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Estimating Bark Beetle-Killed Lodgepole Pine with High Altitude Panoramic Photography

KA-80A optical bar photography is an alternative to frame photography for mountain pine beetle loss surveys.

ABSTRACT: *Panoramic color IR aerial photography taken from a U-2C was evaluated to determine its effectiveness in quantifying annual mortality of lodgepole pine caused by mountain pine beetle. A multistage survey using probability proportional to size (PPS) at three levels was used to estimate numbers of trees and volume killed.*

Mortality of lodgepole pine in 1977 was estimated at 1,891,510 ± 194,804 trees, and 27,001,000 ± 3,682,000 cubic feet of volume. Problems encountered with interpretation and data analysis are discussed. The results suggest that panoramic photography can be effectively used to estimate annual mortality of lodgepole pine caused by mountain pine beetle over large areas.

INTRODUCTION

ONE OF THE MOST destructive insects in the western North America is the mountain pine beetle, *Dendroctonus ponderosae* Hopkins. Within its range this matchhead-size beetle attacks and kills more than twelve species of pine (Furniss and Carolin, 1977). Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) is one of its preferred hosts.

During this century practically all lodgepole pine stands in western North America have experienced at least one major mountain pine beetle outbreak (Klein, 1978). Today, spectacular outbreaks of massive proportions occur in parts of the Rocky Mountains, British Columbia, and eastern Oregon. The magnitude of these losses, as well as losses from other forest pests, are generally unknown. With the trend toward more intensive forest management, reliable data on tree losses are being sought by all levels of management.

During 1977 and 1978 the USDA Forest Service conducted pilot surveys to measure annual mortality of lodgepole pine caused by the mountain pine beetle in two separate outbreak areas, the Targhee National Forest, Idaho, and the Beaverhead and Gallatin National Forests, Montana. These multistage surveys, using aerial sketch mapping, large-scale color aerial photography, and ground sampling, produced estimates of volume and numbers of trees killed within specified levels of precision (Klein *et al.*, 1979; Bennett and Bousfield, 1979).

Availability of the Itek KA-80A optical bar panoramic camera provided an opportunity to evaluate another approach for estimating timber losses due to bark beetles. The advantages of optical bar panoramic photography were that large areas could be covered in a fraction of the time required for conventional photography, and that a preliminary sketch-map flight in a light aircraft to stratify the outbreaks for sampling purposes would not be required. The objective of this survey, therefore, was to evaluate the capabilities of this panoramic photography in measuring annual mortality of lodgepole pine caused by the mountain pine beetle.

THE TEST SITE

The test site was located in an ongoing mountain pine beetle outbreak in portions of the Beaverhead and Gallatin National Forests, in south-central Montana (Figure 1). The area includes two mountain ranges—The Madison and Gallatin—lying between the Madison and Yellowstone Rivers. Elevations within the test site

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range from 5,000 feet in the Gallatin River Valley to over 11,000 feet in the Madison Range. Lodgepole pine is the dominant conifer in the test site with lesser amounts of Douglas-fir, (*Pseudotsuga menziesii* var. glauca (Beissn.) Franco), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), whitebark-limber pine (*Pinus* sp.), and ponderosa pine (*Pinus ponderosa* Laws.). Approximately 300 square miles of land area were included in the test site.

The current mountain pine beetle outbreak began in the late 1960's, increased in size and intensity during the 1970's, and is still increasing. Attempts at direct control, consisting of cutting and burning infested trees and salvage logging, were conducted on a limited scale.

METHODS

A multistage survey using sketch mapping and large-scale color aerial photographs was also conducted in the Beaverhead-Gallatin outbreak during 1978 (Bennett and Bousfield, 1979). The two surveys, using panoramic optical bar and conventional photographs, were conducted independent of each other, but ground data were acquired simultaneously.

