of the digital imagery to % reflectance. Thus pixel reflectance spectra were readily obtained for targets at the site.

A priority of this experiment was the comparison of airborne and laboratory spectra for individual trees. The positions of two white panels marking the extremities of the site were easily located in the imagery. Along with the known flight azimuth and the ground pixel size these markers provided the ability to scale the site base map to the imagery and therefore permit individual tree crowns to be located.

The extraction of a red reflectance edge spectral parameters (the inflection point position λ_p and the chlorophyll-well position λ_o) from the 6 spectral measurements of MEIS II was accomplished using an Inverted-Gaussian Model (IGM) which represents the red edge curve in terms of the spectral parameters λ_p , λ_o and the reflectance parameters R_s, the IR shoulder reflectance and R_o, the chlorophyll-well reflectance (Miller et al., 1985; Miller et al., 1988). Analysis results on MEIS and laboratory spectra are reported in Tables 4 and 5 for control trees and selected treated trees.

RESULTS:

Of the treated Balsam fir only injection with sodium arsenite produced visible symptoms on first and second year needles (Table 1: Trees 1&11). Symptoms did not include chlorosis but rather increasing defoliation. Second year and older needles were equally prone to drop as first year needles. Symptoms were expressed in both trees at 0.46ppm dry weight in the case of Tree 1 (Table 1) and at 3.58ppm dry weight in the case of Tree 11 (Table 1).

Of the remaining treatments the analysis for the nickel ion suggested it is probably immobilized in the stem. Copper exhibited greater mobility but at concentrations indicated (Table 1) did not produce visible symptoms.

From the analysis of chlorophylls (Table 2) in first and second year needles of the symptomatic Tree 1 (Table 1) on the day of the MEIS flight (Aug. 9) it was observed that the values did not differ from the control trees (Tree 4, Table 1) or from various background trees.

Red edge reflectance analysis from laboratory optical studies (Table 3) did not reveal large differences in the red edge parameters. The red edge position λ_p for 1st year needles and for 2nd year needles are each seen to be constant within $\pm$ 1.5nm except for the Tree 11 sample treated with 500ppm arsenite which gave anomalously low and high values. The problem of increased needle droppings with metal uptake made the collection of representative spectral data difficult. The observed red shift of the red edge by approximately 1.5nm in the 2nd year needles relative to the 1st year needles taken from the same sample cutting is consistent with the reported chlorophyll pigment differences (Table 2).

The corresponding MEIS data for sodium arsenite treated Trees 1 & 2, see Table 5 and Figure 2, indicates a blue shift in the red edge inflection point λ_p of approximately 7nm. This shift is suggestive of a loss in chlorophyll which may reflect excessive defoliation of second year needles relative to first year needles, the former with considerable higher total chlorophyll than the latter. However, laboratory spectra of treated needles (those which remained on the stem for these measurements) would suggest a smaller blue shift. The canopy understorey also yielded blue shifted red edge spectra which would add support to a defoliation interpretation for the observed blue shift for the treated trees. This interpretation for observed spectral shifts is similar to one explanation proposed in analysis of imaging spectrometer data (Rock et al., 1988). The absence of a detectable blue shift in the red edge in the August 9 MEIS data (5 days after injection) for Tree 11, which received highest concentration treatment, might be explained by the relative sizes of trees 1 & 11 and the observed much more rapid rate of metal uptake in Trees 1 & 2.

The systematically lower red edge positions derived from the MEIS data compared to the laboratory spectra may be related to canopy effects or to the edge weighting effect of the spectral resolution of MEIS of approximately 10nm.

CONCLUSIONS:

Analysis of red edge spectra on individual Balsam fir tree crowns obtained from the MEIS pushbroom imagery showed blue shifts of of the red edge inflection point λ_p of approximately 7nm on two of the trees treated with high levels of sodium arsenite. No other Balsam fir trees showed spectral shifts. The extraction of red edge positions from the MEIS imagery was not sensitive to canopy radiometric texture for closed canopy situations, in agreement with Rencz et al. (1986). However, in open canopy scene conditions the understory in deep shadow showed potentially confusing blue shifts, an observation requiring attention in operational use of red edge mapping with airborne data.

