PC-BASED DIGITAL ANALYSIS OF MOUNTAIN PINE BEETLE CURRENT-ATTACKED AND NON-ATTACKED LODGEPOLE PINE

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RÉSUMÉ

La technologie micro-informatique de traitement des images et de tableurs numériques a fourni différentes solutions pour l'analyse des données de télédétection appliquées à l'identification des dégâts causés par le dendroctone du pin ponderosa. Huit clichés 70 mm en couleur infrarouge au 1:2000 ont été numérisés, avec un pas de 100 microns (0,1 mm), à l'aide d'un scanneur et de filtres bleu, vert et rouge. Trente-quatre arbres sains et trente-quatre arbres infestés récemment ont été identifiés sur les clichés, leurs contours numérisés et sauvegardés en fichiers de pixels ASCII. Les tests ANOVA ont montré des différences significatives (p = 0,01) entre les deux conditions de la végétation dans les images numériques des couches jaune et magenta. Ces différences n'étaient cependant pas significatives dans l'image numérique cyan.

Des transformées de Moore, lesquelles transforment les densités des couches du film en réponse spectrale relative dans les bandes verte, rouge et infrarouge, furent appliquées. Les valeurs des transformées de Moore ont montré également des différences significatives (p = 0,01) pour les bandes verte et rouge.

Les résultats graphiques révèlent un accroissement des valeurs magentas et une augmentation des réflectances relatives dans la bande rouge pour les arbres infestés. Même si ces résultats montrent que pour des clichés couleurs infrarouges à grande échelle, des différences numériques détectables existent entre les pins sains et ceux ayant subit une attaque récente, la détection numérique à distance de ce phénomène reste à réaliser.

SUMMARY

PC-based image analysis and spreadsheet technology have provided different methods for analyzing remotely sensed data of bark beetle non-attack and current-attack lodgepole pine. Eight, large-scale (1:2000) colour-infrared, 70 mm aerial photographs were digitized with a 100 micrometer (1/10 mm) scan through blue, green and red filters. Thirty-four known non-attack and 34 current-attack trees were identified on the photos, masked and saved as ASCII pixel files. ANOVA tests indicated significant differences (P = 0.01) between non-attack and current-attack for the yellow and magenta dye-layer's digital number (DN) values. The cyan dye-layer DN values were not significantly different.

Moore transformations, which convert dye-layer density values to relative spectral effect on the film dye-forming layers for total green, total red, and total near-infrared reflectance, were applied. Moore transformed values of the dye-layer DN density data also showed significant differences (p = 0.01) for the total green and total red response.

The graphed data displayed a shift in magenta DN, and in the relative red reflectance values of the current-attack data towards a higher DN value when compared to the non-attack data. Although these results show that for digitized large-scale colour-infrared photographs, detectable digital differences do differentiate non-attacked and current-attacked pine, remote digital detection has yet to be achieved.

Key words: *Digital image analysis, mountain pine beetle, colour-infrared photographs, large-scale.*

INTRODUCTION

The early and rapid detection of bark beetle-attacked trees in British Columbia's forests translates into one of the major pest management problems in the province. To manage attacked stands selectively, infected trees must be identified as soon as possible after killing attack. Current techniques depend primarily on ground surveys, aerial sketch mapping, and medium-scale aerial survey photographs. But these techniques are time consuming and costly. Large-scale aerial photographs and other remotely sensed data have been evaluated with varying degrees of success (Gimbarzevsky, 1984; Hall *et al*, 1983; Heller, 1968; Hobbs, 1983; Murtha, 1985a, 1985b; Murtha and Cozens, 1985). Some of the successes or failures may have been related to the state of development of the remote sensing data interpretation capabilities. Visual techniques have been more successful than computer-based image analysis (Gimbarzevsky, 1984). Recently, our efforts have been aimed at bridging the gap between visual and digital techniques.

Preliminary analysis of digitized aerial photographs in a PC-based image analysis and a spreadsheet environment had shown a shift of the red record data[1] towards the near-infrared (NIR) data for six current-attack trees (Murtha and Wiart, 1987). This paper reports on the follow-up study of digitized aerial photographs of mountain pine beetle [**Dendroctonous pondersae** *Hopk.*] current-attack and non-attack lodgepole pine [**Pinus contorta** *Doug.*] using PC-based image analysis and spreadsheet techniques. The purposes are to show:

1. that detectable digital differences do exist between non-attacked and current-attacked pine-crown digital images; and
2. that the natural foliage age-class spectral variations in the crown of a conifer need to be accounted for during digital analysis.