AERIAL PHOTOGRAPHY

The panoramic photography was taken 25 July between 12:12 and 12:59 P.M. (MDT) by a NASA U-2C aircraft flying from Moffett Field, California. The aircraft flew at 19,800 m (65,000 ft) at a ground speed of 400 knots. Two hundred and fifty-one

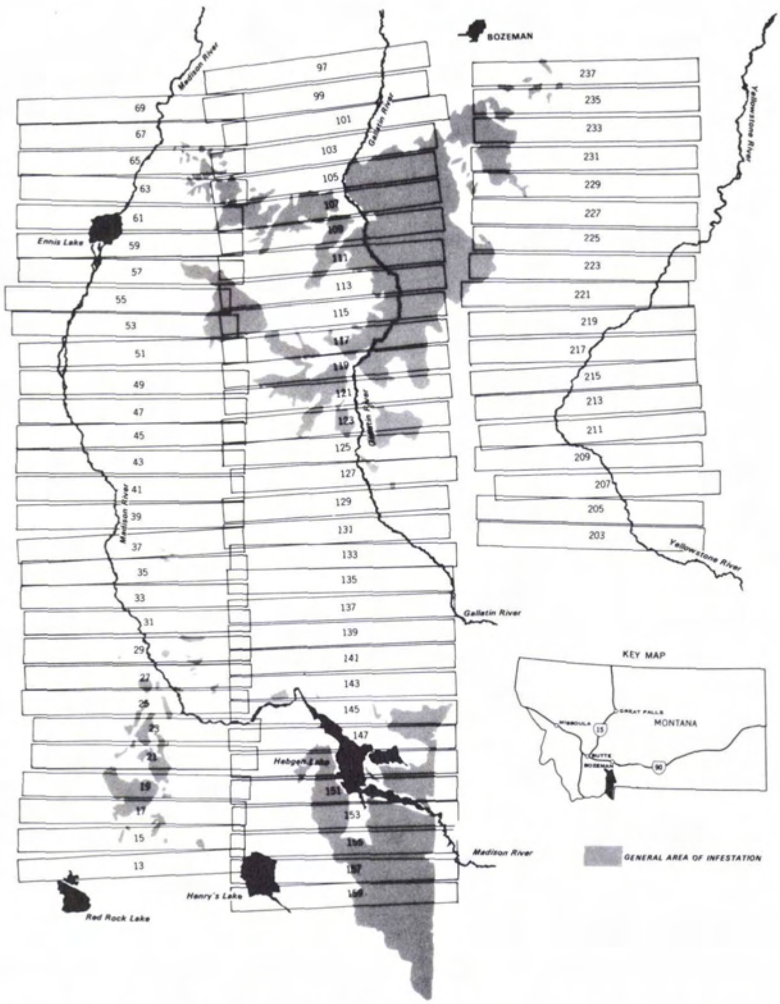

FIG. 1. Portions of the Beaverhead and Gallatin National Forests showing the location of the optical bar frames (±40°) and distribution of the mountain pine beetle outbreak as determined from a 1978 aerial sketch map survey.

PLATE 1. More or less typical lodgepole faders found on ground plots. These trees were attacked and killed by the mountain pine beetle in 1977 and reached optimum fading in 1978. Photo taken 27 May 1979.

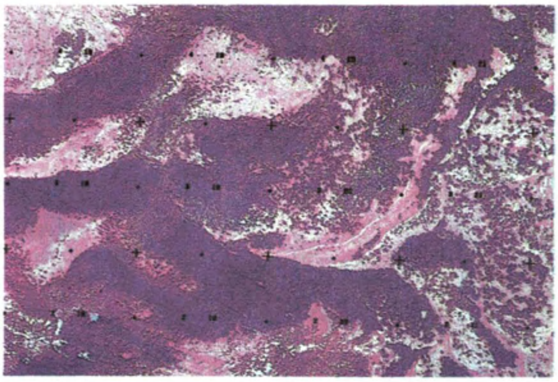

PLATE 2. Portion of infrared panoramic frame overlaid with transparent equal-area grid. Area within plus marks represents 160 acres.

