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Beetle-Killed Pine Estimates

35-mm color aerial photos can be used to detect and quantify insect-killed lodgepole.

ABSTRACT: *A study was undertaken to determine the feasibility of detecting mountain pine beetle-killed lodgepole pine with 35-mm color aerial photographs at a 1:5,000 scale. Photographs were obtained with a standard 35-mm camera from a light aircraft. Counts of dead trees were made from stereo photographs by untrained interpreters and compared to actual ground counts. Additionally, interpreters were asked to separate new faders from all other mortality. Both tree condition categories were discerned from the photos with acceptable accuracy, indicating the potential of 35-mm aerial photography as an inexpensive and effective measurement method. The method was to be applied operationally in 1971 within the framework of a double-sampling design.*

INTRODUCTION

THE MOUNTAIN pine beetle (*Dendroctonus ponderosae* Hopk.) in lodgepole pine (*Pinus contorta* Dougl.) is the most important forest insect problem in the Intermountain West today. The present outbreak began in the early 1950's, reached its peak during the mid 60's, and is now on the decline. In some areas, however, a high level of tree killing is still occurring. Left in the wake of this widespread epidemic are countless numbers of dead trees. *Ball-park* estimates place the loss somewhere between 100 million and one billion trees. The myriad management problems caused by these depleted stands now fall squarely on the land manager. He must now revise his management goals; in doing so, however, he must know both the intensity and extent of tree losses.

The most efficient method for accurately assessing damage and tree losses caused by forest insects on large areas is with large-scale color aerial photographs (Wear et al. 1966). At present, the only effective photographic systems in use either to detect or quantify insect infested and killed timber are those with a format of 70-mm and larger. No work of this type has been done with 35-mm aerial photographs.

BACKGROUND

Methods to procure good-quality color stereophotography from a light aircraft with a 35-mm camera were recently developed (Klein 1970). In a follow-up study, an effort was made to produce imagery at a scale from which counts of individual trees killed by bark beetles could be made with consistent accuracy. As a start, in 1968 an area on the Bridger National Forest, Wyoming, containing mountain pine beetle-killed lodgepole pine, was photographed at three altitudes to produce scales of 1:4,000, 1:6,000, and 1:8,000. The number of dead trees on the photos were counted by three untrained interpreters. Analysis of the results showed that photo counts approached ground truth with each increase in scale, but the mean differences were not significant. All comparisons, however, regardless of scale, were highly correlated. This information, as well as supplemental tests on various lens, film and filter combinations, laid the groundwork for the present study.

The 35-mm system showed promise as an effective sampling technique, but a much more thorough and comprehensive analysis was needed before it could be tested on an

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operational basis. A study was begun with the primary objective of detecting and recording on 35-mm aerial photography, all lodgepole pine mortality over 7.0-inches diameter-breast-high (d.b.h.) caused by the mountain pine beetle in designated areas. As an adjunct, in the hope that it was possible to record mortality trends, we considered it important to know whether it was feasible to separate the *new faders*° from all other mortality.

METHODS

All photographs were taken through a specially constructed camera port (Figure 1) in a Cessna 182 in late August 1970 of two mountain pine beetle infestations; one on the Caribou National Forest, southeastern Idaho; and the other in Grand Teton National Park, western Wyoming. A variety of stand types and conditions were photographed; dense versus open and pure versus mixed. The camera was a Nikon F with an Auto-Nikkor 85-mm lens and a Nikkor L1A filter. Film was Kodacolor-X, a color negative film. Flying height for a 1:5000† scale, and cycle interval to procure stereo pairs were determined by a pocket computer (Figure 2); film advance and shutter release were by hand.

° A *new fader* is a bark beetle-attacked tree whose crown discolors the season following attack. For example, new faders in this study are trees that were attacked in 1969 but did not discolor until 1970. An *old fader* is a tree that was attacked in 1968, faded in 1969, but retained most of its needles through summer of 1970; in some areas they are frequently confused with new faders.

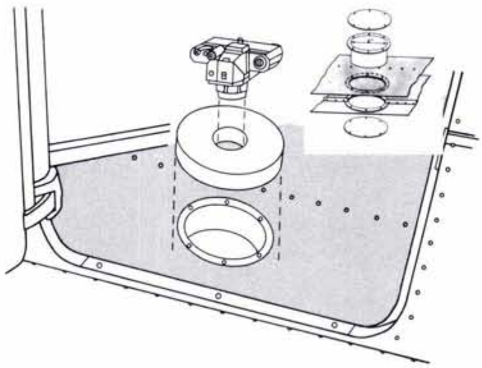

FIG. 1. Details of camera port in floor of baggage compartment of Cessna 182: *A*, camera; *B*, foam rubber cushion to minimize vibration; *C*, camera port. Camera was kept level by small fisheye bubble mounted on back plate. *Inset*—construction details of camera port.

