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Estimating Mountain Pine Beetle-Killed Ponderosa Pine Over the Front Range of Colorado with High Altitude Panoramic Photography

The results of a pilot test compared favorably with those from a conventional survey conducted concurrently.

Abstract: *The potential of high altitude panoramic photography for improving the efficiency of statewide mountain pine beetle (*Dendroctonus ponderosa *Hopkins) damage surveys in ponderosa pine (*Pinus ponderosa *Laws.) forests is discussed.*

Based on the successful results of an earlier design test, a pilot test of the new inventory procedure was conducted over 5.5 million acres in the Front Range of Colorado. The results compared favorably with those from a conventional survey conducted concurrently.

Use of Itek KA-80A optical bar panoramic photography in a loss assessment survey is an alternative to the conventional survey technique. The new survey procedure has a potential for increased survey efficiency, while providing total photographic coverage of the target area. The photographic coverage can serve as a resource data base for other applications.

Introduction

There is a need for periodic estimates of ponderosa pine (*Pinus ponderosa* Laws.) mortality caused by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). These data are used in integrated pest management decision making at all planning levels (Ciesla *et al.*, 1982). In recent years, the Forest Pest Management staff in the Rocky Mountain Region of USDA Forest Service, Denver, Colorado, has been participating in the development of multistage survey techniques to estimate this annual mortality (Hostetler and Young, 1979). These survey techniques consist of a two-stage stratified sampling design. Stratification is based on an aerial sketch map survey. First-stage sampling is based on 90-acre large-scale color aerial photo plots selected systematically from each strata. The second-stage sample, 2.5-acre ground plots, is selected with probability proportional to the number of faders† counted on the photo plots. Ground truth data collected in 1978 from one of these surveys in the Black Hills of South Dakota and Wyoming were coupled with aerial photographs taken over the same area with the Itek KA-80A optical bar panoramic camera in order to develop a new sampling procedure (Dillman *et al.*, 1979a).

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† Fader is a colloquial expression for the discolored, yellow/orange foliage of a dying ponderosa pine resulting from attack by the mountain pine beetle.

Photogrammetric Engineering and Remote Sensing,
Vol. 48, No. 5, May 1982, pp. 741-747.
0099-1112/82/4805-0741$02.25/0

This technique was evaluated on a larger scale in 1979 along the Front Range of the Colorado Rockies from the Continental Divide eastward (Dillman *et al.*, 1980). As part of the evaluation process, this area was surveyed concurrently using a sampling procedure modified from Hostetler and Young (1979a, 1979b).

The two primary objectives of this survey were to (1) evaluate a multistage sampling using panoramic photography to measure current tree mortality in the Front Range of Colorado and (2) compare mortality estimates and costs from this system with those from a conventional survey (Lister, 1981).

Description of the Study Area

The Colorado Front Range was selected as the target site because a mountain pine beetle epidemic exists in an area that is uniquely different from the forest and terrain conditions of the Black Hills. Along the Front Range, ponderosa pine is interspersed with other tree species. In addition, it displays a mottled density unlike the more uniform stocking of stands in the Black Hills.

The Colorado Front Range is a complex of forested mountain ranges, mesas, and plateaus interspersed with nontimbered valleys, foothills, and low hills. Below 5,500 feet, vegetation is largely grass or salt-desert shrubs. These cover types blend into sagebrush (*Artemisia sp.*), gambel oak (*Quercus gambelii* Nutt.), pinyon pine (*Pinus edulis* Engelm.), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) at about 5,500 to 6,500 feet. Under the most favorable moisture conditions at higher elevations, forests of commercial timber quality predominate. Ponderosa pine (*Pinus ponderosa* Laws.) (Plate 1), Douglas-fir (*Pseudotsuga menziesii* var. glauca (Beissn.) Franco), aspen (*Populus tremuloides* Michx.), lodgepole pine (*Pinus contorta* Engelm.), spruce (*Picea engelmannii* Engelm.), and fir (*Abies lasiocarpa* (Hook.) Nutt.) occur in that general sequence up to timberline at about 11,500 feet. Extreme climatic and physiographic differences in Colorado cause local and statewide differences in growing conditions, which result in varying tree sizes, quality, and species (Miller and Choate, 1964).

Several types of insects and diseases occur in this area. Mountain pine beetle is present throughout the ponderosa pine forests of the Colorado Front Range and is presently epidemic over much of the host type. In other parts of Colorado, mountain pine beetle infestations are considered endemic ($<$0.1 tree/acre) and were not surveyed. The western spruce budworm (*Choristoneura occidentalis* Freeman) and dwarf mistletoe (*Arceuthobium* sp.) are also active within the study area.

In recent years the mountain pine beetle has caused extensive damage to Front Range forests. In 1977 an estimated 1.25 million trees were killed by this insect in the Colorado Front Range alone (Johnson and Creasap, 1978). Responding to this threat, public agencies and private landowners are currently spending large sums of money to combat the beetle.

The study area extended from the Continental Divide east to an elevation of about 5,000 feet. The northern boundary was at latitude 39°30′N, and the southern boundary was at latitude 37°00′N, the Colorado-New Mexico border. This area comprises a gross area of approximately 5.5 million acres and includes portions of the Pike, San Isabel, and Rio Grande National Forests.

