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ANOTHER LOOK AT DUTCH ELM DISEASE VIA DIGITIZED AERIAL PHOTOGRAPHY

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I. ABSTRACT

Previous studies have indicated that crown morphology and within-crown color variations, rather than between-crown color differences, are principal keys to the accurate aerial detection of Dutch elm disease (DED). Because within-crown color variations often tend to be very subtle on conventional infrared photographs, microdensitometry and subsequent digital enhancement were evaluated as potential means of improving detection accuracy.

Vertical 70 mm color infrared photographs at scales of 1:6,000 and 1:12,000 were taken on several dates during 1979-80 over a St. Paul, Minnesota study area containing high incidence of DED. Scanning microdensitometer data from the photographs were processed using three enhancement techniques: color contrast stretch, two-band spectral ratioing, and multiple discriminant analysis. The numerically processed data were subsequently reconverted to image form using a high resolution color film recorder. Experienced interpreters analyzed both the original imagery and the enhanced products.

The computer enhanced images dramatically increased the expression of subtle within-crown and between-crown color variations, but only nominally improved detection accuracy. Thus, the factor limiting detection from vertical photography appears to be the inconsistency, not the subtletly, in which DED is manifested as crown color variation.

II. INTRODUCTION

The success of any Dutch elm disease (DED) control program is contingent upon, among other things, early and accurate detection of the disease in affected trees. Numerous studies have investigated the potential of using manual interpretation of color infrared aerial photography to detect DED. The success of these studies has been quite mixed, but generally the photographic methods have not yielded detection accuracies adequate for disease control.[1-3,8,10]

As disappointing as the overall results of previous research had been, they did suggest that if subtle, anomalous, within-crown variation could be better interpreted from the photography, much improved detection might be realized. The approach taken in the current study was to obtain spectral density measurements from color infrared images and analyze them using various digital processing methodologies in hopes of enhancing subtle crown color variation.

In contrast to the more conventional interpretation procedures, densitometric techniques for DED detection have received limited attention in previous investigations. Notable exceptions are studies reported by Stevens, and Hammerschlag and Sopstyle.[11,4] In the former effort, whole-crown spectral density measurements were obtained from color infrared photographs of healthy and diseased elms in a Madison, Wisconsin, test area. Relative density differences were noted for healthy and diseased samples but results were inconclusive due to the use of oblique photography for the experiment and a 35mm camera having an erratic focal plane shutter. However, Stevens' work indicated that subtle disease symptoms were potentially detectable using image density measurement.

Hammerschlag and Sopstyle tested various forms of aerial photographic detection in a Washington, D.C., test area. Among other things, they attempted to expedite detection by computing ratios of densities obtained from two images taken simultaneously in two spectral bands (reflected infrared and red). Since the resulting images were not superimposable point for point, average density readings over areas had to be compared. Possibly due to this data generalization, the two-band ratio values measured were insensitive to stress levels.

Applying microdensitometry of color infrared photography to a different shade tree problem, Lillesand et al. were able to use spectral density measurements to quantify decline levels in a sample of street-side maples in Syracuse, New York.[5] Between-crown density differences proved to be a reliable "automated" indicator of relative crown vigor in this case. In the current study, digital image processing was employed as an enhancement tool used in a subsequent manual interpretation of the image data.

This study was conducted in two phases. First, multidate color infrared photographs were acquired at two scales over test areas which were surveyed concurrently by field crews. A preliminary interpretation of all imagery was then made to determine which combination of film type, date, and scale of photography was best for DED detection purposes. A detailed visual interpretation of this optimum data set was then performed by two experienced interpreters to establish a benchmark against which subsequent interpretations of computer enhancements could be compared.

In the study's second phase, 17 photographs covering a representative portion of the test area were digitized using a scanning microdensitometer and three forms of computer enhancement were applied to the resulting data: color contrast stretch, two-band ratioing, and discriminant analysis. The numerically processed data resulting from the application of each of these procedures were subsequently re-converted to image form using a computer controlled color film recorder. These enhanced image products were then interpreted visually and the results were compared to the interpretation of the original images.

