J. J. ULLIMAN*
D. W. FRENCH
University of Minnesota
St. Paul, MN 55108

Detection of Oak Wilt with Color IR Aerial Photography

Tests of various film/filter combinations at several scales indicated that detection was possible at less cost than by ground surveys alone.

ABSTRACT: *During the period 1971-73, the following film/filter combinations at various scales were used to detect oak wilt infection centers in North Oaks, Minnesota: Ektachrome MS/Wratten 2A, Ektachrome IR/Wratten 15, and Ektachrome IR/Wratten 21 at scales of 1:6,000, 1:12,000, 1:15,840, 1:24,000, and 1:31,680. Up to 100 percent detection of oak wilt infection centers was achieved with the 1:24,000 scale Ektachrome IR/Wratten 21 combination, although commission errors, i.e., calling dead trees or dead branches as oak wilt infection centers, remains a problem. The use of other combinations also proved relatively efficient and less costly than ground surveys alone.*

INTRODUCTION

EARLY DETECTION OF OAK WILT, caused by *Ceratocystis fagacearum* (Bretz) Hunt, aids in control of this important tree disease. To date, the detection of oak wilt, as of Dutch elm disease, has relied primarily on ground surveys. Although past studies (Roth, Heller, and Stegall, 1963; Meyer and French, 1967; Latham, French, and Meyer, 1969), have shown that detection by means of aerial photography is apparently as efficient as ground surveys in some cases, no practical system relying totally on aerial photo interpretation has been adopted. One of the greatest problems in ground survey methods has been the relocation of diseased trees for treatment or eradication. The ground survey crew in one year incorrectly located 50 percent of the infection centers on their maps (Latham *et al.*, 1969). In view of this problem, and the cost and time involved in ground survey, aerial photo interpretation offers a feasible alternative. This study was designed to evaluate further the technique of detecting oak wilt by means of aerial photo interpretation and is based on three years of photography.

The site selected for this study, in the city of North Oaks (a suburb of St. Paul, Minnesota), has a high percentage of oaks and a reasonably high incidence of oak wilt. The actual study site included 260 acres, or 14 percent of the total acreage in North Oaks.

* Now with the College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843.

AERIAL PHOTOGRAPHY

Other studies by the senior author have indicated that the combination of a higher-than-Wratten 12 filter with Ektachrome infrared film enhances natural and cultural feature differences and aids in detecting changes in vegetation. Three film/filter combinations were tested in North Oaks in 1971: Ektachrome MS with a Wratten 2A filter (EMS2A), Ektachrome IR with a Wratten 15 filter (EIR15), and Ektachrome IR with a Wratten 21 filter (EIR21). These filters, at 10 percent transmittance, cut out wavelengths below 410, 520, and 540 nanometers respec-

PHOTOGRAMMETRIC EGINEERING AND REMOTE SENSING,
Vol. 43, No. 10, October 1977, pp. 1267-1272.

tively (Eastman Kodak, 1970). Four different scales were flown with each of these combinations: 1:6,000, 1:12,000, 1:24,000, and 1:31,680. Additional photographic and flight data for each of these film/filter/scale combinations are listed in Table 1. It was assumed for interpretation purposes that the other variables noted in Table 1, such as exposure, focal length, date, solar altitude, cloud conditions, and haze, did not significantly affect interpretation results. The imagery from the various combinations appeared to be consistent in color and contrast for similar film/filter/scale combinations.

Results of these tests led the authors to select one combination, EIR21/1:24,000, for use in 1972 over the same study area (Table 1). In 1973 the same film/filter combination (EIR21) was used (Table 1), but the scale was increased to 1:15,840 because of problems encountered in working with smaller scales. Aerial photography in all three years was obtained with a 70mm Hasselblad quadricamera system (Ulliman *et al.*, 1970).

Ground Survey

The oak stands were surveyed on the ground throughout the summers of 1971, 1972, and 1973 by a trained crew of two to four men who located diseased trees on the ground and marked their location on maps. Any single tree or number of trees in a close grouping was identified as an infection center. The ground team did not intepret the aerial photographs or use the results of photo interpretation. When both ground survey and photo interpretation were complete, the results were compared. Where differences were noted, additional checks were made on the ground by the ground survey crews and the photo interpreter.