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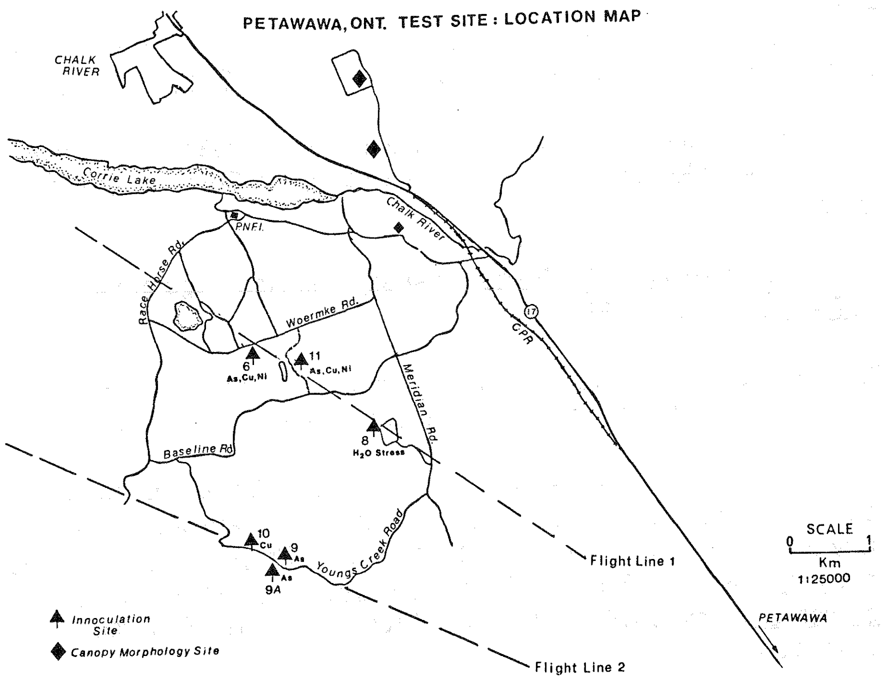


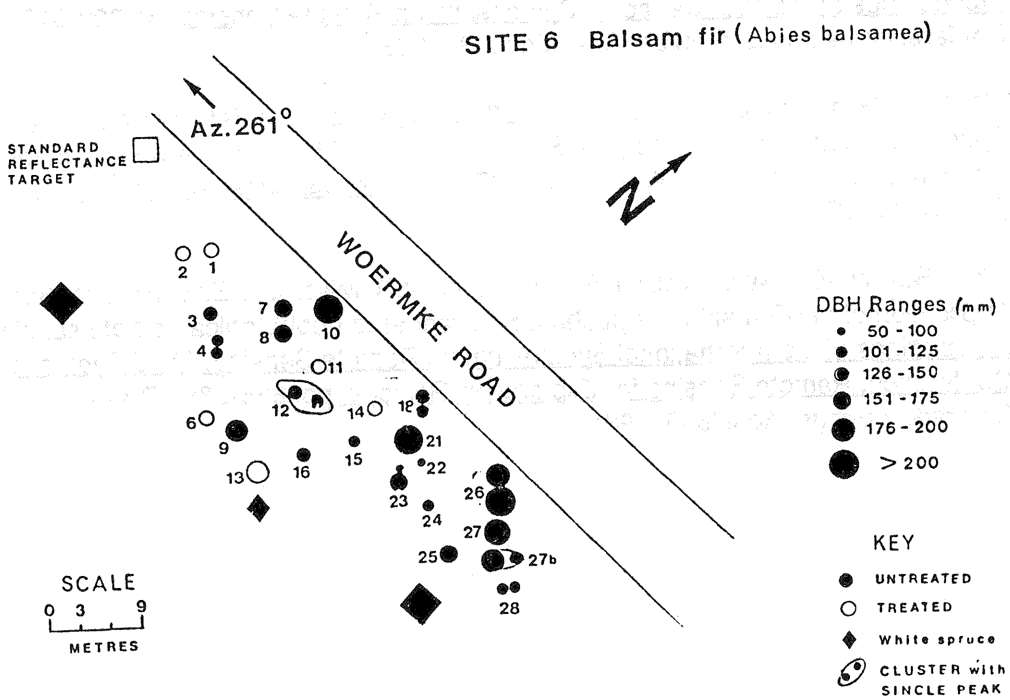


Figure 1: Base map of Balsam fir metal injection experiment test site at the Petawawa National Forestry Institute (PNFI), Petawawa, Ontario, Canada.