The remainder of this paper summarizes the various data acquisition and analysis procedures employed in the study, and the comparative results of the conventional and computer-assisted interpretation procedures.

III. DATA ACQUISITION

The primary test area used is an older residential St. Paul area (2.6 km^2) containing a mature shade tree population consisting primarily of American elms. The site was selected because it generally represents the range of environmental conditions under which operational DED monitoring programs are conducted in the Twin Cities area. Further, the site includes a number of "control" elms which have been the subject of years of intensive monitoring as part of DED research conducted by the University of Minnesota Department of Plant Pathology. The entire study area was intensively surveyed by city and university field crews regularly during the 1979 growing season.

The test area was photographed on five dates during the 1979 growing season: May 3, May 15, June 25, July 25, and September 6. Hasselblad 500 EL motor driven cameras (f=80mm) were used to obtain the 70mm color infrared positive transparencies (Kodak film type 2443, Wratten 15 filter). For comparison purposes, both 1:6,000 and 1:12,000 scale images were taken during the July and September missions. All photographs were obtained with a nominal 60% endlap to afford stereoscopic viewing, all film used was manufactured in the same emulsion batch, and step wedges were exposed on each film leader prior to processing.

The overall appearance of the various sets of imagery was quite variable. The May images were "leaf-off" images, which were used solely to locate and index each tree in the test area on a base map. The photography taken during June coincided with the incidence of severe defoliation of elms in the study area by canker worms, and shortly after a period of excessive storm damage. The September photographs, while of good photographic quality, contained long shadows due to the low solar altitude. It was found that the July 25 date provided the most useful photography. Accordingly this data set was the subject of the computer-assisted interpretation. Images from all dates were analyzed to varying degrees during the manual interpretation process.

IV. INTERPRETATION OF ORIGINAL PHOTOGRAPHY

A. PROCEDURE

The visual interpretation process commenced with locating and indexing all street-side elms on a base map. The 1:6,000 May photography was found to be very effective for this task. In these leaf-off images, elms were readily separable from other tree species because of the elms' characteristic feather-duster shadow and dark trunk and limbs. Flowering was also taking place at the same time of photography and this added another identifying characteristic for the elms. Consequently, individual elm crowns were easily discriminated from other species on the images and could be individually referenced on a map base. Accomplishing these tasks with leaf-on images is much more difficult given overlap between crowns and the similar appearance of elms and other species.

Only street-side trees were included in the interpretation process in that ground data on yard trees were not readily obtainable for comparison. This resulted in a population of 1428 trees which were located between the streets and sidewalks in the study area.

Image interpretation was performed after field visits were made to sites of selected healthy and diseased trees for training purposes. The entire set of 1:12,000 photographs for each date was first analyzed, followed by the 1:6,000 images. All images were viewed by two trained interpreters having access to conventional monocular viewing devices and a Bausch and Lomb Zoom 70 Stereoscope mounted on a light table.

The general guidelines used by the interpreters for disease identification were developed during previous studies.[1] They included the following:

1. Variation in color among street-side elms makes the identification of a diseased tree on the basis of the general crown color almost impossible. Therefore, crown examinations should key on morphological peculiarities and color changes <u>within the crown</u>. Crown discoloration in one portion as compared to the remainder <u>may be extremely subtle</u>.

2. A stereoscope should be used to determine if what appears to be a disease symptom is actually in the crown. It is easy to mistake a street, sidewalk, or driveway showing through the crown for a crown reflectance anamoly.

3. Note should be made of a crown with a tattered or shredded appearance as compared with surrounding crowns.

4. Elms with foliage in distinct tufts rather than uniform full crowns should be noted, as should generally thin crowns.

5. Shadows cast by a suspect tree should be studied; defoliated branches may thereby become more apparent.

6. Diseased elms sometimes have foliage adhering very close to only the main limbs. In these cases the shadow will appear very thick and heavy.