Aerial Photo Interpretation

The senior author, who was not involved in any way with the original ground surveys, interpreted all imagery.

The 1971, 70mm positive transparencies were viewed over a light table with a pocket

Table 1. Aerial Photography and Flight Condition Variables

Film	Filter (Wratten Number)	Shutter Speed, f no.	Focal Length	Scale (altitude)	Date	Time (CDT)	Solar Alt. (deg.)	Cloud Condition	Haze
Ekta MS	2A	(1/500,4)	50mm	1:6,000 (950′)	8/11/71	0930	47	Widely scattered cumulus	Med.
Ekta IR	15	(1/500,5.6)	50mm	1:6,000 (950′)	8/11/71	0930	47	Widely scattered cumulus	Med.
Ekta IR	21	(1/500,4.5)	50mm	1:6,000 (950′)	8/11/71	0930	47	Widely scattered cumulus	Med.
Ekta MS	2A	(1/500,4)	80mm	1:12,000 (3150′)	8/4/71	0945	50	Very light cirrus	Med.
Ekta IR	15	(1/500,4)	80mm	1:12,000 (3150′)	8/4/71	0945	50	Very light cirrus	Med.
Ekta IR	21	(1/500,4.5)	80mm	1:12,000 (3150′)	8/4/71	0945	50	Very light cirrus	Med.
Ekta MS	2A	(1/500,4.5)	80mm	1:24,000 (6300′)	8/4/71	0955	52	Very light cirrus	Med.
Ekta IR	15	(1/500,4.5)	80mm	1:24,000 (6300′)	8/4/71	0955	52	Very light cirrus	Med.
Ekta IR	21	(1/500,4.5)	80mm	1:24,000 (6300′)	8/4/71	0955	52	Very light cirrus	Med.
Ekta MS	2A	(1/500,4.5)	80mm	1:31,680 (8310′)	8/4/71	1005	52	Very light cirrus	Med.
Ekta IR	15	(1/500,4.5)	80mm	1:31,680 (8310′)	8/4/71	1005	52	Very light cirrus	Med.
Ekta IR	21	(1/500,4.5)	80mm	1:31,680 (8310′)	8/4/71	1005	52	Very light cirrus	Med.
Ekta IR	21	(1/500,4.5)	80mm	1:24,000 (6300′)	8/4/72	1035	54	Very light cumulus	Light
Ekta IR	21	(1/500,4.5)	80mm	1:15,840 (4160′)	7/31/73	1025	56	Widely scattered cumulus	Light

lens stereoscope of the type and quality that the average land manager might possess. Acetate was laid over the 70mm frames and landmarks were indicated so that the acetate could be repositioned later. Individual trees or groups of trees suspected of having oak wilt were marked on the acetate as infection centers. The colors of various vegetation stages on the different film/filter combinations are listed in Table 2. An opaque mask was used around the 70mm frame to prevent stray light from interfering with the interpretation.

In order to reduce bias arising from image analysis by only one interpreter, the order of interpretation proceeded from the combination assumed to have the least interpretation advantage (based on past experience) to the combination having the best interpretation advantage, from small-scale to large-scale, and from the least-studied film/filter combination (EIR21) to the more familiar combinations.

When all film/filter/scale combinations had been interpreted, the overlays were enlarged to a common scale on an overhead projector, and results obtained with the various combinations and by ground survey were compared.

