R. C. ALDRICH*
U. S. Forest Service
Berkeley, Calif.

Forestry Applications of 70 mm. Color

Potential uses exist to combat insects, disease, and fire, and for inventory studies.

ABSTRACT: *As a forest sampling tool, 70 mm. color photography could help gain more detailed information about our national timber supply. It could be used to determine losses due to insects, diseases, and fire as well as to inventory quantity, quality, and location of the supply by tree species. Fast shutters and rapid pulse rates of 70 mm. cameras, the ability to view 70 mm. films in the roll, and new high-speed color films with improved acuity and resolution—all these factors will contribute to successful photo sampling at scales as large as 1:600. Two major limitations remain unsolved: (a) the inability to determine photographic scale accurately without costly ground work and (b) poor camera stabilization resulting in photographic distortions caused by tip and tilt.*

INTRODUCTION

IN AUGUST 1957 some white pine (*Pinus strobus* L.) plantations in upstate New York were photographed in color with a 70 mm. aerial camera to assess damage caused by a terminal weevil[1]. The photography demonstrated one of the greatest potentials of 70 mm. color in forestry: to appraise forest insect damage by detailed interpretation of large-scale photo strips supplemented by a small subsample of points checked on the ground. New developments in forest sampling such as this will be needed in the future to provide forest managers with timely information too expensive to obtain by conventional ground survey methods.

Rising costs have made ground surveys prohibitively expensive. To keep survey costs within a limited forestry budget, small-scale aerial photographs have been used effectively in the past 20 years to stratify the forest area by types, volumes, or timber size classes for a double-sampling technique. In this survey technique, a large number of inexpensive photo plots of designated area are classified into several forest strata by stereo examination, and a small but expensive subsample of plots in each strata is checked on the ground to determine tree species, tree size distribution, tree quality, volume of sawtimber and other products. These data are then expanded to the total acreage in the strata by an acreage factor. For example, one ground plot might represent as many as 5,000 acres.

Many variations occur in double-sampling techniques, depending on the area of the

R. C. ALDRICH

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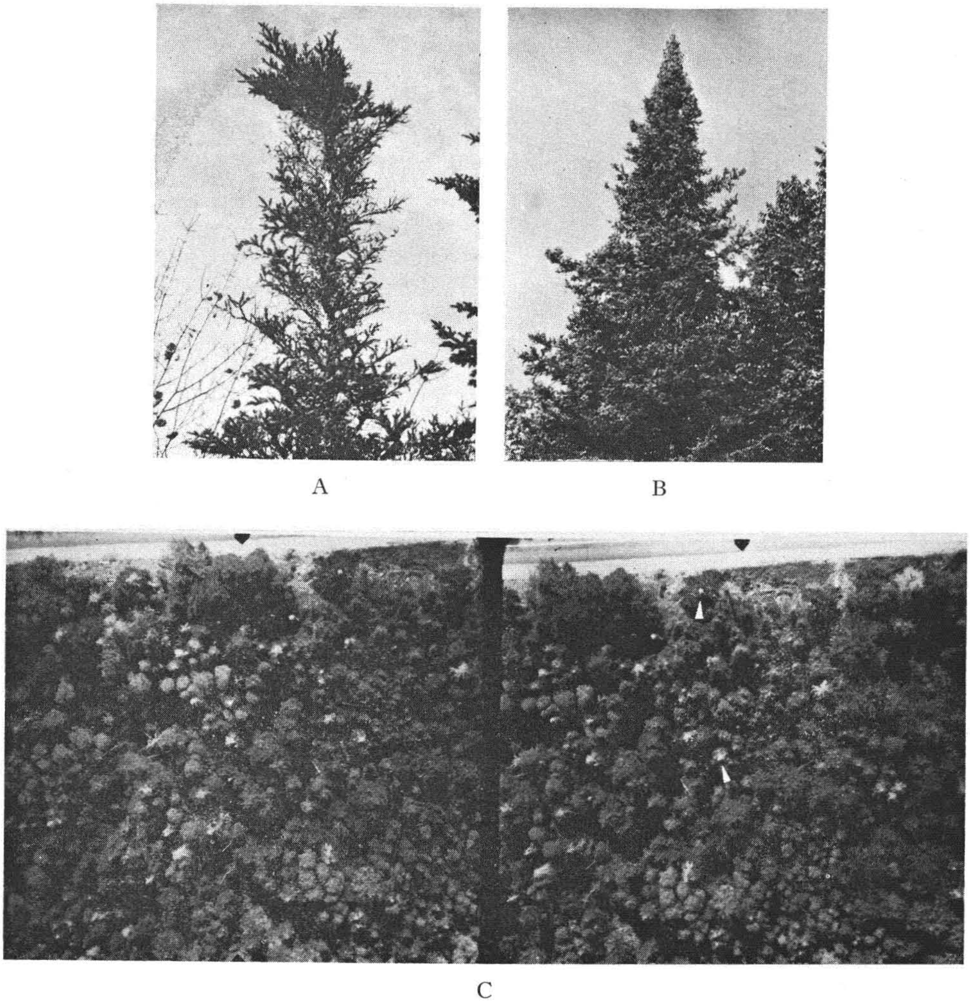