Using the above interpretation guidelines, each interpreter noted all apparent diseased trees and classified them into high, medium, or low levels of interpretation confidence. After the image interpretation process was completed, ground data were collected on the precise location, date of field detection, and date of removal for diseased elms. The aerial and ground data sets were then compared.

B. RESULTS

As mentioned previously, the July data set was found to be the most useful for disease detection. As anticipated, the 1:6,000 images were slightly more amenable to interpretation than their 1:12,000 counterparts--but both were judged acceptable by the interpreters. (A scale such as 1:10,000 would probably represent an optimum compromise between areal coverage and image detail).

As in the previous studies, accuracies were found to be low and errors high. Table 1 lists the results of the conventional interpretation process. Table 1a gives the results for the more experienced interepreter, Table 1b for the less experienced. Note that the study population of 1428 street side elms included 1357 healthy trees and 71 diseased trees.

The left side of Table 1 is a matrix of photointerpreted vs. ground data. The photo-interpretation categories of disease existence are low confidence (D^3), moderate confidence (D^2), and high confidence (D^1). The ground data category of "diseased" trees includes those diagnosed by city crews as having DED and removed in 1979, as well as diseased trees noted by University personnel which had not yet been marked for removal by city crews. This latter group stemmed from an intensive resurvey of the study area early in the 1980 growing season.

The right side of Table 1 lists the photo-interpretation accuracies and errors. Accuracies are given as percentages of interpreter identified vs. ground verified diseased trees. Errors of omission are simply the complements of the accuracy values. Errors of commission indicate the number of healthy trees (by ground designation) which were mistakenly classified as diseased by the interpreters. These errors are also expressed as a percent of total diseased trees. All three quantities are expressed for three different thresholds of interpretation: on the top line, only the D^1 category (high interpreter confidence in DED existence) is considered as diseased. In this case, the D^2 and D^3 classes would be considered non-disease anomalies. This yields very low errors of commission, but causes many diseased trees to be omitted. The second line considers classes D^1 and D^2 to be diseased, and the bottom line considers all three interpretation confidence categories.

The two tables indicate considerable difference between the two interpreters. Interpreter 1 had a higher decision threshold, classifying a total of 62 trees as diseased, as opposed to 289 trees for Interpreter 2. As a result, Interpreter 1 had less inclination toward misclassifying healthy trees (errors of commission) but also had a greater tendency to overlook diseased trees (errors of omission). Interpreter 2 found more of the diseased trees, but at the expense of including many healthy trees.

V. DENSITOMETRIC PROCEDURES

A. DENSITY MEASUREMENT

A subset of 17 images was digitized using a modified Optronics P-1700 drum scanner operated by the Environmental Remote Sensing Center (ERSC) at the University of Wisconsin-Madison. The scanner data are expressed as density values from 0 to 3D, digitized into 256 levels. Each 70mm frame of photography was scanned at an interval of 50μm, yielding a grid of 1100 x 1100 pixels. Given three spectral density measurements per pixel (one for each color sensitivity layer of the film), a total of over 3.6 million measurements were taken on each photograph. The ground area represented by each pixel was 0.3m square for the 1:6,000 scale images, and 0.6m square for the 1:12,000 data set.

All data processing for the enhancement procedures was performed on a CDC Cyber 172 computer system using the University of Minnesota Image Processing Software (UMIPS) developed by the Remote Sensing Laboratory. The enhanced image data sets were recorded using the Dicomed D-47 color film recorder operated by the University of Minnesota Special Interactive Computation Laboratory. Photographic positives were generated for interpretation purposes and negatives for preparation of enlargements. The various forms of enhancement used to generate these images are described below.