BACKGROUND

The variegated pattern

Previous studies have revealed that on large-scale air photos, healthy trees present a variegated pattern within their crowns, which is attributed to the different foliage age-classes (Murtha, 1985a). Associated with large-scale colour-infrared (CIR) photographs, it was termed the variegated magenta pattern, was described after photo interpretation of 624 ground-checked spruce [**Picea engelmannii** *Parry*] (Murtha, 1985a), and was used as a description for non beetle-attacked trees. The variegated pattern is explained by foliage age-class spectral differences along a branch; the younger age-classes are more reflective than are the older age-classes. Thus, a branch will have light-coloured foliage for the current year's growth and darker foliage for successively older age-classes.

The variegated pattern and effects of bark beetle attack

When a conifer has been successfully beetle-attacked and killed, two sequences are known to occur. First, a drop in near-infrared reflectance occurs. Heller (1968) measured a small (5–10%) decrease in near-infrared reflectance concurrent with a smaller increase in red reflectance for beetle-attacked pine 45 days after attack. Second, the foliage subsequently dries out. Like a conifer indoors at Christmas, although remaining visually green, the foliage becomes more reflective, and all age-classes of foliage develop visually similar reflectance patterns (Murtha, 1985b).

For current-attacked pine, the two sequences are as follows: 1) soon after the initial attack, the foliage looses reflectance (Heller, 1968) and would be imaged darker on CIR photos, with the variegated pattern of the healthy tree still present; and 2) several weeks after a killing attack and during the dry summer weather, the foliage dries out, becomes more reflective, and the tree crown appears brighter than the non-attacked tree; at the same time the variegated pattern is being lost or reduced in contrast. The brighter crowns and apparent lack of the variegated pattern has been the major clue to the visual interpretation of current-attack (Murtha and Cozens, 1985).

The variegated pattern affects densitometry studies

Using densitometric techniques, Hobbs (1983) did not measure significant dye-layer density differences for beetle-attack classes based on ground-derived beetle attack categories and tree condition classes: (non-attack, green (current) attack, pitch-out, strip attack, red attack, and other 'undefined' stress). The reason for the lack of significant differences between non-attack and other attack classes was attributed by Hobbs (1983) to the large standard deviation of optical density values around the optical density means for the non-attacked trees. Optical density data had been collected using a MacBeth TR524[2] optical densitometer with an aperture of 1 mm diameter. At a photo scale of 1:2000, the densitometer reading was an average of a 3.1 m^2 circular area on the tree crown. Consequently, crown shadows, bare branches, and all foliage age classes, which contribute to the variegated pattern, had been averaged into one reading.

Dye-layer density coversion to relative spectral reflectance

Attempts have been made to relate developed dye-layer densities to relative spectral reflectance. Hall *et al*, (1983) and Hobbs (1983) implemented so-called Moore Transformations in order to make statements about relative total spectral reflectance (total green — TG; total red — TR, and total near-infrared — TNIR). In Table 1, the relationships between the response of the film dye-forming layers and inferred spectral reflectance are summarized.

Hall *et al*, (1983), using 1:1100 scale colour-infrared photos, found significant differences ($p < 0.05$) in the total response ratios of green/red and red/NIR between bark beetle non-attacked and current-attacked Douglas-fir [**Pseudotsuga menziesii** *(Mirb) Franco*]. However, Hobbs (1983) did not find significant differences between current-attack and non-attack in the total film responses for green, red, and near-infrared, or in any of the response ratios. The negative results were attributed to the averaged densitometric reading taken on the 1:2000 scale photos of the lodgepole pine crowns. Ultimately, the negative findings of the densitometric portion of the Hobbs (1983) study had led to the definition of the variegated pattern to explain the large standard deviation of densitometric values noted for non-attack trees. Re-interpretation of the Hobbs (1983) photos revealed that the non-attacked pine had a variegated pattern in their foliage.

[1] The red record data was obtained by digitizing colour-infrared transparencies on the Optronics Colormation C-4500 through a green filter.

[2] The mention of trade names is for information only and does not imply endorsement by the authors.

Table 1
Relationships among Optronics filters, film dye layers, and film spectral response (Fritz, 1967; Moore, 1980).

Optronics Filter	Dye-Layer Measured	Colour-Infrared Film Spectral* Response	DN Data File
Blue	yellow (Y)	100% green	Green
Green	magenta (M)	12% green + 88% red	Red
Red	cyan (C)	12% green + 36% red + 52% NIR	NIR

Moore Transformations (Hall *et al*, 1983) for CIR photos taken through a Wr.12 filter and a CC20M filter.