FRONTISPIECE. Gouted balsam fir in southeast Maine: *A*, ground photo of severe top deformation; *B*, normal balsam fir with typical conical shape; *C*, aerial stereogram (1:1,188 scale) of gouting damage (note arrows pointing to gouted tops). Photos made from Super Anscochrome transparencies. (See page 809)

country and specific survey objectives[2]. Results can vary, too, depending on the age of the photographs, their quality, and the experience of the interpreter. Although small-scale photographs will continue to be important for surveys in the future, improvements will depend on acquiring sharper more-detailed imagery and constructing better interpretation aids, viewers, and measuring devices. Many forest interpreters already feel that we have reached an impasse, where improvements in the application of aerial photography to forestry will require the use of larger scales and new and more imaginative sampling designs.

LARGE-SCALE DEVELOPMENTS

Developments in large-scale aerial photography during the past 15 years now offer a medium from which more information can be derived than previously possible on small scales. One of the first advocates of large-scale photography was Losee[3] who in 1953 pointed out two important advantages of large-scale photographs for making measurements: lower standard errors of measurements and reduced measurement times. He used a panning camera to overcome image motion and produced sharp images even at a scale of 1:1,200. Because image motion was a major obstacle to the use of large scales, Heller, et al,[4] in-

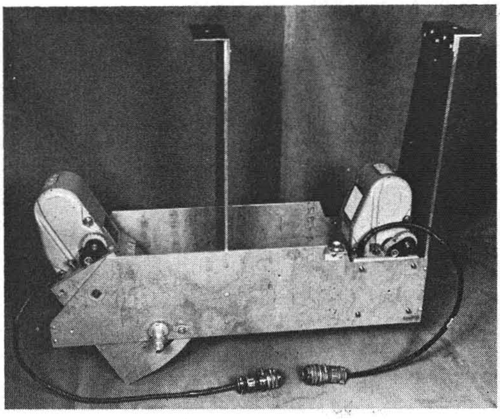

FIG. 1. Dual KB-8 70 mm. cameras mounted in tandem; frame fits inside NR-1A aerial camera mount.

vestigated several systems for overcoming this problem; they concluded that 70 mm. cameras with shutters of 1/1,000 second duration or faster were the most practical and most effective way of overcoming image motion. These cameras could be pulsed as often as eight times a second to take overlapping photographs for stereo examination.

Another important contribution was made by Avery[5]. He found that large-scale stereograms taken from a helicopter gave more consistent measurements of tree height and crown diameters than the conventional 1:20,000 scale. He also found that these dimensions were more accurately measured on the large scale. Canadian researchers, Kippen and Wittgenstein[6], showed that large-scale 70 mm. photographs may allow estimates of volume for individual trees or stands if precise-enough equations can be derived to determine volume for species from crown diameter and height. Another of our Canadian neighbors, Lyon[7], using 70 mm. helicopter stereograms, could show no significant difference between volume estimates made by paired ground and photosamples.

These independent studies and others all show great promise for large-scale photographs as a forest inventory and management tool. Although the most recent developments have been made using 70 mm. photography, if other cameras are developed with fast shutters, other film sizes too may be used. Besides fast shutters and rapid pulse rates, 70 mm. cameras have other attributes that make them popular for large-scale photography: (1) they are relatively low in cost; (2) their small size and light weight allow versatility in small aircraft camera systems (Figure 1); (3) they have interchangeable lenses that are easily changed in flight; (4) their narrow angles of view reduce effects of tilt on parallax measurements; (5) 70 mm. film is easy to process with consistent results (Figure 2); and (6) films can be interpreted in the roll without cutting, using only a pocket stereoscope (Figure 3).