B. CONTRAST STRETCH ENHANCEMENT

While the densitometer records density values over the entire range from 0 to 3D, most of the features in a typical photograph have values within a small range of the total density scale. As a result, slight differences are often very hard to distinguish and are frequently undetectable by the human interpreter. In the contrast stretch enhancement process, the original image density values are modified such that the more frequently occurring "medium" levels occupy a larger range of image values. This makes variation in the medium tones easier to differentiate, at the expense of less differentiation in the infrequently occurring very bright or very dark features. Because the elm tree crowns tend to be of medium tone, contrast stretching enhances the total rendition of these features. The form of contrast stretch used in this project is called <u>histogram equalization</u> because it is <u>based on the histogram of</u> digital values in the image. It is performed independently on each color sensitivity layer in the image, generating three modified primary color image files. During film recording, the data are composited through color filters, creating an image which enhances color variation in the medium tonal range.

C. RATIO IMAGES

A ratio image is derived by dividing the image density value in one spectral layer by the value in another layer for each pixel in the image. The resulting ratio values are then displayed as an image. This procedure tends to negate various extraneous factors that act nearly equally in each of the spectral bands under analysis. For example, from the sunlit to the shaded side of a tree crown, the image values will change considerably and this change will have no relation to the crown spectral characteristics per se. Yet if the shade reduces <u>both</u> the green and red levels approximately equally, the ratio of green to red values should remain fairly constant throughout the crown. True color changes within the crown, as opposed to overall brightness changes, will result in different ratios. In theory, these differences should be more noticable after removal of the extraneous variations. This technique essentially attempts to screen out meaningless tonal variations caused by such factors as position within the photograph, shading, etc.

The measurement unit of density in which the densitometer data are expressed is logarithmic. As a result, ratios are computed simply by subtracting the digital values in two image layers and adding 127 to avoid negative values. Since a ratio image is computed for a pair of film sensitivity layers, three combinations are possible: green/red, green/infrared, and red/infrared (as well as the inverse of these). We recorded ratios such that an equal reflectance in both channels appears as a medium grey, a high reflectance in one film layer relative to the other appears as white, and a high relative reflectance in the other layer appears as black. The inverse ratio images were generated by producing both positive and negative images at the film recording stage. Furthermore, the ratio data were contrast stretched with the histogram equalization technique prior to film recording.

Additional discussion of contrast stretch and ratio enhancements can be found in Lillesand and Kiefer.[6]

D. MULTIPLE DISCRIMINANT ANALYSIS

The principal shortcoming of the ratio technique is the limitation to two image bands in a given display. It is difficult to say which of the possible ratio combinations is optimum for the application at hand. Discriminant analysis is similar to the ratio technique except that all bands of data are used in a single display and the values are combined using weighting factors which maximize the discriminability of the features being analyzed. The weighting factors are determined from a sample of image values from each of the two types of features to be distinguished (in this case, diseased and non-diseased elms). Statistical analysis of the two sets of values (using the two means and a pooled variance/covariance matrix) are used to compare the factors.[9]

When generating a discriminant image, the three spectral values for each pixel are multiplied by their corresponding coefficients and added to derive the discriminant image value. This process expressed in equation form is:

$$X' = X_g C_g + X_r C_r + X_{ir} C_{ir}$$

where

X' = multiple discriminant value

X_g, X_r, X_{ir} = original image values (green, red, IR)

C_g, C_r, C_{ir} = discriminant coefficients for each film layer

Using the above technique, "discriminant images" were prepared by relating image brightness to discriminant value during the film recording process.

VI. INTERPRETATION OF ENHANCED IMAGERY

Cost precludes our including samples of the computer enhanced color images in this proceedings volume. These are to be published elsewhere.[7] Suffice it to say that the enhanced images afforded considerable improvement in tonal information. For example, on the contrast stretch images dramatic color variations were depicted in crowns which appeared in identical tones on the original images. The problem is that the stretch process enhanced color variations in healthy crowns as well as diseased. Another deficiency of the digital imagery was the reduced spatial detail due to the scanning process. This made very sparse crowns difficult to pick out. This problem was particularly acute on the 1:12,000 products. Thus, the interpreter must view both the originals and the enhancements to be certain to not miss very sparse crowns.

