detic Restraint Method and also indicates why the method was so named.

RESULTS OBTAINED

The Direct Geodetic Restraint Method was first tested on a series of 26 problems. This initial series was made up from the fictitious data developed by Earl Church and given in the Harvard Computational Laboratory Report No. 25. Correct photographic-coordinates and ground-point positions were used in these tests, each of which was a minimum theoretical case. The tests ranged in complexity from the resection of a single photograph to the solution of a block of eight photographs. In addition to some normal cases, a number of bizarre problems were included, as well as a few that depended for solution upon exposure station restraints. The results of this series of tests are available at the U. S. Geological Survey's Washington office.

A second series of tests is now being conducted to determine the practical range within which the initial estimates must fall. A report on this series will soon be available.

A preliminary test using photography over the Arizona test area is also under way. The photographic coordinate data was measured by the U. S. Army Map Service on a Cambridge Stereocomparator. The results of this test will be available in the near future.

The results obtained with the Direct Geodetic Restraint Method to date have been satisfactory. It is contemplated that the present computer program will be used for additional testing, largely in relation to errors in the physical components of the system, the propagation of errors, and data weighting methods. It is expected that tests under production conditions will be possible in approximately one year.

In closing, I would like to acknowledge the important contributions to this work of the other two members of the U. S. Geological Survey's research team: Mr. Robert C. Eller and Mr. David Handwerker.

*An Evaluation of Aerial Photography for Detecting Southern Pine Beetle Damage**

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U. S. Dept. of Agriculture

(*Abstract is on next page*)

INTRODUCTION

FOREST insects are insidious killers of our Nation's timber. The most recent compilation of statistics (5) showed that they were responsible for killing seven times the sawtimber volume as that consumed by fire. In the South alone, during the past 5 years, the southern pine beetle (*Dendroctonus frontalis*, Zimm) killed more than 400 million board-feet of pine timber annually (3). How are we going to reduce these losses to tolerable levels? How can we best detect outbreaks while they are small and easy to control? The old army maxim, "Those that get there fustest with the mostest, win the battles!" applies equally well in the battle with the beetles. Because bark-beetle epidemics frequently cover large areas of timberland and fluctuate widely in amount and degree of damage, an aerial method to discover and locate outbreaks rapidly has more merit than the slow and costly ground methods used in the past.

Two aerial approaches for speeding up detection are possible. The first involves visual observation from the air by trained observers who plot suspected infestations on maps. The second involves taking special aerial photographs on which interpreters try to locate the infestations. The first method is inexpensive

* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 8 to 11, 1959. This paper is a part of the Panel on The Application of Color Photography in Photo Interpretation.

and is now used in the absence of better methods, but its plotting accuracy is of a fairly low order (1). The second method has found wide acceptance in fields related to forestry, such as geology, soils mapping, and military intelligence, so that it seemed worthwhile to investigate its potential for making forest insect surveys.

The idea of taking pictures of tree mortality from the air is not new. Keen, in 1920, leaned over the side of a surplus Jenny and snapped obliques of bark-beetle damage in eastern California with encouraging results. For a while after World War II, modified infrared aerial photography seemed to be a panacea for all forest-inventory problems; however, its limitations as well as advantages were soon discovered.

Abstract: *A large scale experiment was set up to test the usefulness of special aerial photography taken to locate and appraise insect-killed timber in the mountains of North Carolina. Previous tests had narrowed the selection of films down to color and panchromatic with a red filter (A-25). Interpretations made on aerial color film were more accurate than those made on panchromatic. A scale of 1:7,920 was the best compromise of accuracy and cost. While the color photography was more expensive than aerial sketch-mapping methods currently used, it was also more accurate. Ground cruising proved to be the most expensive and time-consuming survey method. It was concluded that color photography would be most useful where it is necessary to map the location of infested trees with a high degree of accuracy—particularly on expensive bark beetle control operations.*

Because of infrared film's reputed ability to separate reds and infrared from other colors, Heller and Bean (2) made limited tests of bark beetle damage in Texas during 1950. The tests revealed that infrared film exposed through a red (A-25) or minus blue filter was of no value in detecting faded pine trees. Panchromatic film with a red (A-25) filter gave somewhat better results, but Ektachrome Aero film seemed to offer the best possibilities of the three films tested.

In 1950, Wear and Bongberg (7) were trying similar aerial photography tests for detecting western pine-beetle damage on ponderosa pine in eastern Oregon and California. They found that Super XX film used with A-25, G, and K-1 filters was promising at vertical scales of 1:2,500, 1:5,000, and 1:7,500. Color film was not suitable over some of the light-colored soils. However, 3 years later color film taken at 1:7,920 scale in western Oregon proved highly useful in salvaging beetle-killed Douglas-fir timber.

Waters, *et al.* (6) found that aerial color photography could be used to detect heavy and moderate spruce budworm defoliation of fir trees in northern Maine. Subsequent tests during 1957 indicated that 70 mm. high-speed shutter cameras with the newer and more sensitive color films provided more accurate appraisal of spruce budworm defoliation than was possible with conventional cameras and films.

Other fields related to forestry are turning to color photography to increase interpretation accuracy. Ray and Fischer (4) found that aerial color photography has significant uses in geologic interpretation not possible with available black and white.

The objectives of this study were designed to answer the following questions: Is the aerial photographic approach the best one to use for detecting bark-beetle damage? How does it compare in accuracy, manpower requirements, and cost, with ground and other aerial methods? Of the photographic methods, is color photography significantly better than panchromatic photography? How can the photographic method be applied to sampling surveys and control programs? What scales and techniques are necessary in the use of color photography in the field and in the office?