Although in 1971 the EMS2A combination provided the best interpretation results for the large scale (1:6,000), the EIR21 combination proved generally better at the smaller scales of 1:12,000, 1:24,000, and 1:31,680 (Table 3). Accuracy of locating disease centers increased as the scale increased; but commission errors also increased with scale. For example, the EMS2A/1:6,000 combination resulted in detection of 43 of 48 of the infection centers, but at the same time the interpreter identified 44 centers which did not have oak wilt. In order to place this in perspective, a formula was devised to provide a better indication of the efficiency of interpretation:

$$e = i(p) \cdot (i(n)/c)$$

where: e = efficiency of interpretation
i(p) = % of infection centers accurately located on the photos
i(n) = number of infection centers accurately located on the photos
c = number of commission errors

The 1972 and 1973 positive transparencies were interpreted in a manner similar to the 1971 interpretation except that a Bausch and Lomb Zoom 70 Stereoscope was used at 7× magnification, experience from the 1971 interpretation having indicated that a magnification greater than 2× was preferable at the smaller scales. Infection centers again were indicated on acetate overlays, which then were enlarged and compared with the ground truth

Results

The 1971 interpretation (Table 3) indicated the following:

(1) Accuracy of detection of disease centers on aerial photos increased with larger scales.

(2) Omission errors were due to: (a) differences in contrast enhancement with the various film/filter combinations; (b) differences in scale and enlargement of the image; and (c) interpreter oversights. Of the three film/filter combinations, EIR21 provided the best contrast enhancement, followed by EIR15 and EMS2A, at 1:31,680 and 1:24,000; at the 1:12,000 scale, EIR21 and EIR15 were equal in omission errors; and at the 1:6,000 scale, the order of enhancement was reversed. Increased optical magnification would have assisted the interpreter in identification of diseased trees; this was verified by a check of the imagery using a 7× magnification. Lack of magnification accounts somewhat for oversights by the interpreter. In this study, overtopping trees were not a cause of omission errors.

(3) Commission errors increased with larger scales.

(4) The sources of commission error, including identification of dead trees, dead branches, other species, errors in interpretation, and those discovered to have oak wilt the following year, increased in number and variety with larger scales.

(5) Total interpretation time, including actual interpretation and set-up and take-down time, increased with larger scales.

(6) Except at the largest scale, 1:6,000, accuracy of detection of oak wilt infection centers increased from the EMS2A to the EIR15 to the EIR21 film/filter combination. At the largest scale this order was reversed. For the 1:12,000 scale the EIR15 and EIR21 were equally accurate.

(7) Commission errors at the scales 1:6,000, 1:12,000, and 1:31,680 were minimized by use of the EIR15 film/filter combination. At the 1:24,000 scale, the EMS2A film/filter combination had the fewest commission errors.

(8) The only film/filter combination which showed significant differences as to source

TABLE 2. COLOR APPEARANCE OF VARIOUS VEGETATION STAGES OF OAK ON DIFFERENT FILM/FILTER COMBINATIONS

Vegetation Condition (Oak)	Color Appearance on Film/Filter Combinations EMS2A	EIR15	EIR21
Live	green	magenta	orange
Stressed	greenish yellow to yellow	yellow	orangish yellow to yellow
Dead	yellow to brown	yellowish brown to yellowish green	yellowish brown
Defoliated branches	brown to dark gray	yellowish green to blue-green	yellowish brown to light grey
Defoliated branches and exfoliated bark	light gray to white	light gray to white	light gray to white

of commission error was the EIR21 combination, which at the three smaller scales identified a greater number of dead trees as oak wilt infection centers.

(9) Averaged over all film/filter combinations, the 1:24,000 scale exhibited the highest efficiency of interpretation (Table 3).

(10) Interpretation time increased from film/filter combination EMS2A to EIR15 to EIR21 at 1:31,680 and 1:24,000; at 1:12,000, EMS2A and EIR15 were equal; and at 1:6,000, interpretation time for EIR15 was less than for EMS2A.

(11) The interpreter thought that the EIR21 combination was easiest on the eyes and he had the most confidence in it. At increasing altitude the Wratten 21 filter eliminates more of the scattered wavelengths and provides greater contrast enhancement than either the Wratten 2A or 15. This advantage is not apparent at the lower altitudes.

The 1972 interpretation (Table 3) indicated the following:

(1) All disease centers were accurately located on the EIR21/1:24,000 film/filter/scale combination.

(2) Commission errors were relatively high at 21 percent, with most of these in the "dead tree" category.