Total Film Response for Primary Spectral Bands

Total Blue (TB)	= Eliminated by Wr.12 filter		
Total Green (TG)	= (1.0 × Y) +	(.12 × M) +	(.12 × C)
Total Red (TR)	=	(.88 × M) +	(.36 × C)
Total NIR (TNIR)	=		(.52 × C)

Dye-forming layer	Sensitivity Range (nm)
Yellow	510–610
Magenta	520–685
Cyan	515–885

* Wavelength Sensitivities of Aerochrome infrared film, 2443. When used with a Wratten (Wr.) 12, minus-blue filter.

Table 2
Means, standard deviations (+/−STD), and *ANOVA* F ratios for 34 non-attack and 34 current-attack trees for digital number (DN) and Moore Transformed digital numbers to total spectral response.

DN Data File	Mean DN Non-attack X	SD	Mean DN Current-attack X	SD	F ratio
Green	127.4 +/−	11.4	139.0 +/−	12.2	15.959*
Red	117.3 +/−	15.7	135.3 +/−	12.9	25.877*
NIR	184.2 +/−	8.9	188.1 +/−	9.0	3.141
DN Ratio Value					
Green/Red	1.097 +/−	0.108	1.027 +/−	0.045	11.144*
Green/NIR	0.691 +/−	0.036	0.738 +/−	0.036	28.737*
Red/NIR	0.637 +/−	0.077	0.719 +/−	0.053	25.701*
Moore Transformations (MT) of Digital Number to Total Spectral Response for the FILM (Table 1)					
MT Digital Number					
Total Green (TG)	163.6 +/−	13.9	177.8 +/−	14.6	16.521*
Total Red (TR)	169.6 +/−	15.6	186.8 +/−	13.7	25.589*
Total NIR (TNIR)	95.8 +/−	4.6	97.8 +/−	4.7	3.138
MT Ratios					
TG/TR	0.98 +/−	0.14	0.96 +/−	0.11	0.329
TG/TNIR	1.71 +/−	0.08	1.82 +/−	0.08	29.923*
TR/TNIR	1.78 +/−	0.19	1.91 +/−	0.17	9.769*

* Significant at P = 0.01

[3] The Optronics Colormation C-4500 film scanner/writer, UBC Laboratory for Computational Vision was used.

[4] Meridian PC Version 4.3, by MacDonald Detwiller and Assoc., Richmond, B.C.

METHODS

The 1:2000 CIR aerial photographs used by Hobbs (1983) were selected for digital analysis. The study site and aerial photography details have been reported by Hobbs (1983), and Hobbs and Murtha (1984). Located in the Tranquille River valley near Kamloops, B.C., the study site was photographed from 1981 to 1984, using the 70 mm wingtip camera system described by Williams (1978), until a firewood operation had removed all the study trees. Ground checking had been performed from 1981 to 1984.

A series of eight pairs of the 1981 CIR photo frames covering the study site were optically scanned[3] (Deigan 1981) at a 100 micrometer resolution. The 1:2000 photo scale gave a digitized pixel resolution of 20 cm by 20 cm (about 8 inches by 8 inches). This scanning resolution was effectively 78 times smaller than the 1 mm densitometer aperture (2 m diameter resolution) used during the Hobbs (1983) study. The photos were scanned through blue, green, and red filters (Table 1). Digitization converts the film dye-layer densities to digital numbers (DN), with a possible range from 0 to 255 for each pixel.

Thirty-four non-attacked and 34 current-attacked lodgepole pine were selected for digital study. Digital image analysis was performed using commercially available PC software.[4] The 68 lodgepole pine crowns were outlined and specific pixel information was extracted as ASCII files, using in-house programs:

- the yellow dye files were called green DN data;
- the magenta dye files were called red DN data, and
- the cyan files were named near-infrared DN data because of the different dye-layer primary response patterns (Fritz, 1967; Moore, 1980) (Table 1).

Means, variances, standard deviation, and ratios (green/red, green/NIR, and red/NIR) were calculated for each tree. The mean green, red, and NIR DN data were graphed. Moore transformations (Hall *et al*, 1983) were completed to obtain relative total green (TG), total red (TR), and total near-infrared (TNIR) responses (Table 1). Ratios (TG/TR, TG/TNIR, and TR/TNIR) of total responses were also calculated. The data were analyzed using analysis of variance (ANOVA).