Physical Characteristics of the Study Area

A study area of approximately 3,546 acres was selected in western North Carolina near Brevard. Within the boundaries of the area were 36 active southern pine-beetle infestations ranging in size from 1 to 189 dead pines. The topography of the area is relatively rough, and above-sea-level elevations range from 2,300 to 3,500 feet; with an average of approximately 2,800 feet. The major forest type is upland hardwood which occupies 80 to 85 per cent of the area. Major hardwood species include red, black, white and chestnut oaks, hickory, yellow-poplar, black gum, and maple. Shortleaf, pitch, and Virginia pine are scattered throughout the area and are present as pure types mainly along ridgetops, in old fields, and on southerly facing slopes.

METHODS

This study was designed to compare ground-survey data derived from field inspection with information derived from aerial photographic techniques under test. For a valid statistical test it was necessary to use an area with 30 to 50 active spots that had a variable number of trees per spot. A spot in survey terminology is synonymous with a southern pine-beetle infestation. It represents a fading, off-color pine tree or group of pine trees which may be infested with the southern pine-beetle, and mav serve as a nucleus for additional tree killing. Since the only known active southern pine-beetle outbreak at the time was in western North Carolina, our study was restricted to a region that had a preponderance of hardwoods, and was difficult on the ground because of rugged topography.

Timing of the ground survey and aerial photography was critical. The fading of tree foliage in the spring and summer can occur in a 2- to 4-week period, depending on weather, number of beetle attacks, and tree vigor. Therefore, if the data were to be comparable, the ground cruise and aerial photography had to be completed as closely together as possible. This restricted the study to an area that an 8-man ground crew could cover in a 2- to 4-week period. Aerial photographs of the active beetle infestations were taken from 2 to 4 weeks after ground inspection. Thus, there was a possibility of some change in foliage color and needle complement during the period between the field inspection and photographing. This lapse of time favored the ground method rather than the photographic, and should be recalled when considering the results of this test.

The ground cruise was timed to coincide as nearly as possible with foliage discoloration and the occurrence of fresh pitch tubes on trees killed by the spring generation of beetles.

GROUND SURVEY

Base lines with stations 5 chains apart were laid out to traverse the area on the south, the north, and through the center. Prior to the ground cruise, an intensive aerial reconaissance was made over the area to eliminate large, continuous areas of hardwood from ground inspection. Cruise lines were run on azimuths of 45° and 225° from the center base-line except in areas eliminated from ground inspection by the aerial reconnaissance.

The ground cruise was completed between June 1 and June 25, 1955 by two 4-man crews. Each crew was made up of a compass-man-tallyman, rear chainman, and 2 lateral spotters at $1\frac{1}{2}$ chains on each side of the survey traverse line. All beetle-killed pine trees observed along the cruise lines were located on the mapping diagram of a field tally form, and the dead trees tallied by diameter breast-high, crown position, crown diameter, color of foliage, and foliage per cent classes (foliage remaining). Green trees with fresh beetle attacks, adjacent to killed pines, were also tallied. Each tree tallied was marked with a band of fire-orange paint.

A large-scale base map (1:7,920) was prepared by transferring details from the field maps and plane table diagrams to a photographic blowup of a part of a TVA $7\frac{1}{2}$-minute quadrangle sheet for the area (Figure 1). This base map was used later to check the accuracy of photo interpretation.

AERIAL PHOTOGRAPHY

Scales of 1:3,960 (16 inches = 1 mile), 1:7,920 (8 inches = 1 mile), and 1:15,840 (4 inches = 1 mile) were chosen for testing because they give a good range in scale effect and are convenient for linear measurements in chains.

The photography plan provided for full stereoscopic coverage of the study area in color at the 3 scales and for 60-per cent end lap and 50-per cent side lap (Figure 2). It also provided for the use of panchromatic film with an A-25 (red) filter along 5 predetermined flight lines at scales of 1:3,960 and 1:7,920. Infrared photography was not included in the test because previous experience had indicated that it is of no value in differentiating dead pine crowns from healthy ones.

The aerial camera was an F-56 (Fairchild) with an $8\frac{1}{4}$-inch, focal-length lens and a $6\frac{5}{8}$- by 7-inch format. The airplane was a Cessna 195 which had been modified for aerial photography. The photographs were taken between the hours of 10:00 A.M. and 2:30 P.M. to avoid unusually long shadows. The film used in the test was processed by Forest Service personnel.

TEST OF PANCHROMATIC AND COLOR FILM

The object of this test, referred to hereafter as the "film test," was to determine and com-

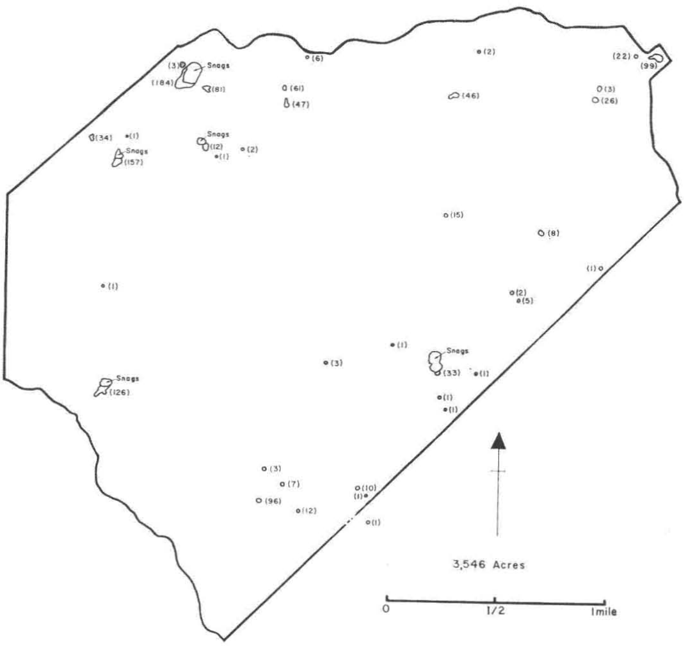

FIG. 1. Southern pine beetle study area near Brevard, N. C., showing active beetle infestations. Numbers alongside infestations indicate how many trees had been killed.

pare the interpretation accuracies of photographs taken with panchromatic and color film.