(3) Interpretation time for this film/filter/scale combination bettered the average for the same combination in the previous year.

The 1973 interpretation (Table 3) indicated the following:

(1) Ninety-six percent of the disease centers were accurately located on the EIR21/1:15,840 film/filter/scale combination.

(2) Omission errors were due to oversights by the interpreter.

(3) Commission errors were very high, due mainly to the identification of dead branches and dead trees.

(4) Interpretation time was greater than in previous years, if the 1971 1:6,000 imagery is excluded from consideration.

Comparative costs for the aerial photo survey and the ground survey appear in Table 4. Although the cost ratio for this 260-acre tract is only 1.3 to 1, the advantage for the aerial photo survey would increase with the size of the area to be surveyed.

DISCUSSION

The study indicates that there is reason for optimism about the operational usefulness of aerial photography in detecting oak wilt. In 1971 only the EMS2A/1:6,000 film/filter/scale combination showed reasonably accurate detection of infection centers, but it also had a high number of commission errors. An attempt was made to determine the optimum combination based on a maximum number of correct interpretations and a minimum number of commission errors. The formula, noted earlier, was devised to determine the efficiency of interpretation for the film/filter/scale combinations. That method indicated the EIR21/1:24,000 combination would be the most efficient for a trained interpreter.

In 1972 all of the disease centers were located on the EIR21/1:24,000 combination. Commission errors were relatively high at 21 percent, largely because the interpreter wanted to insure detection of 100 percent of the infection centers. Dead trees accounted for most of the commission errors.

The 1:24,000 scale proved difficult to work with because of (a) small detail, (b) lack of space for delineating and symbolizing on the acetate overlay, and (c) the necessity of enlarging the overlay in order to compare it against ground truth information. It was also a little more difficult to locate a suspect tree

TABLE 3. RESULTS OF PHOTO INTERPRETATION ON THE VARIOUS FILM/FILTER/SCALE COMBINATIONS.

			Disease centers located on photo and on ground[1]		Ommission errors		Cmmission errors	Sources of Commission Error								
Date	Scale	Film/ Filter	No.	%	No.	%	No.	Detected dead tree	Detected dead branches	Detected other species	Detected in following year with oak wilt[2]	Error in interpretation (detected either under-growth or shadows)	Interpretation efficiency[3]	No. of 70mm frames interpreted	Total interpretation time (min.)	Order of interpretation
8/11/71	1:6,000	EMS2A	43	90	5	10	44	11	10	3	6	14	.88	12	66	12
		EIR15	37	77	11	23	42	10	13	2	4	13	.68	12	64	11
		EIR21	35	73	13	27	44	11	10	2	6	15	.58	12	67	10
8/4/71	1:12,000	EMS2A	29	60	19	40	24	7	3	1	5	8	.73	5	50	9
		EIR15	35	73	13	27	22	8	2	2	5	5	1.16	5	50	8
		EIR21	35	73	13	27	26	10	4	1	5	6	.99	5	54	7
8/4/71	1:24,000	EMS2A	20	42	28	58	6	3	0	0	3	0	1.40	3	43	6
		EIR15	25	52	23	48	10	2	0	0	5	3	1.30	3	48	5
		EIR21	30	62	18	38	10	5	0	0	3	2	1.86	3	49	4
8/4/71	1:31,680	EMS2A	18	38	30	62	6	3	1	0	2	0	1.14	3	39	3
		EIR15	19	40	29	60	4	3	0	0	1	0	1.90	3	45	2
		EIR21	21	44	27	56	9	5	2	0	2	0	1.03	3	52	1
8/4/72	1:24,000	EIR21	33	100	0	0	21	17	1	0	0	3	1.57	3	45	13
7/31/73	1:15,840	EIR21	47	96	2	4	61	21	28	5	4	3	.74	4	59	14

[1] Total number of disease centers: 1971=48; 1972=33; 1973=49.
[2] These trees, although not determined to have wilt according to that year's ground survey, did have wilt the following year.
[3] See text under Aerial Photo Interpretation for explanation.