POTENTIAL 70 MM. COLOR APPLICATIONS

FOREST INVENTORY

Ideally, the forest interpreter should have two sets of photographs—a set of small-scale panchromatic and a set of large-scale color imagery. These photographs might be the product of a dual camera system consisting of a 9-inch-format camera with a 6-inch lens and a 70 mm. camera with a 36-inch lens. If this system could be coupled with a precision LASER or Radar Altimeter for accurate above-ground altitude readings and the entire system inserted in a gyro-stabilized mount, the forest interpreter would be able to make precise area classifications and measure

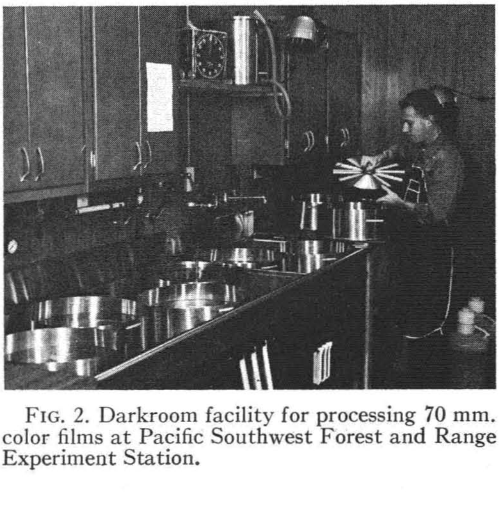

FIG. 2. Darkroom facility for processing 70 mm. color films at Pacific Southwest Forest and Range Experiment Station.

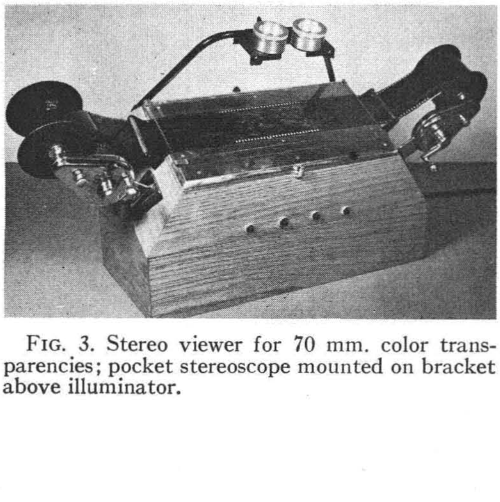

FIG. 3. Stereo viewer for 70 mm. color transparencies; pocket stereoscope mounted on bracket above illuminator.

TABLE 1

SPECIES RANKED IN ORDER OF INTERPRETATION ACCURACY ON SUPER ANSCOCHROME 70 MM. FILM IN PER CENT[1]

Pinus strobus	Picea *spp.*	Abies balsamifera	Pinus banksiana	Pinus resinosa	Thuja occidentalis	Populus tremuloides	Acer rubrum	Betula papyrifera	*All spp.*
100	97	97	97	97	90	90	74	67	90

[1] Average of 2 interpreters; scale 1:1,584.

the stand variables height, crown diameter, and crown closure with great accuracy for volume determination.

Such a system does not exist. Its development should be investigated. There is no doubt that it would have a great potential for use in forest survey if it could provide more information for the same cost as present methods, or less cost.

In lieu of this specialized camera system, many potential forestry applications of 70 mm. color photography are not beyond the present state of the art. For instance, because of the difficulty in separating tree species on 1:15,840 or smaller scale panchromatic photographs, tree species identification is probably the most valuable contribution that 70 mm. large-scale color photographs can make to a forest inventory. Species identification is equally important in many other forestry applications; for example, forest protection, which must contend with insects and diseases that select only certain tree species to attack.

We now know it is possible to tell many tree species apart from their color (hue and chroma), crown descriptions including top form and crown margins, branching habits, and other characteristics seen in a vertical view[8]. New color films provide a wide range in hues and chromas that far outnumber the shades of gray that can be detected even on the best black and white reproductions. This is one reason why color film is more accurate for identifying tree species.