METHODS

Nine small areas, each containing about 56 acres, were selected within the boundaries of the 3,546-acre study area from color photos (1:3,960). Seven of the areas had one or more infestations present; the remaining two were chosen to represent conditions where no insect damage existed. Since each of the nine areas were subjected to four inspections by each interpreter, the areas were randomized for each scale and film, to avoid recollections of earlier observations. For the same reason, the small-scale panchromatic photos were examined first, the large-scale panchromatic next, then the small-scale color, and finally the large-scale color.

Transparent templates, measuring $6\frac{5}{8}$ by 7 inches, were designed to simplify scanning and plotting; the central part of each template was divided into 15 numbered blocks, and each block in turn was further subdivided into 4 smaller units. Each template was taped to the appropriate photo and had fiducial marks for matching those on the aerial photo. A tally form (Figure 3), similar in all respects to the template, was used for recording an interpreter's observations. At the bottom of the

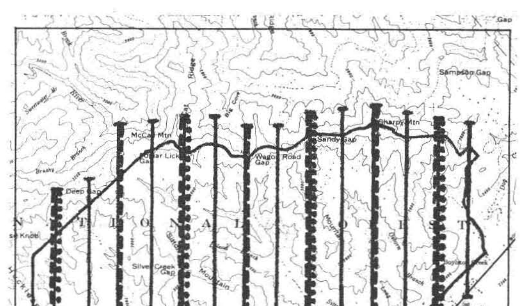

FIG. 2. Locations of flight lines over Brevard study area at scales 1:3,960, 1:7,920, and 1:15,840 with 50-per cent side lap.

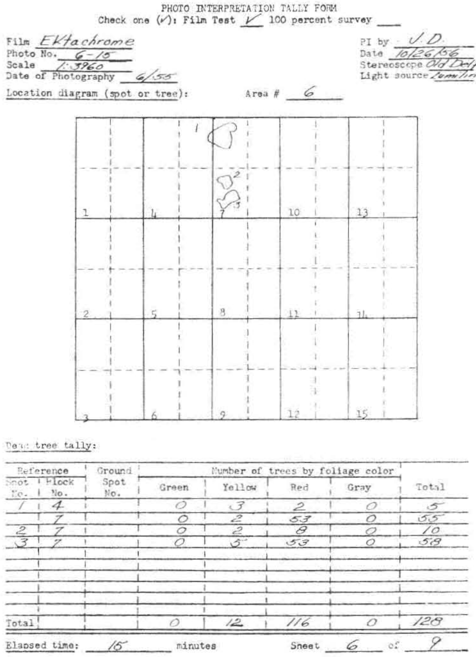

PHOTO INTERPRETATION TALLY FORM
Check one (✓): Film Test ✓ 100 percent survey ___

Film Ektachrome
Photo No. 6-15
Scale 1:3960
Date of Photography 6/55

PI by J.D.
Date 10/26/56
Stereoscope Old Delft
Light source Lumiline

Location diagram (spot or tree): Area # 6

Dead tree tally:

Reference: Spot No.	Reference: Block No.	Ground Spot No.	Number of trees by foliage color: Green	Yellow	Red	Gray	Total
1	4		0	3	2	0	5
	7		0	2	53	0	55
2	7		0	2	8	0	10
3	7		0	5	53	0	58
Total			0	12	116	0	128

Elapsed time: 15 minutes Sheet 6 of 9

FIG. 3. Photo interpretation on tally form.

tally form, spaces were provided for entering infestation numbers according to their block location and the tree counts within each infestation. The area corners and blocks established on the 1:3,960 color photos were transferred to the smaller scale color photos by stereoscopic inspection and thence to the panchromatic photos; this procedure made certain that identical areas were interpreted at both scales and for both films.

Photographic interpretation of insect damage is mainly a subjective process and not a quantitative one. Consequently, it is subject to both human and measurement errors, the variance of which must be taken into account and kept to a minimum. In this experiment, six interpreters viewed all scales and film combinations. However, because a difference existed among them, they were divided into two groups of 3 men each. One group was comprised of those who had used color film and the associated equipment before, and who were familiar with the typical appearance of beetle-killed trees. Those in the second group were experienced in forest photo interpretation of small-scale black and white photographs; but they had not used color film previously nor were they familiar with the appearance of insect-damaged trees on photographs. A short training session was given the less experienced men prior to the film test, by having them practice on a sample that had film and scale combinations similar to the study area.

All 6 of the interpreters used the same viewing equipment (Figure 4) which consisted of the following:

1. Old Delft Scanning Stereoscopes with $1\frac{1}{2}$ and $4\frac{1}{2}$ power magnification.
2. A 2-tube fluorescent desk lamp to provide reflected illumination for panchromatic photos.
3. A 16-tube fluorescent (3,400°K) light table with individual switching to provide even illumination over color transparencies that varied in density.
4. Hinged $\frac{1}{8}$-inch Plexiglas covers to hold transparent templates and color photos in place during interpretation.