Once the imagery was obtained, 19 areas ranging in size from 0.3 to 4.0 acres were delimited on the 3 × 5-inch color prints and checked on the ground. All mountain pine

† In this exercise, the airplane was flown at 4500 ft. above ground to obtain a 35-mm negative scale of approximately 1:16,134. By enlarging the negative to a 3 × 5 format, the scale was increased to 1:5000.

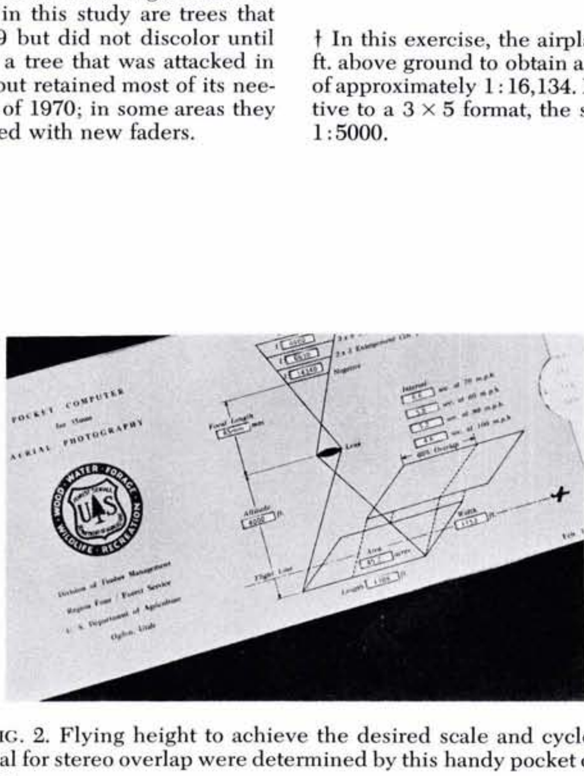

FIG. 2. Flying height to achieve the desired scale and cycle interval for stereo overlap were determined by this handy pocket computer.

FIG. 3. Photo interpretations were made from 3 × 5-inch Kodacolor-X color prints with a standard pocket stereoscope.

beetle-killed trees 7.0-inches d.b.h. and larger were recorded and separated into two categories: (1) new faders (1969 attacks) and (2) old faders and snags. There was a total of 669 bark beetle-killed trees.

Photo estimates were made from the color prints with a pocket stereoscope (Figure 3) by five inexperienced interpreters: three entomologists, a National Park Service biologist, and a laboratory technician. No training was given except a preliminary 20-minute photo exercise showing some 40 trees in various stages of decline. Each interpreter was instructed to (1) detect and record all mortality, and (2) to separate new faders from all other mortality.

Comparisons of photo counts to ground truth for each interpreter were made and analyzed. The analysis entailed computing a linear regression line, a standard error of estimate *Sy.x* and coefficient of determination r^2 for each interpreter in each of the three exercises (Figure 4).