Interpretation of the contrast stretch enhancements was performed by Interpreter 2 (Interpreter 1 was unavailable at the time of this activity). The 1:12,000 contrast stretched photos were interpreted for D^1 and D^2 classes (high and moderate confidences in the detection of DED). The D^3 class was omitted due to the lack of success with it in the earlier analyses. A representative subset of the entire study area was used for the detailed analysis of the enhancements.

The interpretation was performed on the original positive enhanced transparencies. Both positives and negatives had been originally generated on the film recorder, and color enlargements were produced from the negative. While useful for annotation, the prints were found to lack the color fidelity and spatial resolution of the first generation positive transparencies. The square shape of individual pixels in the 1100 x 1100 grid could readily be seen on the positive transparency, but not on the prints. Due to the small size of the transparencies (the Dicomed image recorder uses 4x5" film) the interpretation was done under 2X to 4X magnification.

Table 2a summarized the results of the interpretation of the contrast stretch images. The "original photography" table was extracted from the Interpreter 2 analysis done previously for the limited geographical subset area of the enhancement test. Table 2b lists the corresponding accuracy and error rates. The results show an improvement in errors of omission and commission for the contrast stretch interpretation.

Also shown in Table 2 are the results of interpreting the ratio images. These images were generated such that healthy trees were recorded in dark tones and the diseased trees in light tones (the reversed rendition was also generated but was found to be the less interpretable). Regrettably, a very high correlation between the green and red reflectance data was found in the tree crowns. Because of this, a small range of grey values resulted. Contrast stretching of the data caused the small, correlated differences to be greatly exaggerated. The result was not found to be particularly useful.

A final note on the ratio images is that they did not completely eliminate the shading influence present in the scenes (particularly when the IR sensitive layer was used in a ratio image). Rather than being equally reduced in brightness across the spectrum, scene illumination was reduced as a function of wavelength resulting in slight tonal variations of uniform features on the ratio images.

A review of the multiple discriminant images was equally disappointing. These products tended to be equivalent visually to the ratio images. Consequently, a detailed analysis of interpretation accuracy was not performed for these images.

VII. CONCLUSIONS

The results of this study have indicated an improvement in interpretation accuracy can be realized with the use of digitally enhanced imagery. These improvements are not, however, on a large order of magnitude considering the added expense of the digital processing. Nor do they offer sufficient improvement in accuracy to offer a viable alternative or complement to the ground survey process for DED control.

The digital techniques were found to dramatically increase the visual expression of crown color variations. The problem is the inconsistency with which these variations indicate DED. Some diseased trees have manifestations on lower branches only, presenting a healthy crown to the aerial camera. No amount of enhancement will enable interpretation of these crowns on vertical photography. Conversely, healthy crowns having slight color variations due to other causes may be interpreted as diseased after the enhancement process amplifies the variations. In short, the <u>inconsistency</u> of the manifestations of DED is a problem in addition to their subtlety. When applied to detection of tree (and agricultural crop) stress having more consistent spectral manifestation, it appears that the digital processing approach developed in this study is very effective. Applied to DED, it unfortunately is not.

The specific conclusions drawn <u>under the conditions of this study</u> are listed below.

1. Initial identification of elm trees was most easily performed on the May "leaf-off" photography. The characteristic color, branching, and early foliage made distinction of the elm crowns possible, and the lack of dense foliage aided in the differentiation of closely spaced trees for base mapping purposes.

2. A mid-season (July 25) date of photography provided the best interpretation. Early season photographs were more difficult to use due to effects of a canker worm outbreak in our study period. Late season photography had excessive shadows due to the lower sun angle. The optimum detection period will vary with conditions in any given study area.