An example can best illustrate how the photo interpretation proceeded. Photographs were scanned in an orderly manner from block to block. Suspected infestations were located and drawn to approximate size on tally forms. Infestations were numbered consecutively and the number of trees involved in each spot was counted. Alternate photos of adjacent lines were often needed to produce stereo coverage at the 1:3,960 and sometimes at the 1:7,920 scales.

Following the interpretation of film for all nine areas, the tally-form diagrams were checked against master diagrams of the ground cruise.

RESULTS

Accuracy in locating the 13 spots (infestations) will be considered first. To be considered a correct observation, a spot had to be identified and plotted accurately on the tally diagram as compared with the ground cruise. Summaries were made of the correct number of spots interpreted and trees counted; they were also made of the omission and commission errors by spots and trees.

Accuracy of locating infestations. Where correctly plotted observations were tabulated and the data were subjected to analysis of variance, highly significant differences were found between the accuracies involved in locating spots on color film and those on black and white. This was true regardless of how the data were grouped—by all 6 interpreters combined, by the experienced ones only, or by the inexperienced ones only. In all cases, the number of spots accurately located on color film was closer to the number recorded in the ground-survey than was the number accurately located on the panchromatic. Significant differences were also found among the

FIG. 4. Aerial color transparencies in Plexiglas holders being scanned with an Old Delft Stereoscope on a fluorescent light table.

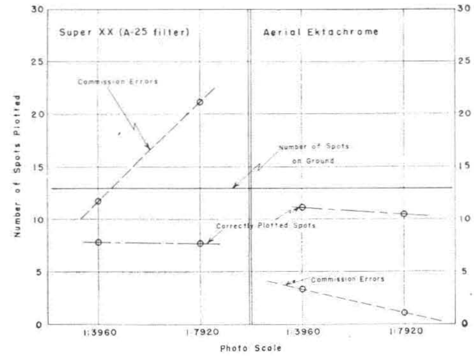

FIG. 5. Accuracy of locating southern pine beetle infestations on two films and at two scales (average of 6 interpreters).

interpreters, especially between the groups of experienced and inexperienced ones; however, no differences showed up among the experienced ones alone. The experienced interpreters plotted more spots accurately than the inexperienced. Scale had no apparent effect on plotting accuracy; the 1:7,920 scale was just as effective as the 1:3,960 scale.

An analysis of commission errors* showed that an average of 17 spots were mistakenly identified as infestations on panchromatic photos and only 2 on color by the interpreters. Differences in committed errors among the interpreters were not significant. The relationship between the number of spots found on the ground and the numbers plotted correctly and incorrectly from aerial photos is shown in Figure 5. Commission errors are important when comparing different assessment methods.

By grouping the 13 infestations shown in Table 1 into 5 size classes, and plotting them (Figure 6) it can be seen that the color film interpretations followed the ground data more closely than did the panchromatic ones. Only the largest spots (51 trees or more) were interpreted similarly on both films.

Accuracy of counting trees. The six interpreters also attempted to count the faded pine trees within each infestation. This is more difficult than plotting spot locations, because spots offer fairly large targets on photos. Tree counts are least accurate in dense stands (8), but even in fairly open stands with overtopped and intermediate crown trees they lack accuracy. To determine which of the films and scales were nearest the ground count, an analysis identical with the one for spot data was made for the tree count.

Differences in tree counts among the six interpreters were highly significant. Even when the experienced and inexperienced men were grouped separately, significant differences were still apparent (Figure 7). However, for color film only, estimates by experienced interpreters were close enough to show no difference.

Color film gave significantly better results

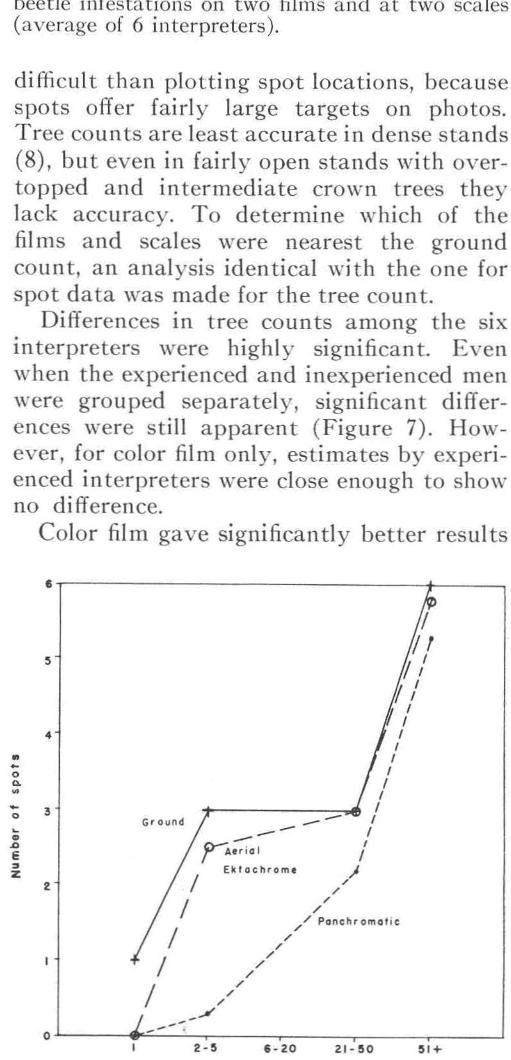

FIG. 6. Average number of southern pine beetle infestations located on panchromatic and color film (average of 6 interpreters).