The scale of photography is also important in tree species identification and, as would be expected, the larger the scale the better the interpretation. There is a point, however, where further increases in scale produce only small gains in accuracy; this scale is 1:1,584, or 132 feet to the inch. With this scale, accuracy of experienced interpreters for all tree species can be expected to be about 90 per cent (Table 1). We have found no significant difference in accuracy between observations made by any photo interpreters of color film Because of this experience, we recommend that a scale of 1:1,584 be used for forest inventory problems.

Using color transparencies of this scale, Weber[9] studied the stand components of volume. He found that average stand height and crown closure are highly correlated with stand volume and can be measured accurately on 70 mm. film in the roll if the scale can be precisely determined. When the scale is known, the variation in measurements among interpreters for any single tree can be expected to fall within ±2 feet. This is considered very accurate for photo measurements; in fact, more variation may occur when measuring tree heights on the ground with a hypsometer or Abney level.

On the photographs, total height is measured with a stereometer (Figure 4). A standard instrument was modified so that the marker plates could be brought together with a minimum separation of 1.30 inches—the separation of image points on 70 mm. photographs with 50 per cent overlap. Measuring the average total height of 5 dominant or codominant trees on a one-acre plot will result in an acceptable estimate of the stand height with an error of ±3 feet.

The other component of photo volume, crown closure, is accurately measured with a dot templet. Tests with varying intensities of dot patterns showed that 144 dots per square inch would result in an estimate of crown closure within one per cent of crown closures determined by planimetering crown closure patterns on 10-time enlargements. Other methods may work as well or better and may be faster. Further research is needed to determine the best measure of this important component of stand volume.

Volume tables can be constructed by multiple regression techniques with average stand height and crown closure as the independent variables and gross cubic-foot volume as the dependent variable. Weber[10] constructed a

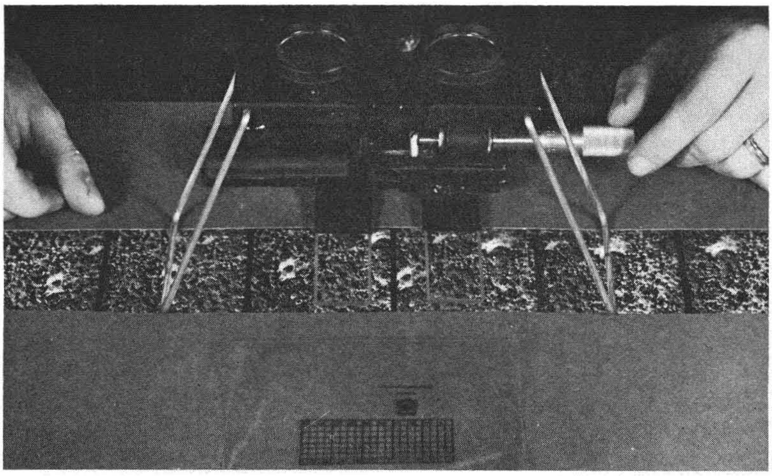

FIG. 4. Fairchild Stereocomparagraph modified for measuring tree heights on 70 mm. color transparencies.

volume table from two multiple regression equations for cubic volume of dead white spruce (*Picea glauca* (Moench.) Voss.) and balsam fir (*Abies balsamea* (L.) Mill.) in northeastern Minnesota. These equations were used in a special-purpose survey to measure the volume of fir and white spruce killed by spruce budworm (*Choristoneura fumiferana* (Clem.)), Figure 5. With these tables and 70 mm. color photo samples of 49 one-acre plots, he estimated rather quickly that there were 1.5 million cords of dead white spruce and balsam fir on the 544,000 acres of spruce-fir type.

