Cluster Analysis of Pine Crown Foliage Patterns Aid Identification of Mountain Pine Beetle Current-Attack

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ABSTRACT: Remote detection of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) current-attack has been the focus of several recent PC-based image analysis and statistical studies. Results have shown that digital number (DN) values of current-attack trees are significantly different from non-attack trees when stratification has been based upon ground data. Digital stratification of these two attack categories based on DN has not been possible because of overlapping values. This paper describes the PC-based cluster analysis of foliage patterns in current-attacked and non-attacked lodgepole pine (*Pinus contorta* Dougl.).

DN values for crowns from 34 current-attacked and 34 non-attacked lodgepole pine were analyzed using clustering techniques and principal component analysis. The results of the analysis support the variegated premise which suggests that non-attacked pine crowns have a highly variable patterns caused by the presence of foliage age-class spectral differences. Using four cluster groupings for each crown, current-attack was found to present a homogeneous clustering usually represented by two cluster groups, whereas non-attacked tree crowns were very heterogeneous and usually represented by all four cluster groups. The results are significant in that cluster analysis of DN provides another variable which can be used in the remote detection and digital analysis of mountain pine beetle current-attack.

INTRODUCTION

MOUNTAIN PINE BEETLE (*Dendroctonus ponderosae* Hopk.) current-attack on lodgepole pine (*Pinus contorta* Dougl.) has been the subject of numerous remote sensing studies (Gimbarzevsky, 1984; Heller 1968; Hobbs, 1983). Most of the studies have used visual techniques (Klein, 1982). In the pursuit of digital techniques to detect current-attack, Murtha and Wiart (1988) reported that significant differences ($p = 0.01$) existed between non- and current-attack digital numbers (DN for inferred green and red reflectance values digitized from large-scale (1:2000), color-infrared (CIR) aerial photographs. Ground data were used to stratify the non-attack from the current-attack pine.

To achieve remote detection of current-attack using digital techniques, factors in addition to DN must be utilized. Murtha's (1985a, 1985b) analyses of bark beetle current-attacked have led to the description of a *variegated* pattern associated with foliage age classes on non-attacked conifers. Current-attack trees lose the variegated pattern some weeks after a killing attack. Interpretations of current-attack have been based on qualitative visual interpretations of the tree crown and these included the halo effect, color (spectral) patterns, and the lack of the foliage age class differences (spatial patterns) (Murtha, 1985b).

The purpose of this paper is to describe the foliage digital patterns associated with mountain pine beetle current-attack and non-attack lodgepole pine.

OBJECTIVES

Digital analysis of tree condition requires quantitative evaluations. Subjective analyses, those associated with visual interpretation of current-attack versus non-attack trees, are a combination of both spectral and spatial information based on the expertise of the analyst. The objective of this study is to show that successful current-attack lodgepole pine have foliage digital cluster patterns different from non-attacked pine.

METHODS

The data for the 34 non-attacked and 34 current-attacked lodgepole pine extracted from the 1:2000-scale CIR aerial photographs used by Murtha and Wiart (1988) were selected for study. The study site and aerial photography details have been described by Hobbs (1983), Hobbs and Murtha (1984), and Murtha and Wiart (1988).

The photos had been digitized with a 100-micrometre scan on the Optronics Colormation C-4500 film scanner/writer in the Laboratory for Computational Vision in the University of British Colombia (UBC) Dept. of Computer Science. At a scale of 1:2000, a 100-micrometre scan would give a pixel size of 20 cm by 20 cm (about 8 in. by 8 in.). The photos were scanned through blue, green, and red filters (Table 1). Digitization converts the film dye-layer densities to digital number (DN), with a possible range from 0 to 255 for each pixel. Digital image analysis was performed using commercially available PC software.[1] 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 called near-infrared DN data, because of the

TABLE 1. RELATIONSHIPS AMONG OPTRONICS FILTERS, FILM DYE LAYERS, AND FILM SPECTRAL RESPONSE (FRITZ, 1967; MOORE, 1980).

Optronics Filter	Dye-Layer Measured	Color-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

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

* Wavelength sensitivities of Aerochrone infrared film, 2443, when used with a Wratten (Wr.) 12, minus-blue filter.

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

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different dye-layer primary response patterns (Fritz, 1967) (Table 1).