RESULTS AND DISCUSSION

An average of 289 pixels were masked and extracted from each of the 34 non-attacked and 34 current-attacked lodgepole pine. The mean DNs for green, red, and NIR for the non-attack and current-attack trees are given in Table 2. ANOVA tests indicated that significant differences ($p = 0.01$) existed between non-attack and current-attack DN green and red data, and that there was no significant difference between the NIR data. The Moore transformed DN values also gave the same result: significance in the TG and TR bands and lack of significance in TNIR (Table 2). In all cases, the DN ratio values (green/red, green/NIR, red/NIR) were significantly different ($p = 0.01$). Similarly, the ratios of TG/TNIR and TR/TNIR were also significant ($p = 0.01$) for non-attack versus current-attack trees; however, TG/TR was not significant.

Even though detectable significant reflectance differences do exist between the DN means for non-attack and current-attack lodgepole pine, on an individual tree to tree basis, scatter plots

(Figure 1, 2, and 3) of the green, red, and NIR DN means for the non-attacked and current-attacked trees display overlap. There is so much overlap among the DN means that remote detection and conclusive separation of the attack classes cannot be made based solely on inferred spectral values. We speculate that the overlap is caused by the initial drop in NIR reflectance (as reported by Heller, 1968) and the subsequent increase in reflection at all wavelengths as the crown dries out. Trees are known to respond differently to stress, and the mixture of the responses causes a darker/lighter problem. This indicates that, as a predictive tool, calculation of mean DN is ineffective for separating non-attack from current-attack pine. The ratios do not provide any additional information for separating individual trees on a spectral basis.

Differences between the mean digital number for the 34 current-attack and the 34 non-attack trees are graphically depicted in Figures 4, 5, and 6. The non-attack trees have lower green and red DN values when compared to the current-attack trees, but the NIR data overlap. These results, from a different photo set, support the preliminary findings reported by Murtha and Wiart (1987). The higher mean values for the current-attack trees in the green and red region indicates that the visual reflectance has increased. These data confirm the subjective visual interpretation that, after killing current-attack, the foliage dries out and becomes brighter (more reflective), but not until after the initial drop in reflectance during the early days of attack.

The variegated effect comes into observation with the calculation of the standard deviation (SD) about the mean DN for each tree and with the display of the (ordered) pixel values for a non-attacked and current-attacked pine (Figures 7 and 8). The saw-