3. Interpreters of the original photography preferred 1:6,000 over 1:12,000 scale. The larger scale improved the interpretation of crown shape and condition but limited areal coverage per frame. A scale of 1:10,000 represents a reasonable compromise between coverage and detail.

4. The digital enhancements dramatically improved the visual expression of crown color variations. The factors of crown shape and condition were more difficult to analyze due to a slight loss of spatial detail on the digital imagery. At the same time, background effects (where the ground shows through the crown) were reduced by the spatially integrated nature of the digital imagery, especially on the 1:12,000 scale images which were preferred by the interpreter.

5. Analysis of ratio images showed the red/infrared and green/infrared combinations to be useful and nearly equivalent. The green/red combination was not useful. A multivariate discriminant analysis was also used to transform the data. Results were very similar to the two ratio products. Because of this result, and considering the extra effort required, the discriminant analysis was not effective in this application.

6. Test results indicated improved

accuracy with the contrast stretch and green/infrared ratio images compared to the original photography. The improvement is not, however, large enough to warrant the cost of digital processing, nor are the accuracies high enough for the data to be of practical value.

7. The problems encountered in detecting DED accurately with the digital data seem to be largely due to the characteristics of the disease. Again, the digital techniques employed have been found to be more effective when applied to tree and plant stresses having more consistent spectral manifestations.

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Table 1. Conventional Image Interpretation Results

(a) Interpreter 1

P.I. DATA		GROUND DATA: healthy	GROUND DATA: diseased
healthy		1320	46
diseased	D1	3	11
	D2	9	11
	D3	25	3
total:		1357	71

classes considered "diseased"	ACCURACY	ERRORS: omission	ERRORS: commission
D1	$\frac{11}{71}$ = 16%	$\frac{60}{71}$ = 84%	$\frac{3}{71}$ = 4%
D1, D2	$\frac{22}{71}$ = 31%	$\frac{49}{71}$ = 69%	$\frac{12}{71}$ = 17%
D1, D2, D3	$\frac{25}{71}$ = 35%	$\frac{46}{71}$ = 65%	$\frac{37}{71}$ = 52%

(b) Interpreter 2

P.I. DATA		GROUND DATA: healthy	GROUND DATA: diseased
healthy		1120	19
diseased	D1	8	12
	D2	132	34
	D3	97	6
total:		1357	71

classes considered "diseased"	ACCURACY	ERRORS: omission	ERRORS: commission
D1	$\frac{12}{71}$ = 17%	$\frac{59}{71}$ = 83%	$\frac{8}{71}$ = 11%
D1, D2	$\frac{46}{71}$ = 65%	$\frac{25}{71}$ = 35%	$\frac{140}{71}$ = 197%
D1, D2, D3	$\frac{52}{71}$ = 73%	$\frac{19}{71}$ = 27%	$\frac{237}{71}$ = 334%

Table 2. Results of Enhanced Imagery Interpretation Test

(a) Summary of results

PHOTOINTERPRETED DATA			GROUND DATA: healthy	GROUND DATA: diseased
A. Original photography	healthy		349	12
	diseased	D2	43	20
		D1	1	2
B. Contrast Stretch	healthy		352	10
	diseased	D2	19	7
		D1	22	17
C. Ratio (green/ir)	healthy		360	12
	diseased	D2	19	13
		D1	14	9
total:			393	34

(b) Accuracy and errors

	ACCURACY	ERRORS: omission	ERRORS: commission
A. Original Photography	$\frac{22}{34}$ = 65%	$\frac{12}{34}$ = 35%	$\frac{44}{34}$ = 129%
B. Contrast Stretch	$\frac{24}{34}$ = 71%	$\frac{10}{34}$ = 29%	$\frac{41}{34}$ = 121%
C. Ratio (green/ir)	$\frac{22}{34}$ = 65%	$\frac{12}{34}$ = 35%	$\frac{33}{34}$ = 97%

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