This is just one example of how 70 mm. color photography can be applied to a special forest inventory problem. The sample was small—about one photo-plot for every 11,000

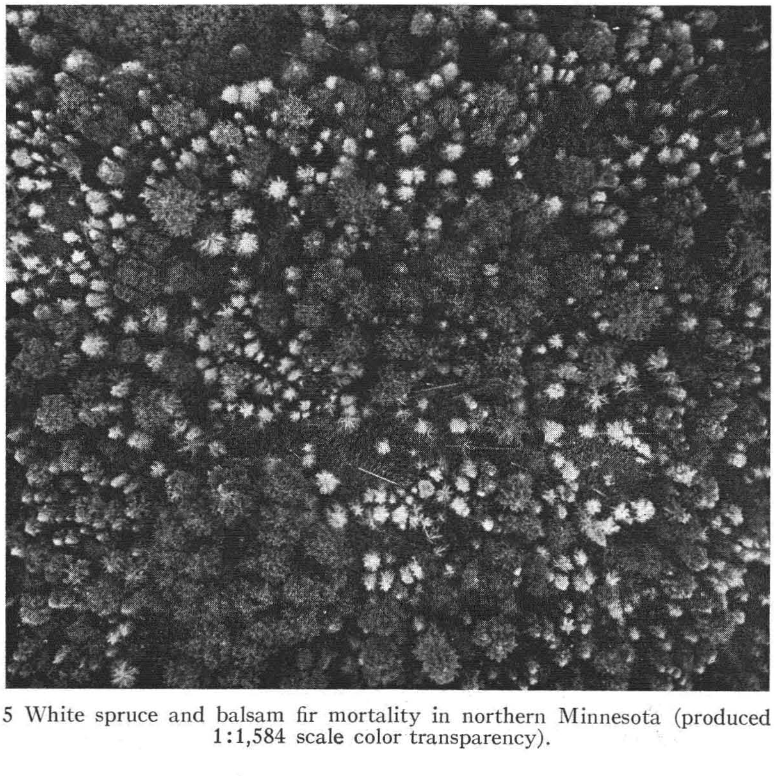

FIG. 5 White spruce and balsam fir mortality in northern Minnesota (produced from 1:1,584 scale color transparency).

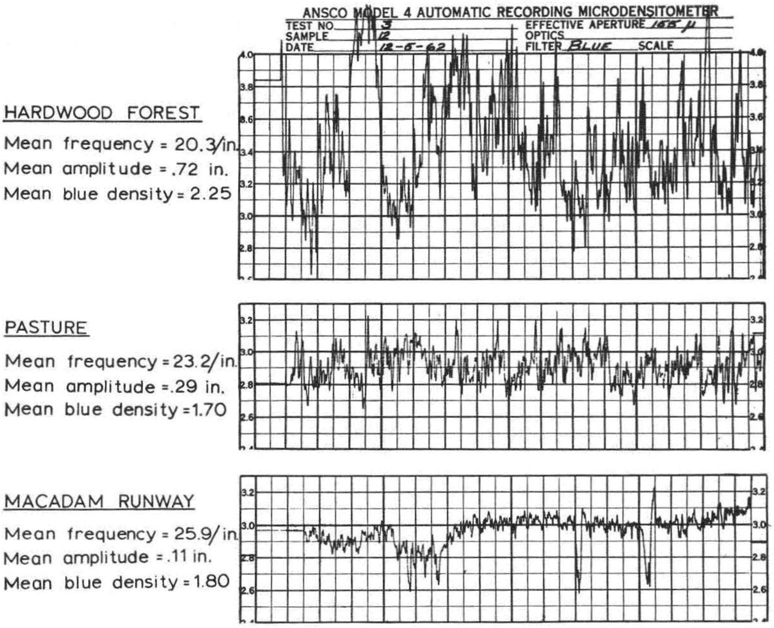

FIG. 6. Microdensitometer traces across three frames of 70 mm. Super Anscochrome exposed over hardwood forest, pasture, and an airfield runway. Note differences in frequency and amplitude of the strip chart recording. Traces made with blue filter and round aperture; 0.155 inches in diameter.

acres of the spruce-fir type. Hence the standard error of estimate was a rather high 25 per cent. This error would be unacceptable for most inventory problems but was within the error limits generally considered acceptable for insect damage surveys.

Other possibilities for forest inventory applications of 70 mm. color photography are as yet unexplored. At the large scales recommended, it is possible that the condition of the forest could be assessed; that is, areas needing cultural improvements such as thinning of young stands, removal of competing poor-risk trees and underbrush, slash removal, and planting might be identified. Possibilities also exist for using 70 mm. color films with automatic recording microdensitometers to classify land use, forest type, and even degrees of damage caused by forest defoliators. Our first attempt to use an automatic recording microdensitometer to interpret land use based on differences in color density was not successful[11]. This test showed that color density alone does not differentiate land use. However, land-use classes did exhibit distinctive frequency and amplitude patterns on a strip chart recorder. Combining these patterns with color density readings may lead to more positive results (Figure 6). In this example the hardwood forest has a mean frequency of 20.3 peaks per linear inch compared with 23.2 for pasture and 25.9 for an airfield runway. The mean amplitude of these traces, in the same order, is .72, .29, and .11 inches.