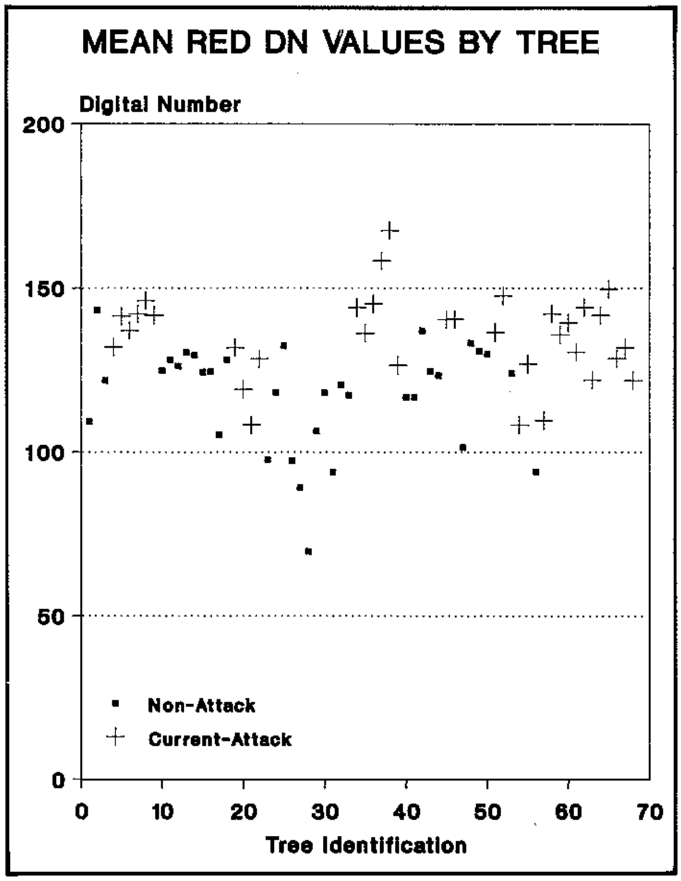

Figure 2
Scatter plot of red data file-means by tree

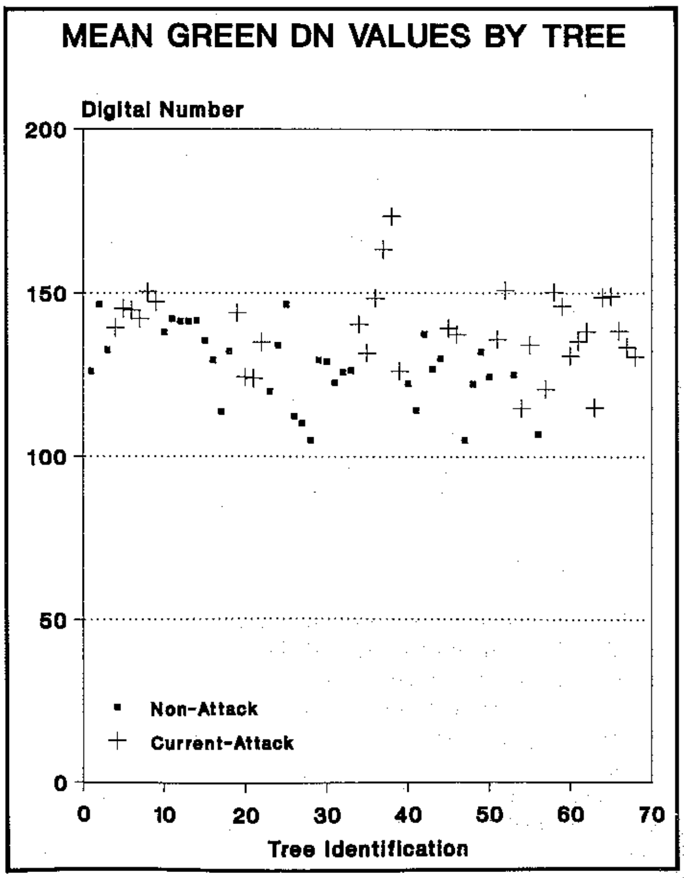

Figure 1
Scatter plot of green data file-means by tree