* *Commission error.* An incorrect interpretation caused by an interpreter tallying hardwood trees, openings in the forest canopy, snag patches, etc., as a faded pine tree.

Omission error. Interpretation errors that result from not being able to count as many spots or trees on the photos, as occur on the ground. For example, in spot counts, these are infestations that were not detected on the photographs. In tree counts, fewer trees are seen on the photographs than are actually present on the ground.

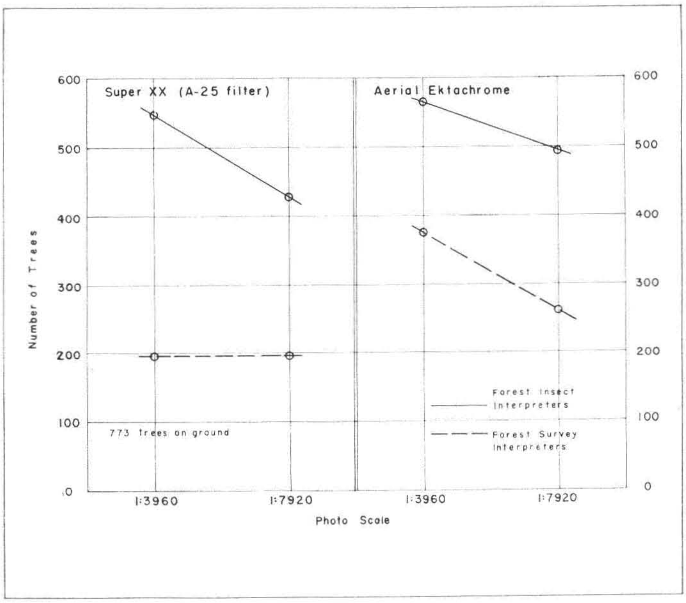

FIG. 7. Difference in tree counts between 3 experienced interpreters and 3 inexperienced interpreters.

than panchromatic; almost 1,000 more trees were counted on color film by the 6 men. In addition it took 20 per cent less time to interpret the color transparencies than the black and white prints. By scale and film, counting accuracy ranked as follows:

1. 1:3,960 Color film
2. 1:7,920 Color film
3. 1:3,960 Super XX (A-25 filter)
4. 1:7,920 Super XX (A-25 filter)

A highly significant difference in commission errors was found between the two film types. A major reason for the greater number of these errors on the panchromatic photos was that hardwood crowns frequently photograph light in tone, and are difficult to separate from infested pine trees that also appear light in tone. On color film, hardwoods appear light green and are readily separated from the dying pines which show up as yellow, red, or brown. No differences in commission errors were apparent in comparing scales or interpreters.

COLOR PHOTOGRAPHY SCALE TEST

A similar interpretation test was conducted over the entire 3,500 acre area instead of just the 9 selected plots. In this test 3 scales (1:3,960, 1:7,920, 1:15,840) of color film were examined by the 3 experienced interpreters. The 1:15,840 scale which is often referred to as the best compromise scale for forestry was included to determine whether it is also suitable for detecting and counting dead pine trees.

METHODS

Preceding photo interpretation, boundaries of the study area were delineated on alternate transparencies in India ink. The central parts of these photographs were then delineated to rule out any possibility of interpreting the same area more than once.

Transparent templates similar in design to those described previously but larger in size (6 by 6½ inches) were made to cover the centers of alternate photographs. The same tally form illustrated in Figure 3 was also used for this phase of the study.

Bias in interpretation was prevented by having interpreters proceed in their interpretations from the smallest scale to the largest. Each interpretation was also kept independent of all others, and the order of interpretation was randomized by photographic line numbers for each scale.

In practice, an interpretation was made as follows: A transparent template was attached to the underside of the top half of a Plexiglas sandwich used to hold the transparency flat. Then a transparency was inserted and oriented by fiducial marks showing on both it and the template. Using an Old Delft Stereoscope, the interpreter scanned the areas outlined in black ink, proceeding from the lowest to the highest numbered template block within the outlined areas. When a suspected southern pine beetle spot or fader* was located, it was sketched on the location diagram of the tally form within the numbered block indicated on the template.

Accuracy of photo interpretation was determined by orienting each tally sheet with and checking it against the base map described earlier. It was recorded as an accurate interpretation when a spot on the photograph corresponded with one on the base map. Spots showing up on photographs, which did not correspond with those on the base map, were counted as commission errors, and conversely, those which were located on the base map, and which were not spotted on the photographs, were counted as errors of omission.

When the data were summarized it was apparent that many more "commission errors" showed up on all 3 scales than would normally be expected. The possibility that the spots discovered on the photographs may have been caused by missing them on the ground survey prompted another visit to the area in November, 1957. Almost half of the committed spots were determined to have been killed by bark beetles. Some of these errors attributable to the ground method may have been caused by tree fading occurring between the time of the ground work and the aerial photography; however, this does point up the fact that errors in ground surveys do occur. Adjustments were made to the original ground survey and the interpretation data were resummarized.

RESULTS

The accuracy of spot detection and plotting by the 3 interpreters is shown in Table 1. Analysis of variance for correctly plotted spots indicated a highly significant difference in accuracy by scale but no difference among interpreters.

The accuracy of detection by spot-size varied considerably, with single trees being the most difficult to detect. With increasing spot-size, differences were less noticeable. Nevertheless, an analysis of variance showed that these differences were highly significant.