TABLE 4. COST COMPARISON BETWEEN AERIAL PHOTO INTERPRETATION AND GROUND SURVEYS FOR DETECTING OAK WILT.

Cost factor	Ground Survey		Aerial Photo Survey	
Aircraft and automobile transportation	30 miles/day for 2 days @ $0.10/mile for auto	= $ 6.00	30 miles/day for 1 day @ $0.10/mile for auto	= $ 3.00
			½ hour for aircraft @ $50.00/hour	= $25.00
Film and processing	——			= $21.00
Aerial photo interpretation	——		1 hour @ $7.00/hour	= $ 7.00
Ground survey	27 manhours @ $3.21/hour	= $86.67	4 manhours @ $3.21/hour	= $12.84
Total cost		$92.67		$68.84
Cost ratio		1.3		1.0

on the ground when using the small-scale aerial photo as a guide.

Although the 1973 interpretation detected 96 percent of the oak wilt infections centers, commission errors were very high (61 percent). Commission errors are correlated with larger scales, and may not be too serious a problem because it is an advantage to know where inactive centers are as well as active centers. In many cases, the detected dead trees were due to previous oak wilt infection.

Based on the three years' experience, interpretation efficiency has been highest with the EIR21/1:24,000 film/filter/scale combination. Given the facts that the 1:24,000 scale takes less time to interpret and costs slightly less to obtain, the EIR21/1:24,000 film/filter/scale would be the most advantageous to use if the problems of that scale's format size can be overcome. If commission errors are not considered too serious a problem, a larger scale, i.e., 1:15,840, because of its greater ease in handling and only slightly greater cost, may prove satisfactory. However, commission errors may be costly on a large control program unless there is another reason to locate dead trees and those with dead branches.

One of the weaknesses in this study was the use of only one interpreter. This factor must be considered in future studies, especially with the use of an unusual film/filter combination such as EIR21. The EIR21 combination seemed to provide better contrast enhancement at smaller scales for this interpreter, but it may not for others.

Another seemingly obvious weakness of the study was the fact that the interpreter looked at the same scene twelve times in 1971. However, the order of interpretation was from the small scale to the large scale, and the advantage, if there was any, was given to the large scale. Since the interpretation efficiency increased with the smaller scales up to 1:24,000 at least, this would support the good interpretation qualities of the smaller scales. In 1972 and 1973 the scene was looked at only once for each of the relatively small scales.

Compared to ground surveys, the use of aerial photo interpretation is a very feasible and less costly method for detecting oak wilt infection centers. Depending on the scale used, a few operational techniques may have to be refined but, considering the importance of detection systems for controlling diseases such as oak wilt, aerial photography merits further consideration.

ACKNOWLEDGMENTS

Appreciation is expressed to our colleagues Dr. Robert Douglass, Robert Latham, Greg Johnson, and Bruce Gerbig for obtaining the aerial photography; and to Dr. Merle P. Meyer for his advice, review of the manuscript, and general support. Funds for this project were provided under provisions of the McIntire-Stennis Law (P.O. 87-788). This paper was published as Scientific Journal Series Paper No. 9152 of the University of Minnesota Agricultural Experiment Station, St. Paul, MN 55108.

REFERENCES

Eastman Kodak Co. 1970. *Kodak filters for scientific and technical uses*. Kodak Publication No. B-3. Rochester, N. Y. 88 pp.

Latham, R. P., D. W. French, and M. P. Meyer. 1969. Detecting oak wilt by false color infrared aerial photography. *Journal of the Minnesota Academy of Sciences*, 36(1): 14-15.

Meyer, M. P., and D. W. French. 1967. Detection of diseased trees. *Photogrammetric Engineering*, 32(9): 1035-1040.

Roth, E. R., R. C. Heller, and W. A. Stegall. 1963. Color photography for oak wilt detection. *Journal of Forestry*, 61(10): 774, 776, 778.

Ulliman, J. J., R. P. Latham, and M. P. Meyer. 1970. 70mm quadricamera system. *Photogrammetric Engineering* 36(1): 49-54.