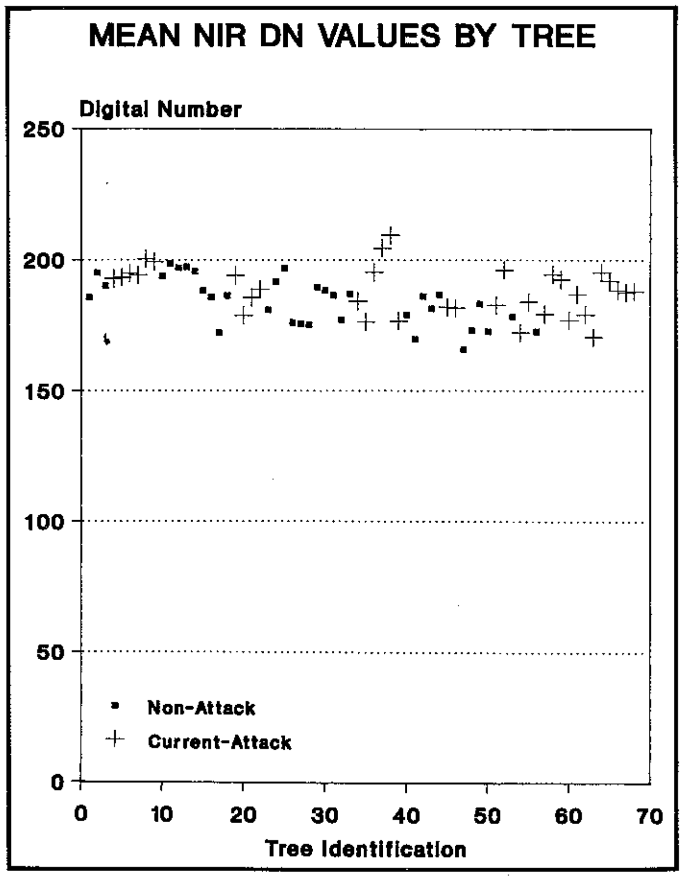

Figure 3
Scatter plot of NIR data file-means by tree

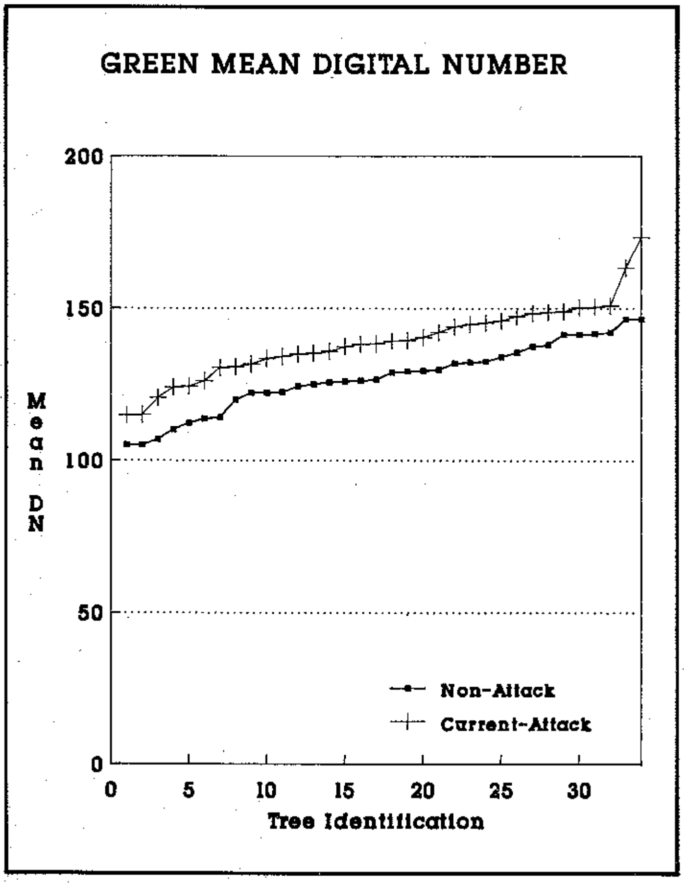

Figure 4
Comparison of ordered non-attacked and current-attacked green data means