Commission errors are probably the most costly ones. When photo intelligence is used to direct control crews on the ground, commission errors unfortunately result in unproductive time and seriously retard control efforts. For 1:7,920 scale photos, the average number of commission errors for 3 interpreters was 9; of these, 3 were inactive beetle kills that were called active (Figure 8). This represents one-third of the commission errors. Although they were called snag patches† in the ground examination, a few needles clinging to the twigs in the upper crowns, combined with woodpecker damage, could easily give these spots the appearance of active infestations when observed from the air. Such questionable spots as these, probably should be placed in a separate category for a limited ground-check. For purposes of this study, however, they must be classed as errors.

TABLE 1

PERCENTAGE OF ACTIVE INFESTATIONS AND BEETLE-KILLED TREES ACCURATELY DETECTED AND LOCATED ON COLOR FILM AT 3 DIFFERENT SCALES BY 3 EXPERIENCED PHOTO INTERPRETERS

Scale and subject	*Photo interpreter* 1	*Photo interpreter* 2	*Photo interpreter* 3	*Average accuracy*
1:3,960—				
Spots	79	87	82	82
Trees	75	79	107	87
1:7,920—				
Spots	63	66	66	65
Trees	67	65	62	65
1:15,840—				
Spots	58	55	55	56
Trees	51	39	39	43

Commission errors were lowest for the 1:3,960 scale and highest for the 1:15,840 (Figure 8). These differences by interpreters were also significant.

Accuracy of tree counts. Counts of dead pine trees (faders) made from 1:3,960 scale photos were more accurate than those made from

* Fader. A dead pine tree whose foliage has changed from green to yellow, red, or brown; it may or may not have been beetle infested. On color film the various colors are frequently distinguishable; on panchromatic film they appear as lighter tones of gray in contrast to the darker gray of healthy trees.

† *Snag.* A pine tree that has lost all or almost all of its needles. (Hardwoods also become snags, but they differ from pine in appearance on color photographs mainly because they look gray instead of brown and generally are larger crowned and have different branching characteristics.) Snag patches are often found around an active infestation, and more or less substantiate the fact that adjacent fading trees are under bark-beetle attack; they may also be found occupying a site where an old infestation either died out, or the beetle population moved on to new host trees. Depending upon the needles remaining and woodpecker damage in the upper crown, these patches may appear as active infestations on photographs.

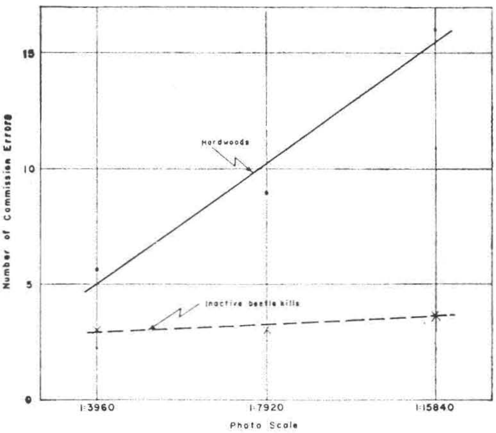

FIG. 8. Average number of instances where interpreters incorrectly plotted hardwoods or dead pines (from which beetles had already emerged) as active bark beetle infestations.

either of the smaller scale photos (Figure 9). On the average, 3 interpreters counted 87 per cent of the beetle-killed pine trees on the 1:3,960 scale photos, 65 per cent on the 1:7,920, and 43 per cent on the 1:15,840. There was very little difference in the number of commission errors among the 3 scales.

PHOTO TO GROUND CORRECTIONS

Estimates of the number of infested trees in individual spot locations can be made reliable by adjusting photo estimates to what actually occurs on the ground, by means of a straight-line regression. This was shown when regressions were computed from combined data of the 3 interpreters (Figure 10) and checked by analysis of covariance. Results showed first, that there was no significant difference in regression line levels for the 3 interpreters; however, for the 1:3,960 scale there was a very significant difference in slopes. Second, the analysis of co-variance for the 1:7,920 and 1:15,840 scales showed no significant differences between levels or slopes for the 3 interpreters. These analyses indicate that to adjust individual interpreter estimates made from 1:3,960 scale photographs, individual regression lines must be computed (Figure 11). When adjusting estimates made from the smaller scale photographs, the average regression lines may be used for all three interpreters.

COSTS

In determining aerial photography costs, separate analyses were made of costs with color and panchromatic film and at different scales. Table 2 shows the costs to the Forest Service, U.S.D.A. that were incurred in taking and interpreting the photographs needed on the study area. They indicate that there is very little difference between the two films; these costs would be narrowed further by commercial firms who would add their legitimate costs common to both films (standby time, overhead, depreciation, and profit).

Film cost and time to complete photo interpretation contribute most to the difference in cost between aerial color photography scales. For example, it took 3 interpreters, on the average, slightly more than $2\frac{1}{2}$ times as

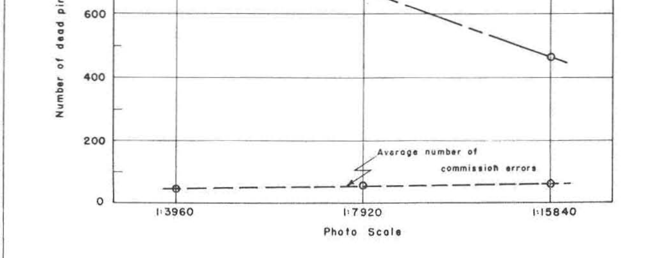

FIG. 9. Average number of beetle-killed pine trees (red and yellow faders) counted and average number of commission errors made by 3 interpreters at 3 photo scales on color film.