K-means[2] clustering (Wilkinson, 1988) was used to separate each tree's three DN data files (green, red, NIR) into four possible cluster groups. Initially, sample trees were analyzed for a variety of cluster ranges (between 3 and 7). Preliminary investigations had determined that four cluster groups were suitable for showing attack class differences while maintaining the character of the tree crown for spatial reconstruction. In addition, principal component analysis was implemented on the cluster groupings obtained from the three DN data files. The first component scores for each tree by clusters were subsequently analyzed using box plot diagrams in order to determine whether cluster groupings were significantly different. In all examples, the box plots established that four cluster groupings for each tree are significantly different from each other ($p = 0.05$). Pixel integrity between data files was maintained throughout the clustering procedure, and cluster groupings were spatially reassembled maintaining spatial locations. The resultant recombination gave a simple crown diagram that displayed multiple digital number variation based on the three data files which were originally extracted.

RESULTS AND DISCUSSION

Spectral Analysis

Analysis of the spectral data for the 34 non-attack and 34 current-attack lodgepole pine had been described by Murtha and Wiart (1988). In summary, with attack classes based on ground data, significant differences ($p = 0.01$) between the green and red data files were established between the attack groups (Table 2). Figures 1, 2, and 3 show the overlap in non-attack versus current-attack means for each data file for each tree. Significant population differences are present, but by inspection of Figures 1, 2, or 3, an interpreter who based mountain pine beetle attack interpretation solely on DN (spectral) mean differences would not be able to separate trees into the proper attack categories. Hobbs (1983), using densitometric techniques, experienced this result. The DN means show no grouping of the two attack categories for any of the three data files which could be used to stratify the data, even though the data show significant differences when stratification was based on ground data.

Cluster Analysis

Analysis of the cluster groupings and crown diagrams indicated that the non-attacked pine crowns are distinguished by a heterogeneity of cluster groups. In contrast, the current-attack tree crowns are separated by a homogeneity of groups, with one or two cluster groups dominating. The patterns associated with the non-attack trees are attributed to the *variegated pattern* (Murtha 1985b) caused by foliage age differences. This pattern is lost in the crowns of current-attack pine which is seen as a reduction in the number of dominant cluster groups. Table 3 presents the percent of pixels by group count for a random sample of four tree crowns in each attack category. For the current-attack lodgepole pine, two groups account for more than 90 percent of the pixels, whereas three or more cluster groups are required to account for more than 90 percent of the pixels in the non-attacked pine crowns. Table 3 also indicates that 61 percent of the pixels in the current-attack crowns are found in the first cluster group, whereas in the non-attacked pine crowns the first cluster group represents 35 percent of the pixels. The cluster groups are related to spectral patterns which represent foliage reflectance differences associated with foliage age classes. Consequently, these data support the assertation that non-attack trees have a detectable foliage age-class variation, and that the pattern is lost after successful attack. Based exclusively on these groupings, and verified by the ground data, 70 percent of the trees clearly exhibit the two distinctive patterns, very heterogeneous for non-attack and homogeneous for current-attack. These 70 percent results are similar to the 74 percent accuracy achieved by *guided clustering* in the classification of wetland habitat (Hodgson *et al.*, 1987). The variegated pattern in the crowns of non-attacked pine is translated to a very heterogeneous clustering of DN triplets, whereas the lack of the variegated pattern translates to a homogeneous clustering of DN triplets. The authors are currently investigating PC-based spatial autocorrelation techniques (Cliff and Ord, 1973) to corroborate the above findings.