TABLE 1: RESULTS OF INJECTION OF METAL IONS INTO THE TRANSPIRATION STREAM OF BALSAM FIR TREES. (Injection date: August 4).

TREE No.	DIA. Class	SAMPLING DATE	TREATMENT (ppm dry wt.)	DISTRIBUTION OF METAL (ppm)
04	2	Aug. 13	nil	As/Cu 0.10/4.00
09	4	Aug. 13	MES	-
01	2	Aug. 13	250 AsO_2^-	As 0.46 (needles)
11	3	Aug. 09	500 AsO_2^-	As 0.22 (needles) As 0.22 (twigs)
11	3	Aug. 13	500 AsO_2^-	As 3.58 (needles) As 5.98 (twigs)
13	4	Aug. 09	500 Cu^{2+}	Cu 3.50 (needles) Cu 5.50 (twigs)
13	4	Aug. 13	500 Cu^{2+}	Cu 5.50 (needles) Cu 7.00 (twigs)
14	3	Aug. 08	500 Ni_1^{2+}	Ni <3.0 (needles) Ni <3.0 (twigs)
14	3	Aug. 13	500 Ni_1^{2+}	Ni <3.0 (needles) Ni <3.0 (twigs)

TABLE 2: CHLOROPHYLL ANALYSIS FROM TREATED, CONTROL AND BACKGROUND TREES.

Tree No.	Treatment	Chlorophyll a* 1styr	Chlorophyll a* 2ndyr	Chlorophyll b* 1styr	Chlorophyll b* 2ndyr	a + b* 1styr	a + b* 2ndyr	100b/a 1styr	100b/a 2ndyr
4	(control)	824.7	1020.9	332.7	437.3	1157.2	1459.8	40.3	42.8
1	(250ppmAs)	884.9	1078.8	413.7	451.4	1258.9	1529.8	48.9	41.8
13	(Backgrd)	867.1	1020.9	352.5	437.3	1219.3	1457.9	40.1	42.9
14	(Backgrd)	754.4	1306.6	306.0	544.4	1059.7	1850.2	40.6	41.7

* in µg per gram of leaf tissue

TABLE 3: CHARACTERISTICS OF SPECTRAL REFLECTANCE MEASURING INSTRUMENTS

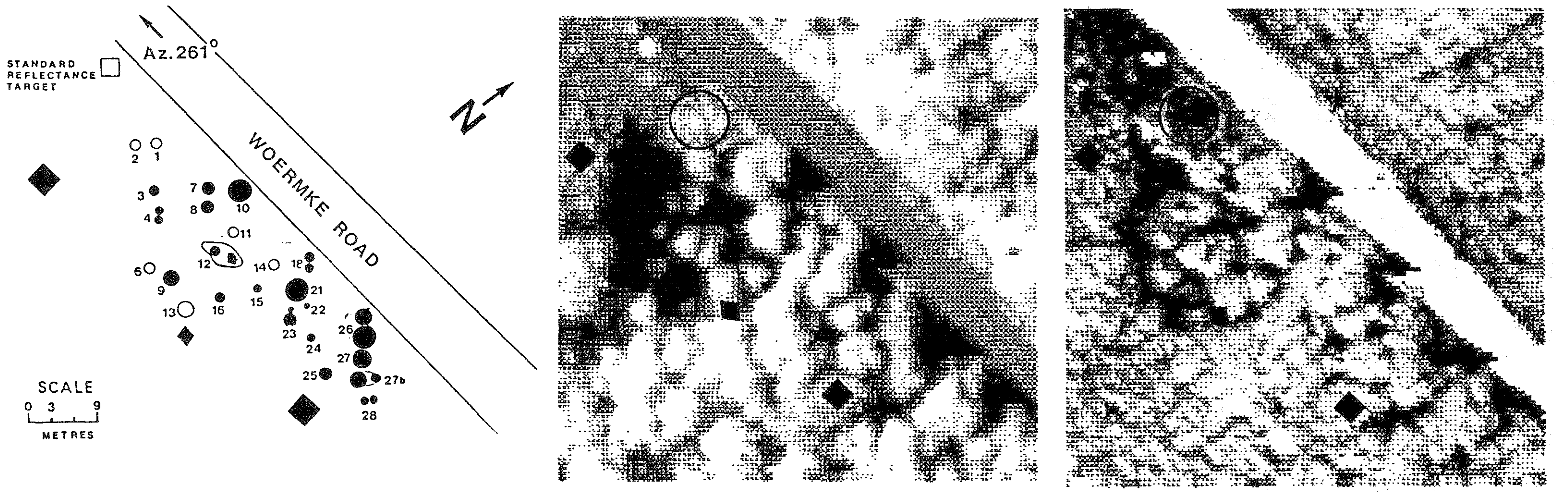
YORK MULTIBAND RADIOMETER		CCRS MEIS II PUSHBROOM IMAGER	
Central Wavelength	Effective Bandwidth (nm)	Central Wavelength	Effective Bandwidth (nm)
444	9	479.7	12.7
551	10	548.4	9.2
672	9	675.1	14.2
682	4	698.3	6.3
705	4		
714	4	710.1	7.9
734	3	734.3	9.9
743	4		
753	11	746.8	10.0
803	10	776.2	17.8