PLATE 3. Portion of infrared panoramic frame overlaid with 160-acre grid divided into sixteen 10-acre square plots.

frames of Kodak high-definition aerial Ektachrome IR film (SO-131) were taken with the Itek KA-80A panoramic optical bar camera operating in the vertical mode. The endlap at nadir was 50 percent. Most of the infestation was covered by 79 alternate frames along three parallel flight lines. Due to a navigational error and intrack gaps between successive equal-area grid overlays, voids occurred between frames and flight lines (Figure 1).

A previous study (Klein *et al.*, 1978) comparing Itek KA-80A optical bar color infrared photographs with HR-732 large-format Hycon-frame camera (9 by 18 inches) photographs showed the color balance of the KA-80A film to be inferior. In this evaluation, during the film duplication process, color balance and contrast between faded trees and their background was improved with #10 red and #20 yellow selective color filters. This step may have reduced the spatial resolution somewhat; however, overall image quality was judged to be excellent.

Photographs were indexed and equal area grids (Liston, 1982) were temporarily attached to each frame. Effective area coverage for each of the 79 frames was plotted on a 1/2 inch = 1 mile working map (Figure 1). These boundaries could not be

FIG. 2. Photo interpretation team classifying optical bar photography by 160-acre cells.

plotted with complete accuracy because the average scale of each photograph was different and the grids did not compensate for topographic displacement. However, the principal points and general orientation of each frame were sufficiently correct for general location of tree mortality.

SAMPLING IN BRIEF

This survey used a three-stage variable probability design where sample units are selectively based on probability proportional to size (PPS)*. The first stage entailed complete and rapid classification of frames covering the outbreak; the second stage involved complete tree counts from 120 160-acre cells selected with PPS from the first stage; while the third or final stage included ground truth enumeration of faders on 20 10-acre ground plots selected with PPS from the second stage.

The Target. The target of interest was discolored crowns of lodgepole pine killed by the mountain pine beetle. Although trees were attacked by the beetle in the summer of 1977, the crowns did not begin to discolor until spring of 1978. These "faders" first turn yellow-orange, then orange, sorrell, red brown, and eventually brown (Plate 1). Fading begins in the lower crown and progresses upward. The optimum time for photography is during mid-to-late July when the initial yellow-orange to orange phase appears as shades of yellow to orange on infrared film.

Classification. The equal-area grids, covering a span of 80° (40° each side of nadir) were sectioned into 152 (4 rows by 38 columns) 160-acre cells (Plate 2). Photo interpreters using specially adapted microfiche viewers quickly classified each 160-acre cell by infestation intensity (Figure 2). A total of 12,008 cells (79 frames by 152 cells) or 1,921,280 acres were so examined. From this list 120 160-acre cells were selected PPS for the next stage, photo interpretation.

Photo interpretation. The second stage entailed precise fader counts under 8 to 10x stereomagnification of the 120 160-acre cells. The 160-acre cells were then subdivided into 16 10-acre subplots through use of a second transparent grid (Plate 3). Thirty 10-acre subplots were then selected with PPS from this second list for subsequent ground checking; however, only 20 of these ground plots were actually sampled, because of time and personnel constraints.

Ground Data. Ground surveys are usually made the season (1978) following attack (1977), but due to the delay in film processing, there was insufficient time to conduct the preliminary and ground phases of the survey before the onset of winter; consequently, ground data collection was postponed until spring of 1979. Fortunately, the faders still retained their identifiable characteristics (Plate 1), and were still easily distinguishable from the previous year's faders (1978).

Ground crews, using specially developed portable stereoviewers and 2, 4 and 7x magnification (Figure 3), located the plots, delineated their boundaries, counted all faders, and measured those faders with diameters breast high (dbh) greater than 5 inches.

RESULTS AND DISCUSSION

Total lodgepole pine mortality caused by the mountain pine beetle during 1977 over that portion of the outbreak covered by the equal-area grids on the 79 panoramic frames was estimated at 1,891,510 trees and 27,001,000 cubic feet of volume (Table 1). The standard errors for fader and volume estimates were quite acceptable; 10.3 and 13.6 percent, respectively.