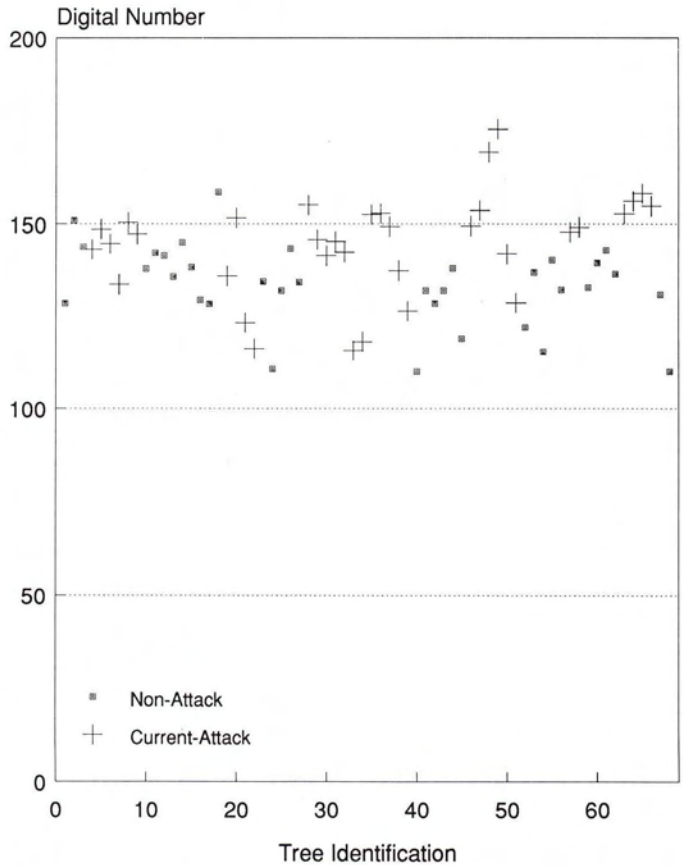

FIG. 1. Scatter plot of green data file-means by tree.

TABLE 2. MEANS, STANDARD DEVIATIONS (±STD), AND ANOVA F RATIOS FOR 34 NON- AND 34 CURRENT-ATTACKED TREES FOR DIGITAL NUMBER (DN).

DN Data File*	Non-Attack	Current-Attack	F ratio
Green	133.6 ± 11.0	144.6 ± 13.6	13.586**
Red	124.6 ± 15.9	140.7 ± 14.6	18.887**
NIR	188.5 ± 7.6	192.3 ± 8.7	3.636

* See Table 1.

** F Ratios significant at $p = 0.01$

[2]K-means clustering splits a set of objects into a selected number of groups by maximizing between- relative to within-cluster variation. In rough terms, it is like doing a one-way ANOVA where the groups are unknown and the largest F-value is sought by reassigning members to each group (Wilkinson, 1988).

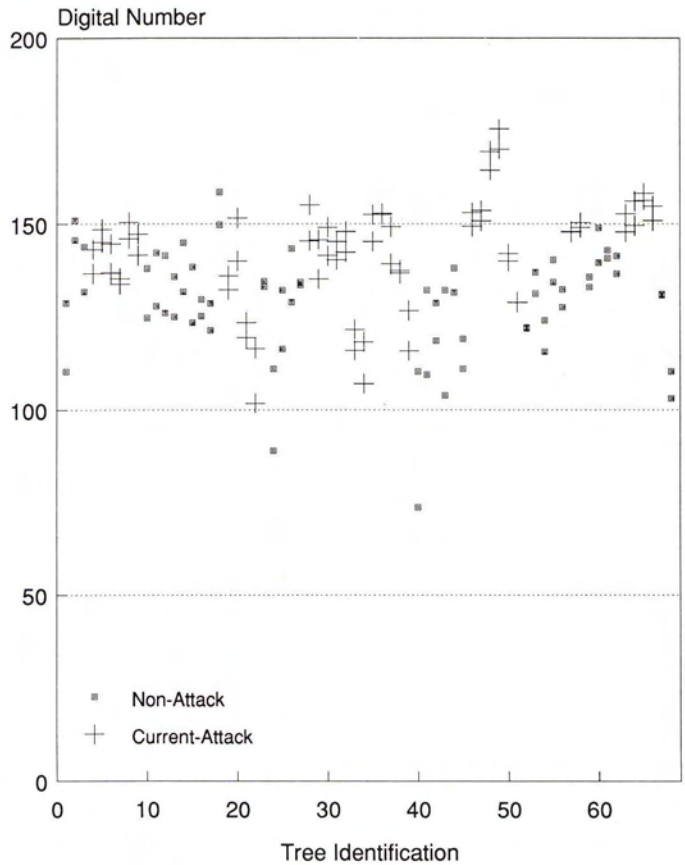

FIG. 2. Scatter plot of red data file-means by tree.