RESULTS

The best relationship between photo counts and ground counts, with one excep-

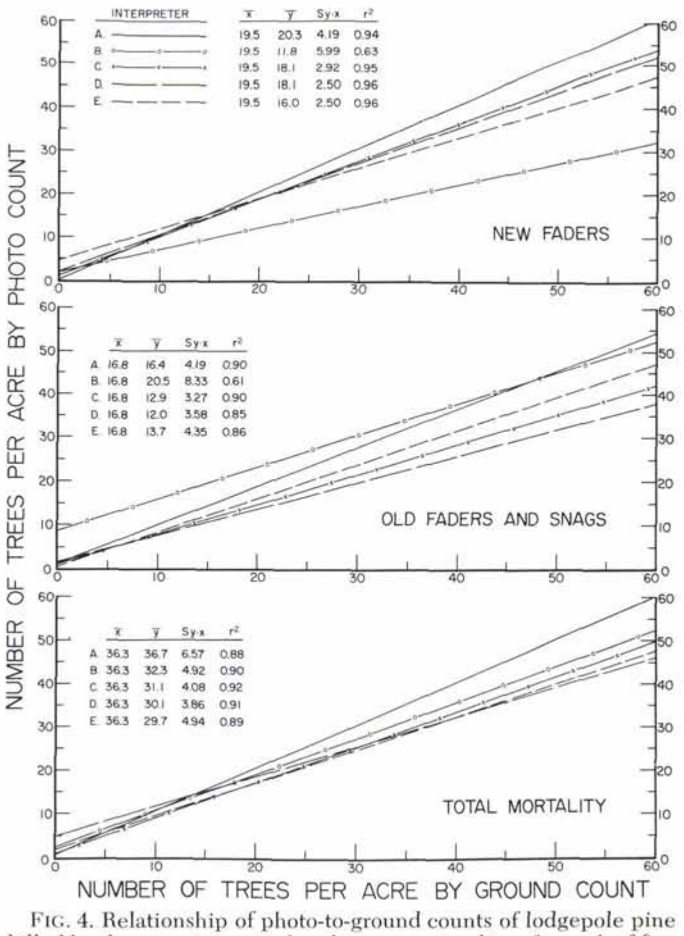

FIG. 4. Relationship of photo-to-ground counts of lodgepole pine killed by the mountain pine beetle—regression lines for each of five interpreters at scale of 1:5000. *Top*, new faders; *middle*, old faders and snags; *bottom*, total mortality.

tion, was with the new faders (Figure 4, *top*). The r^2 values for 4 of the 5 interpreters show that over 94 percent of the variance of photo estimates were associated with ground truth. The one exception, interpreter *B*, was consistent in all areas but one; that area actually contained 60 dead trees—51 new faders and 9 old faders and snags. Interpreter *B* detected 52 dead trees but identified only 13 of them as new; the remaining 39 then falling into the second category. This single misinterpretation resulted in a relatively low r^2 value (.63). It also resulted in an overestimate of old faders and snags ($r^2 = .61$) but did not affect the strength of the overall estimate of total mortality ($r^2 = .90$).

Photo counts of total mortality were also highly correlated with ground counts, the lowest r^2-value being 0.88 (Figure 4, *bottom*). Rather interestingly, interpreter *A*, whose mean photo estimate ($\bar{x} = 36.3$) came closest to the average actual ground count ($\bar{y} = 36.7$), had the lowest r^2-value (0.88) and consequently the greatest variation. This high variation may be explained by the larger number of errors of omission and commission as compared with the other photo interpreters. On the other hand, the other four interpreters consistently underestimated the actual number of trees, but had greater r^2-values and less variation. In an operational program, utilizing a double-sampling system, these interpreters would probably produce more precise estimates, other factors such as cost being held constant. Other studies have shown that as interpreters gain experience, their accuracy generally improves.

With only one exception (interpreter *A*), photo counts were less than ground counts. These omission errors were probably caused by the fact that many of the smaller trees were suppressed by the overstory and were not visible from above.

Discussion and Conclusions

The results indicate that 35-mm color aerial photographs have potential use as an inexpensive and effective method for evaluating the impact of the mountain pine beetle in lodgepole pine. Mortality as discerned on photographs by inexperienced interpreters was highly correlated with actual ground counts. This relationship assumes even greater significance if one considers not only the photographic method used but the nature of the target—lodgepole pine. Mature lodgepole not only occurs in very dense stands but is one of the West's smallest conifers.

The ability to enumerate the intensity of new faders at a point of time will prove to be a unique and useful evaluation tool. A historical photographic record of mortality supplemented by on-the-ground data will provide meaningful information on bark beetle movement, infestation intensity, and trend.

The fact that one interpreter departed from the trend established by the others in identifying new faders, points out the need for training in this type of exercise. Although all other photo estimates were closely associated with the actual count, there is little doubt that familiarity with mountain pine beetle activity, particularly on-the-ground comparisons of the affected trees with their photo images, could not help but improve interpreter accuracy.

Future plans for this small-format system will be to determine the impact of the mountain pine beetle in a portion of the Targhee National Forest, southeastern Idaho. As a formal estimate will be made and as high correlations exist between photo and field counts of dead trees, double sampling with regression will probably be utilized. A double sample involves ground checking, and one difficulty with this large-scale, small-format imagery and its limited area of coverage, is in locating the photo plots in the field. This will be done by first locating the 35-mm photos on existing resource photographs, and then using the resource photographs initially to direct field crews. In addition to procuring mortality data, cost comparisons will be made between the 35-mm photo system, conventional 9×9-inch photographs, and ground surveys of comparable accuracy.

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Literature Cited

Klein, William H. 1970. "Mini-aerial photography." *J. For.* 68:475–478.

Wear, J. F., R. B. Pope, and P. W. Orr. 1966. *Aerial photographic techniques for estimating damage by insects in western forests.* U. S. Forest Serv., Pac. N. W. Forest and Range Exp. Sta. 79 pp.