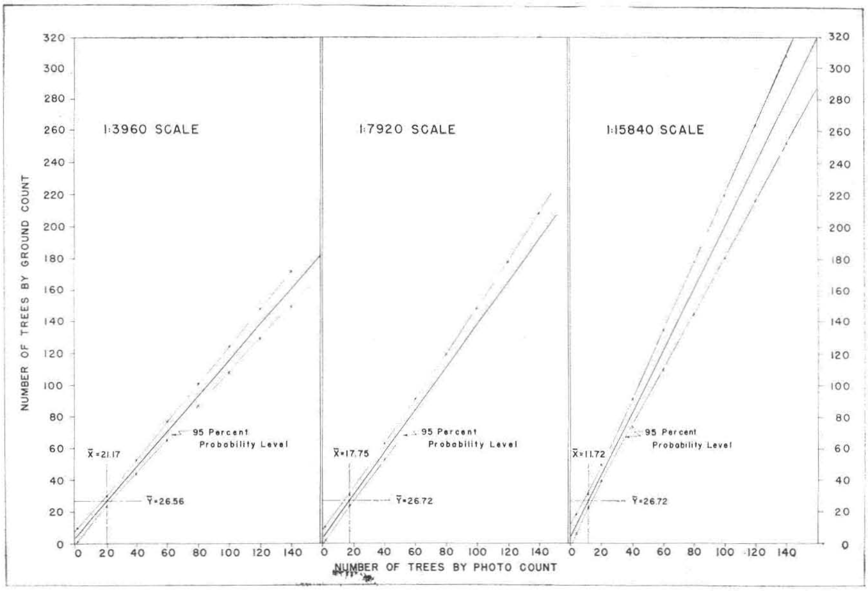

FIG. 10. Regression lines for the relationship between photo and ground counts of dead pine trees (based on 108, 111, and 111 combined independent observations, respectively, for 3 photo interpreters).

long to interpret 208 photos taken at a scale of 1:3,960 as it did to interpret 47 taken at 1:7,920 (Table 3). This would make a significant difference in total cost when a large area is involved.

An analysis was also made of comparative costs required in detecting and locating southern pine-beetle infestations by aerial photography, by ground cruising, and by sketch-mapping (Table 4) on a hypothetical outbreak covering about 50,000 acres. The

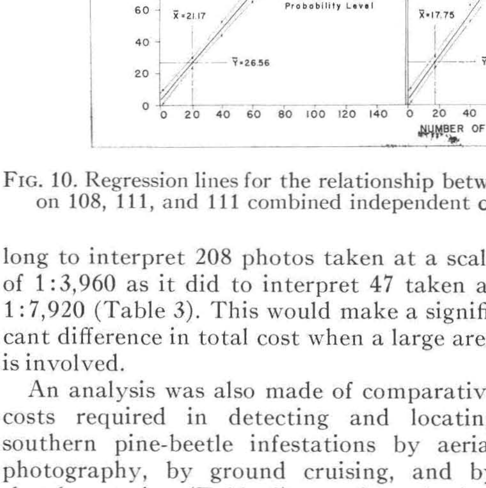

FIG. 11. Relationship of photo tree count to ground tree count—regression lines for each of 3 photo interpreters at 1:3,960 scale.

cost of photography was based on an average of two estimates submitted by well-known

TABLE 2

COMPARATIVE COST TO PHOTOGRAPH AND INTERPRET THE 3,546 ACRE TEST AREA IN COLOR AND PANCHROMATIC FILM, BASED ON CONDITIONS SHOWN BELOW

Photo scale	*Color film*		*Panchromatic film*	
	Total	*Per acre*	*Total*	*Per acre*
		Dollars		
1:3,960	361.17	0.102	314.62	0.088
1:7,920	139.39	.039	118.32	.033
1:15,840	87.04	.025	71.57	0.20

[1] Cost to Forest Service, U.S.D.A. These are government costs and do not include standby time, overhead, profit, and cross country flight time between the home base and field base.

[2] Includes film, pilot and photographer salaries—no standby time, direct aircraft costs (gas, oil, maintenance, and overhaul), insurance, and depreciation. The cost per airplane hour ($20.11) for a Cessna 195 was taken from Cessna Aircraft Co. operating costs data sheet, 1953.

[3] Includes processing chemicals, and salary for a technician to process, edit, and mark film with reference numbers.

[4] Photo interpretation costs determined by multiplying average interpretation time (Table 3) by hourly rate of an interpreter. Cost of delineating area boundaries was also added.

TABLE 3

TIME REQUIRED BY 3 EXPERIENCED INTERPRETERS TO INTERPRET COLOR PPHOTOGRAPHS TAKEN AT 3 SCALES AND 100-PER CENT COVERAGE OF THE 3,546-ACRE TEST AREA

Photo scale	*Total photos*	*Inter-preter #1*	*Inter-preter #2*	*Inter-preter #3*	*Average time*
			Hours		
1:3,960	208	12.0	15.9	11.1	13.0
1:7,920	47	5.0	5.8	4.0	4.9
1:15,840	19	2.6	3.5	2.2	2.8

aerial photographic firms. It included costs of photo preparation and interpretation as obtained in this study. Ground survey cost estimates were based on the time required for a 3-man crew, cruising at the rate of 2 miles per 8-hour day, and covering 5 chain-wide cruising strips to examine 100 per cent of the outbreak area on the ground.

Aerial sketch-mapping costs were based on the time required for a rental aircraft and pilot, plus two observers, to cover the same areas while flying 90 miles per hour along flight lines spaced one mile apart.