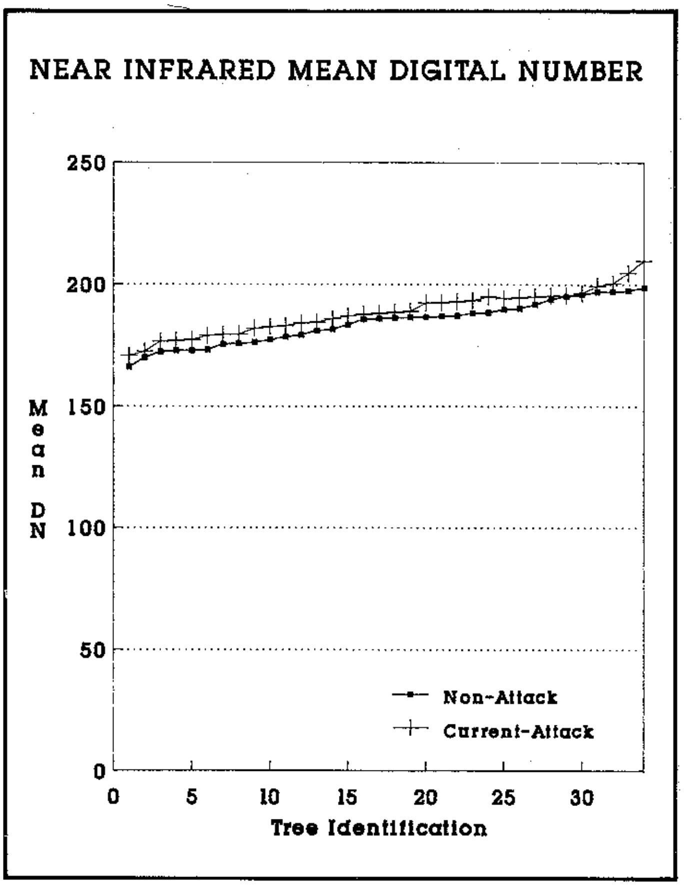

Figure 6
Comparison of ordered non-attacked and current-attacked NIR data means

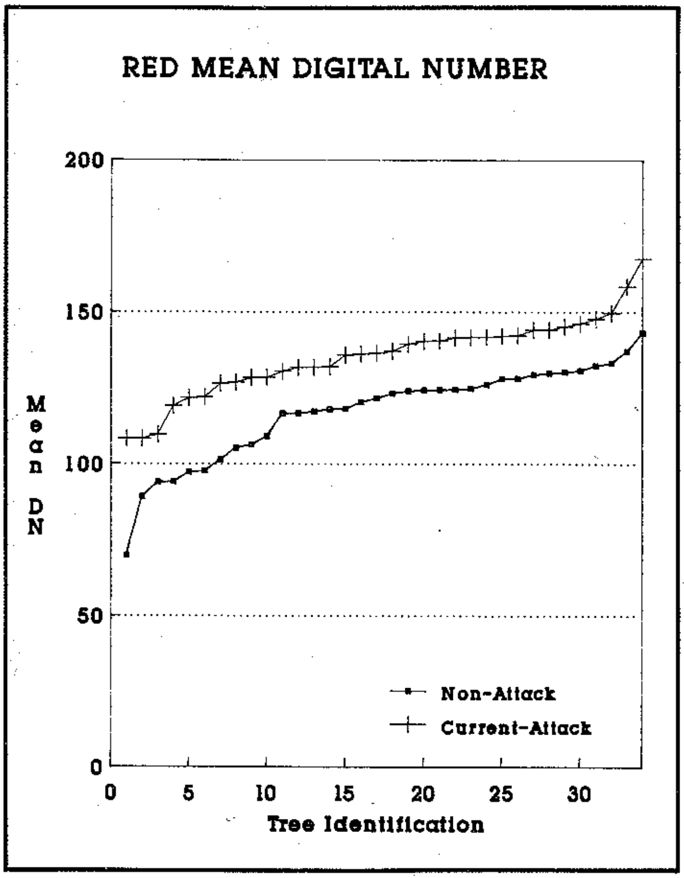

Figure 5
Comparison of ordered non-attacked and current-attacked red data means

tooth pattern of green data and NIR data relative to the red-ordered data suggests the presence of large variations in the tree crown. These saw-tooth patterns are similar to the graphs presented by Murtha and Wiart (1987). We speculate that the optical scanning at the 100um resolution was sufficient to discriminate foliage age-class differences. Along any given branch, there is a progression of light to dark foliage as age-class increases. The DN resulting from the scanning along a series of branches would give a reiterating pattern of high to low DN. The large SD reflects this pattern as part of the mean. The data means show that each falls in the centre of the graph. The mean is then similar to remote sensing systems that images the entire crown. In this case, the mean really does not reflect the true inherent pattern in the tree (Figures 1, 2, and 3). Only the large pixel resolution reflects the tree pattern of the crown (Figures 7 and 8). It is suggested that accurate tree foliage sensing requires the finer resolution data.

CONCLUSION

These results are significant in that digital analysis at a higer densitometric resolution contributes additional information over traditional visual interpretation and optical densitometry. In a previous study using the MacBeth densitometer (Hobbs, 1983), the relatively low resolution of the instrument contributed to a lack of significant differences between non-attacked and current-attacked lodgepole pine foliage. Using the same photos as Hobbs (1983) and changing the resolution from 1 mm to 1/10 mm (100 micrometers), significant mean DN differences were shown between the images of the non-attacked and current-attacked pine crowns.

It is not feasible to provide a separation algorithm solely based on inferred spectral differences using photographic techniques. The means of each data record (green, red, NIR) for non-attacked and current-attacked trees overlap and contribute little in the way of useful information for machine separation. Although differences were shown, the procedure of scanning, digitization, image analysis, pixel DN extraction, and spreadsheet analysis is not thought to be commercially viable. Our objective was to document differences between non-attacked and current-attacked pine using digital techniques. Efforts must be now aimed at automatic digital operational methods.

The existence of variegated magenta patterns in the non-attacked tree crowns indicates that in an operational remote sensing system the sensor spectral and spatial resolution must be fine enough to image the variegated pattern. Further verification of the variegated patterns is being addressed by the authors, using analysis techniques on the pixel spatial patterns.

The red DN data shift towards the NIR DN data after beetle attack, reported by Murtha and Wiart (1987), has been observed again with the current photo set. As a sole indicator of attack status, this characteristic is not totally representative of non-attacked versus current-attacked lodgepole pine. Nevertheless, it adds to the overall explanation for the series of changes that occur as a tree undergoes stress.

The photos used in this study were taken on August 18, a date in the summer when sufficient time has passed for **most** beetle-caused effects to be evident. The study concentrated on digital detection of successful current-attack. These are the trees that are of most interest to forest managers doing intensive single tree management activities. Successful current-attack trees manifest different spectral and probably spatial patters when compared to healthy trees. Although this study did note digital separation, some interesting groundwork has been introduced for achieving an algorithm that objectively classifies non-attacked and current-attacked lodgepole pine. Coupled with spatial recognition and using truly digital data, conceivably an algorithm for separating attack classes may be achievable.