FOREST MANAGEMENT

Forest managers depend on forest inventory to point out where the forest is and the species, volume, and quality of the trees. But forest managers also need to know from time to time the health of their timber; are insects or diseases threatening to wipe out large numbers of trees, or threatening to degrade or cause loss in growth? Everyday surveillance is needed by all forest workers to detect unusual occurrences of dying or sickly looking trees. Sometimes, however, these casual observations are not enough, and serious outbreaks of insects go unobserved. To guard against this happening, a periodic and systematic aerial surveillance is most useful and has been adopted in recent years almost universally by forestry agencies to keep the forest under surveillance during those periods of the year when the danger of outbreaks is greatest.

When outbreaks do occur and it becomes necessary to assess the damage, aerial observation again can be useful to delineate damage and estimate losses. When timber values are high, large format color photographs of scales within the range of 1:5,000

TABLE 2

WEEVIL DAMAGE ESTIMATES MADE ON COLOR PHOTOGRAPHY FOR 3 SUCCESSIVE YEARS ON 25 WHITE PINE PLANTATIONS—14 SPRAYED, 11 NOT SPRAYED

	Weevilled White Pine (per cent)		
	Before Spraying	*After Spraying*	
	1956	*1957*	*1958*
Sprayed	23.0	6.0	12.4
Not sprayed	13.0	11.8	11.3

to 1:10,000 will be useful, particularly where tree mortality occurs and both insect control and timber salvage operations are intended. Under these circumstances it is necessary to know exactly where all infested, dying, and dead trees are located so that control and salvage crews may find them and effectively bring the infestation under control. On the other hand, when it is necessary to estimate damage—the severity, extent, and general location of infestations—aerial photo strip-sampling techniques with 70 mm. color film may be the most appropriate survey system to use.

The usefulness of a 70 mm. color photo sampling system to assess white pine weevil (*Pissodes strobi*, Peck) damage in New York State has already been briefly mentioned. However, a little additional discussion might clarify exactly why and how this system was used. To begin with, entomologists wanted to assess the levels of white pine weevil damage in 25 plantations before and after an aerial spray application to determine the effectiveness of the spray. Conventional 1:1,000 scale aerial color photographs were taken in August 1956, the year before spray application. Counts of the number of red-tipped infested leaders were made, using a photo sampling scheme within the stereo portions of these pictures. In 1957, a Hulcher 70 mm. camera was used with Anscochrome (ASA 32) film pushed to ASA 125 by underexposing and underdeveloping the film. This change was made because image motion caused blurred images on the 1:1,000 scale photos the previous year and there was a need to resolve the smallest weevilled terminals for detection. The pictures were taken with 60 per cent overlap at a pulse rate of 5 frames per second at 300 feet above the ground. With a 6-inch focal length lens, this meant a photo scale of 1:600. The flight was made after the spray application to determine the effectiveness of the spray in controlling the weevil infestation. Recounts of the number of weevilled terminal leaders were made and compared with the original counts. A second reflight was made in 1958 to determine the effectiveness of the spray one year after the initial spray application. The results of the survey for three years are shown in Table 2.

By comparing the photo estimates with estimates made on the ground in several plantations, we found that photo estimates were accurate enough to evaluate the effectiveness of the spray. Seventy millimeter photo sampling has these advantages over ground methods: (1) it samples tall trees and dense stands where weevilling is difficult to see from the ground; (2) it samples more trees per plantation; and (3) it samples remote areas in large plantations that would require too much time to reach on the ground.

Other types of damage caused by forest insects have been interpreted on large-scale 70 mm. color photographs: defoliation of balsam fir by spruce budworm in northeastern Minnesota, tree mortality and top deformities caused by balsam woolly aphid (*Chermes piceae*, Ratz) in balsam fir in Maine, and mortality caused by Black Hills beetle (*Dendroctonus ponderosae*) in ponderosa pine (*Pinus ponderosa* Dougl.) in South Dakota. Each represents a different condition and requires a different photographic approach.