Table 4 reveals that a ground cruise with an expected accuracy of 100 per cent would cost nearly 5 times as much as 1:7,920-scale aerial color photography with an expected accuracy of 80 per cent. This same color photography would cost almost 70 times as much as a visual sketch-mapping survey with an expected accuracy of 60 per cent.

Discussion of results.—The comparison of panchromatic film with color film was very clear-cut. Photo interpreters were able to locate southern pine-beetle infestations far more accurately and more quickly on color. Furthermore, commission errors were very low on color and very high on panchromatic film. If panchromatic photos were used on an aggressive southern pine-beetle outbreak, it is very likely that salvage and control crews would be sent to many nonexistent infestations. This would result, of course, in lost manpower, money, and time, all of which are critical during bark beetle epidemics.

As expected, experienced photo interpreters did a better job than inexperienced ones. Obviously, training would help level out interpreter differences.

In comparing scales of color film and weighing accuracy with cost, the 1:7,920 scale is the best compromise. While a scale of 1:3,960 increases spot detection by 17 per cent, it cannot be recommended because a large part of this increase involves single trees. Finding a single dead tree, sometimes with a narrow crown and below the general crown canopy, is not as important as the killing of larger groups of trees where the tremendous number of beetles represent a potentially more explosive situation. Furthermore, observations made on the study area for 1 year afterward disclosed that the beetles in the 14 single infested trees did not spread to adjacent pines. Either they died in the infested trees or moved to a new location. This point is important not only to any aerial photo survey but to visual plotting surveys and control operations as well and should be settled by the entomologist.

On the basis of this test, certain recommendations can be made as they pertain to southern pine-beetle salvage and control operations.

TABLE 4

COMPARATIVE COSTS (ESTIMATED) FOR A 100-PER CENT SURVEY OF 46,080 ACRES (APPROX. 2 TOWNSHIPS) BY CONVENTIONAL GROUND METHODS, AERIAL COLOR PHOTOGRAPHY, AND AERIAL SKETCHMAPPING

Survey method	*Expected accuracy*[4]	*Time to complete*	*Total cost*	*Cost per acre*
	Per cent	*Man-days*	*Dollars*	*Dollars*
Ground cruise[1]	100	1,728	28,818.80	0.6300
Color photography[2]	80	12.0	6.420.00	.1400
Aerial sketchmapping[3]	62	1.4	91.00	.0019

[1] Includes salaries, vehicle travel, supplies, but assumes no per diem for local personnel.

[2] Includes commercial cost of 1:7,920 scale color photography (average of $0.134 per acre), photo preparations, and photo interpretation.

[3] Includes salaries, plane rental with pilot at $25.00/hr., and materials.

[4] For plotting in groups of 2 or more trees per infestation. Ground cruise had omissions, but it is assumed to be standard for comparison.

1. When valuable timber is threatened by an outbreak of the southern pine-beetle, color photographs at the 1:7,920 scale should be taken; they should be examined by experienced interpreters to direct control planning and operations.
2. Complete coverage should be obtained of areas no larger than can be covered by ground-control crews within a 6-week period. If 50 to 75 men are working on the ground, about 2 townships (72 sq. mi.) can be worked over. This estimate will vary according to number and size of infestations.
3. Areas selected for treatment should be so blocked out as to keep reinfestations from bordering untreated areas to a minimum, and to permit control plans to progress across an outbreak in an orderly manner.
4. For sampling estimates, 1:7,920 color photos taken within the confines of an epidemic could be used in conjunction with the regression curves developed in this paper. One randomly located flight line every 6 miles (about a 16-per cent survey) would provide a satisfactory estimate of insect-caused losses at a reasonable cost.

Summary

A study was made in an active southern pine-beetle outbreak in western North Carolina, to determine if the accuracy and cost of discovering such outbreaks in the southern Appalachians could be improved by aerial photography. An area of 3,546 acres, containing 36 active beetle infestations, as determined by ground examination, was selected for the study. Color (Ektachrome Aero) photographs were taken of the entire area at 3 scales (1:3,960, 1:7,920, and 1:15,840). A large portion of the area also was photographed with panchromatic (Super XX with A-25 filter) film at 2 scales (1:3,960 and 1:7,920).

Photo interpretation of infestations on color film were more accurate than on panchromatic. Errors of commission were low on color and high on panchromatic. Analysis of variance revealed no differences in plotting accuracy by scale by experienced interpreters.

Interpretation of dead trees showed color film to be more accurate than panchromatic. Accuracy varied according to the experience of interpreters—the more experienced the greater the accuracy. Far more trees were miscounted as dead on panchromatic than on color film.

Interpreters located 82 per cent of the infestations on color film at 1:3,960 scale. At the 1:7,920 scale they located 65 per cent and at the 1:15,840 only 55 per cent of them. Most of the missed infestations consisted of single dead trees. The most serious errors of misinterpretation consisted of identifying discolored hardwoods and old inactive infestations as active infestations. These errors were most numerous at the 1:15,840 scale. Interpreters counted 87, 65, and 43 per cent of the dead trees at the 1:3,960, 1:7,920, and 1:15,840 scales, respectively. These differences were significant. Differences between interpreters were not significant.

Regressions were developed for adjusting photo estimates of dead trees to actual ground counts.

It took an average of 13 hours to interpret the photographs of 3,600 acres at the 1:3,960 scale. In contrast, it took only 5 hours and $2\frac{3}{4}$ hours to interpret those at scales of 1:7,920 and 1:15,840, respectively.

References

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