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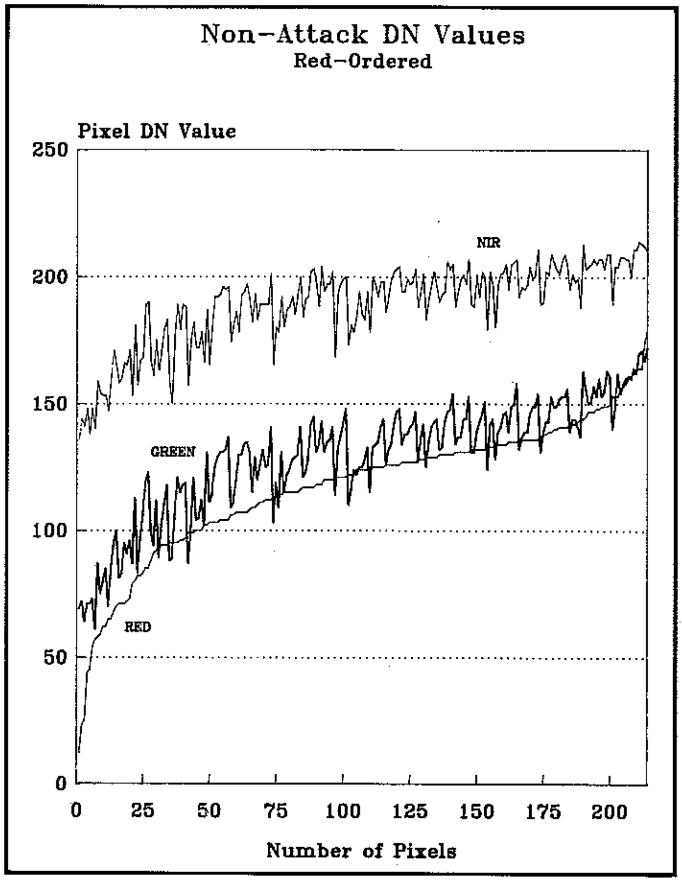

Figure 7
Red-ordered pixel DN data for a non-attacked tree

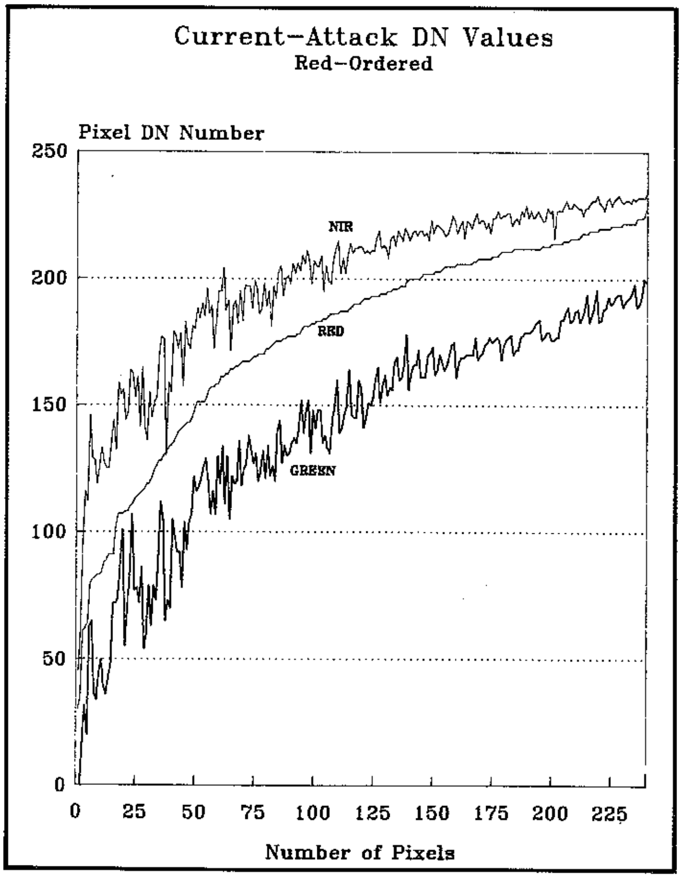

Figure 8
Red-ordered pixel DN data for a current-attacked tree

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PUBLICATIONS

The following proceedings and publications are available from the Canadian Aeronautics and Space Institute. Prices, in Canadian funds and including postage, are effective from June 1, 1988.

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September 22–24, 1975, Edmonton, 516 pp. Price $10.00 Canada, $12.00 elsewhere

Fourth Canadian Symposium on Remote Sensing
May 15–18, 1977, Quebec City, 613 pp. Price $15.00 Canada, $17.00 elsewhere

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