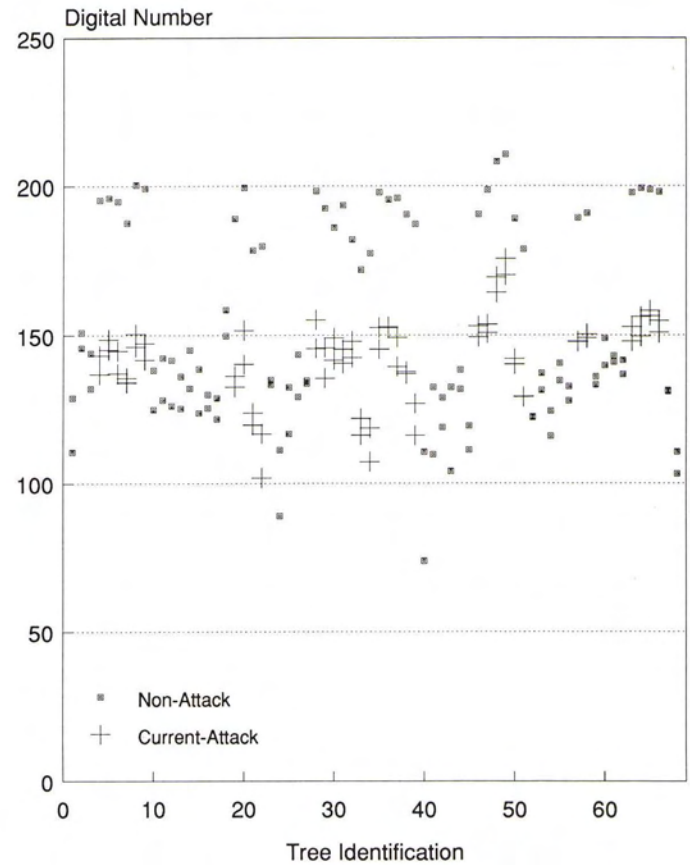

FIG. 3. Scatter plot of NIR data file-means by tree.

CONCLUSIONS

The variegated patterns of foliage age class difference in non-attacked trees are evident in remotely sensed data when the spatial resolution is fine enough to resolve the foliage differences in a tree crown. Using cluster analysis techniques and crown reconstruction, non-attacked pine crowns are characterized by very heterogeneous classes of three or four cluster groups which appear to be randomly distributed throughout the tree crown. Conversely, trees that have been successfully current-attacked display a homogeneity of pattern, with one or two cluster groups per crown being evident. It was initially speculated that non-attacked pine crowns display a spatially related variegated pattern, a pattern which is lost in current-attacked trees. The cluster analysis and spatial reconstruction demonstrated a heterogeneous clustering associated with non-attacked trees, and a very homogeneous clustering for the current-attacked pine.

These results are important in that the relationships between non-attack and current-attack conifers as described by Murtha (1985b) have been demonstrated utilizing digitized aerial photographs, PC-based image analysis and statistical clustering techniques. Two distinctive clustering patterns, very heterogeneous for non-attacked and homogeneous for current-attacked, were found. These techniques were applied to digitized aerial photographs with an effective spatial resolution of 0.2 milliradians, but we speculate that the correlations could be used to analyze airborne-derived digital data such as MEIS-II (McColl *et al.*, 1984). These results also provide further insight into developing machine algorithms and hardware for automatic classification of infested areas (Ahern *et al.*, 1986; Leckie, 1987). We suspect that a finer spatial resolution than is currently used in airborne scanners (i.e., 0.7 milliradian resolution for MEIS-II) is requried to detect and separate non-attacked from current-attacked pine crowns.

TABLE 3. SAMPLE PERCENT OF PIXELS BY CLUSTER GROUP COUNTS FOR A RANDOM SAMPLE OF FOUR NON- AND FOUR CURRENT-ATTACKED LODGEPOLE PINE.

Non-Attacked Cluster Group	Tree Number 132H17	145H10	151BH03	151BH07
1	40.5	31.6	24.9	42.3
2	38.2	38.8	47.5	34.1
3	16.1	23.9	21.0	18.5
4	5.2	5.7	6.6	5.1
Current-Attacked Cluster Group	**Tree Number 145G06**	**148G01**	**151G14**	**151G19B**
1	61.5	63.5	58.7	60.5
2	28.4	27.6	32.2	31.4
3	8.9	8.4	8.3	7.6
4	1.2	0.5	0.8	0.5

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