TABLE 4: RESULTS OF LABORATORY-BASED RED EDGE REFLECTANCE ANALYSIS

TREE #	MEASUREMENT DATE	RED EDGE REFLECTANCE PARAMETERS R_o (%)	R_s (%)	λ_o (nm)	λ_p (nm)	
4 (control)	Aug. 6	2.0	44.3	689.6	719.0	(1st yr)
		1.5	41.8	693.0	721.0	(2nd yr)
4	Aug.13	2.2	50.4	688.0	718.1	(1st yr)
		3.0	51.1	690.0	719.3	(2nd yr)
9 (MES)	Aug. 8	3.6	47.6	688.3	717.5	(1st yr)
(control)		5.1	49.6	691.5	719.7	(2nd yr)
9	Aug. 9	3.0	49.2	689.1	718.3	(1st yr)
		4.1	50.3	691.3	719.7	(2nd yr)
9	Aug.13	4.2	50.3	691.2	719.6	(1st yr)
1 (As250)	Aug.6	2.6	50.0	691.3	719.8	(1st yr)
		4.9	52.4	688.0	721.1	(2nd yr)
1	Aug.9	2.6	42.5	688.5	719.2	(1st yr)
		2.6	50.0	692.1	720.1	(2nd yr)
11 (As500)	Aug. 6	2.7	42.1	688.2	717.0	(1st yr)
		4.5	44.7	690.3	718.5	(2nd yr)
11	Aug. 8	5.7	45.0	686.8	715.3	(1st yr)
		3.3	40.0	689.0	717.9	(2nd yr)
11	Aug.13	2.6	39.2	691.1	721.4	(1st yr)
		1.9	37.9	694.2	722.8	(2nd yr)

TABLE 5: RESULTS OF MEIS RED EDGE REFLECTANCE ANALYSIS

TREE #	MEASUREMENT DATE	PLATFORM	RED EDGE REFLECTANCE PARAMETERS R_o (%)	R_s (%)	λ_o (nm)	λ_p (nm)
4 (control)	Aug. 9	MEIS	5.4	45.1	681.2	713.7
9 (MES) (control)	Aug. 9	MEIS	5.2	38.4	681.2	709.8
1 (As250)	Aug. 9	MEIS	6.4	41.8	676.5	706.1
11 (As500)	Aug. 9	MEIS	4.1	48.3	685.5	715.7



SITE BASE MAP

R_S Image

λ_p Image

Figure 2: A gray-scale representation of the results of the red edge analysis of the MEIS II imagery over Site 6. The site base map is in the left panel, the IR reflectance shoulder image in the centre panel and the image of the red edge inflection point in the right panel. For orientation, the rectangles mark the positions of the white spruce trees and the open circle marks the metal stressed trees.