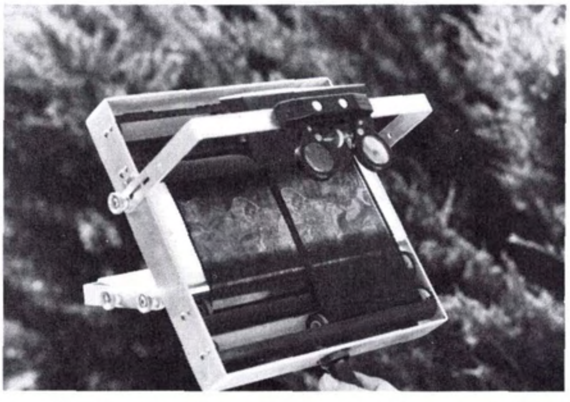

FIG. 3. Portable stereoscope used on the ground plots.

* The PPS sampling approach is a procedure used to select sampling units (plots) based on size, or in this example, on the number of trees. Simply stated, plots with large tree counts have a greater probability of selection than plots with fewer tree counts.

TABLE 1. COMPARISON OF COSTS AND ESTIMATES OF NUMBERS OF TREES AND VOLUME OF LODGEPOLE PINE KILLED BY THE MOUNTAIN PINE BEETLE FROM TWO SEPARATE SURVEYS IN THE BEAVERHEAD AND GALLATIN NATIONAL FOREST, 1977

Survey	Acres	Number of trees		percent	Volume (M cu. ft)			percent	
		Total	SE	SE	per tree	total	SE	SE	Cost
OB	520,640	1,891,510	194,804	10.3	0.0143	27,001	3682	13.6	37,001
Conventional	270,255	1,270,617	55,931	4.4	0.0191	24,237	2403	9.9	32,649

During the course of this survey, particularly the ground stage, it was strongly suspected that omission errors increased with distance from nadir. Although a null hypothesis to test suspected errors was not established at the outset, an analysis was nonetheless conducted to determine whether or not those errors were significant. The twenty 10-acre ground data plots fell into two distinct groups; the first ten between nadir and $\pm 19°$ and the second ten between $\pm 20°$ and 40°. The mean differences of the ground/photo ratios were then subjected to a "T" test. The difference, 3.67 with 18 d.f., was highly significant at the 99 percent level, indicating that the mean ratios were from two different populations.

Since the two surveys were conducted over the same infestation at approximately the same time, comparisons of results, statistical precision, and cost seem appropriate (Table 1). They are not directly comparable; however, since the survey using panoramic photography defined an area of infestation almost twice that of the conventional survey, 520,640 versus 270,255 acres. This difference was ascribed to different minimum fader density thresholds used to define epidemics—0.06 faders/acre for the panoramic survey and 1.0 faders/acre for the conventional survey.

The largest single cost difference between the two surveys was for photo acquisition, $16,376.00 for the panoramic survey and $3,200.00 for the conventional survey. One major advantage of the panoramic survey was that it afforded almost complete coverage of the outbreak and large portions of each forest, while the conventional photography covered only a fraction of the area. Overall survey costs were very similar (Table 1).

CONCLUSION

High-altitude panoramic photographs can be effectively used to provide estimates of lodgepole pine killed by the mountain pine beetle. The most significant problems encountered in this evaluation can be summarized as follows: The data indicate that accuracy of tree counts made from the photos decreased with increasing distances from nadir. This difference was probably due to (1) decreasing scale, (2) increasing obliqueness of the target trees, and (3) a color shift from nadir outward. Voids occurred in the photography between flight lines due to an error in aircraft navigation and between alternate frames due to the skewness of some frames and the inherent design of the equal-area grids. An accurate map product can be produced through use of map registered grids.

In an operational sense, both surveys—optical bar and conventional—worked equally well and both met the required objectives. One major concern with the optical bar survey was the accurate procurement of ground data, i.e., locating a plot and delineating its corners and boundaries, but this was solved with the use of the 7x portable steroscope. The conventional survey had a lower standard error than the optical bar survey, but these and other problems including photo interpretation errors can probably be reduced through additional experience with this relatively new photo format.

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