Spruce budworm defoliation, and the subsequent deterioration of balsam fir stands in northeastern Minnesota, have been followed on 1:1,584 scale 70 mm. color photography for the past 9 years. This study on 35 one-acre photo-ground plots has shown that photo estimates of defoliation are closely correlated with ground estimates of defoliation for a number of years. However, as the first indications of tree mortality appear in the stands, correlation is drastically reduced. When mortality shows up, damage has progressed too far to be benefited by an aerial control operation. Then mortality surveys are more informative than defoliation surveys and can be made as described earlier in this paper.

Eventually we hope to be able to predict what effect insect attacks will have on a stand over a period of years from photo estimates of defoliation and estimates of the insect populations made on selected ground plots. In this way we may be able to tell forest managers when the time is most opportune to control an infestation to save trees, or what would happen to the stands without control.

FIG. 7 Heavy balsam woolly aphid stem attack on balsam fir, Vermont.

Balsam woolly aphid, another enemy of balsam fir, is a serious pest in the Northeast. This insect is small—not much larger than the head on a pin—and locates itself either on the main bole of a tree or in the branches of the top (Figure 7). Once located, it inserts its stylet (mouth part) into the bark of the tree and injects a substance that causes abnormal growth of wood. When the insect population is large, the attack eventually causes the tree to die. Trees that have been attacked over a period of years by moderate to heavy infestations will show stress through a thinning and yellowing of the tree crowns. Attacks made in the tops of trees cause abnormal branch and twig growth and eventually a deformity of the top. These deformities are called gouts (Frontispiece).

In 1959, 1960, and 1962 tests were made using 70 mm. color photography to determine the most appropriate scale and angle of photography to detect both stem-attacked and gouted trees. Vertical, 20-degree side oblique, and 45-degree forward obliques were tried at scales ranging from 1:792 up to 1:3,960. A vertical scale of 1:1,188, or approximately 100 feet to the inch, proved most accurate for detecting gouted tops. Since any photographic survey would need to detect these top abnormalities, 1:1,188 would represent the minimum scale requirement for a balsam woolly aphid survey where top gout is prevalent. At this scale, 95 per cent of all stem-killed and infested trees and 75 per cent of all gouted trees can be detected[12].

We know that trees killed by bark beetles can be detected on color film once tree crowns have changed color. Seventy millimeter large-scale color can be used in a sampling scheme to appraise this mortality and determine the volume of losses; an appropriate scale for such a survey would be 1:7,920. But regardless of how successful color photography is for detecting the typical faded crowns of killed trees, it does not detect trees that are newly attacked by new generations of beetles. Such trees remain green. Some workers have suggested that new camouflage detection film might help in the early detection of these green infested trees. Our latest experience with this film on the Black Hills beetle infestation in South Dakota showed no advantage over three-layer color films.

Forest disease symptoms are not as readily detected as insect damage on aerial color film. Even if the symptom is detected, forest pathologists argue, it is too late to do anything for the individual tree infected. This argument is probably true, but information regarding the extent of the disease once it has been detected should be important to any manager.

So far, we have experience with only three important forest diseases: white pine blister rust in Minnesota, maple wilt in Wisconsin, and ash dieback in New York. White pine blister rust is detectable by the bright orange-red flags created by dead branches. Symptoms of the maple wilt disease are much more subtle, and the photo interpreter probably will find himself first identifying maple trees and then the typical wilted-brown undersize foliage of the disease. An intensive study is now aimed at identification of ash dieback disease. It seems very likely that these three and many other diseases that show characteristic symptoms in the tree crown will be detectable on large-scale 70 mm. color photography.

CONCLUSION

Many potential applications of 70 mm. color photography in timber management have been discussed; some that we are certain about and some we have not yet explored. Applications are also possible in range management, wildlife management, watershed management, and recreation. Additional research is needed to test these applications and develop the interpretation tools to use with large-scale color photographs. We will also need to develop improved camera systems that will include precision altimeters for accurate scale determinations and gyro-stabilized mounts to reduce tip and tilt caused by turbulent air at low altitude. If these systems can be developed, the next step would be a dual camera system that would provide the interpreter with both the overview of the forest on small-scale panchromatic photography and the close-up view on large-scale color samples.

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