Methods

Aerial Photography

National Aeronautics and Space Administration (NASA) was requested to acquire 743 frames of Itek KA-80A optical bar panoramic photographs over the Front Range target site with a U2C aircraft (Figure 1). Vertical photographs were taken from 60,000 feet above mean sea level with a planned 60 percent forward overlap at nadir. The average terrain elevation was assumed to be 8,000 feet; thus, with the 24-inch lens, the nadir scale of the photographs was 1:26,000. Kodak Aerochrome high-definition infrared film (SO-131) was used. The actual sidelap varied depending on actual ground track and terrain elevation, but ± 35 percent sidelap was assumed.

Survey Design

The survey design used was a three-stage sampling with selection probability proportional to size (PPS) at each stage (Dillman *et al.*, 1980). Six photo interpreters analyzed the photographs monoscopically on a Richards MIM-4 light table with the Bausch and Lomb Zoom 240 stereoscope. The study area was divided into 373 primary sampling units (PSU). A PSU is each even-numbered photo frame covered by an equal-area grid at 35° either side of nadir (Liston, 1982). The PSU is divided into 132 cells or secondary sampling units (SSU) which are 112 acres in size. Each SSU is further subdivided into 25 equal subcells or tertiary sampling units (TSU). The TSU is approximately 4.5 acres in size (Figure 2).

The first stage of the design involved a quick count of the number of faders in each PSU. This was done by accumulating the fader counts from each of the 4.5 acre subcells located in the lower left hand corner of all 112 acre cells in the PSU.

In the second stage, a sample of 80 PSU's was chosen with probability of selection proportional to the quick count. Those PSU's selected more than once were counted by different photo interpreters each time. The count of faders was recorded for

PLATE 1. Ponderosa pine stand in the Colorado Front Range containing a group of trees killed by mountain pine beetle.

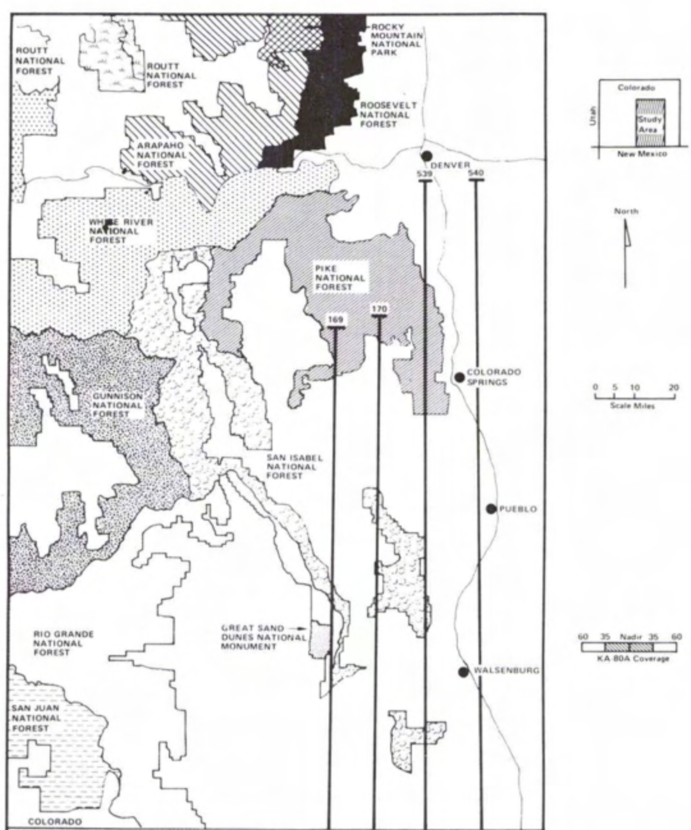

FIG. 1. The Colorado Front Range study site with flight lines displayed.

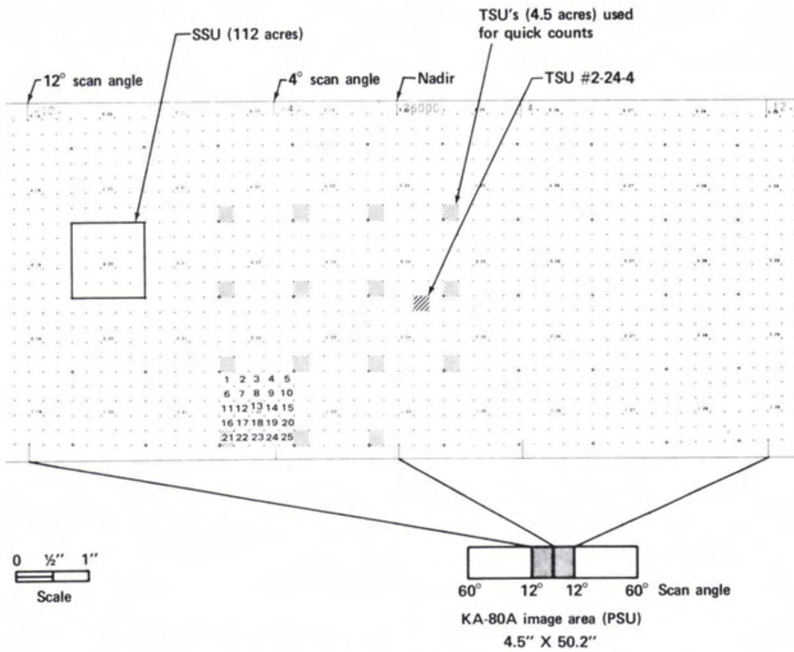

FIG. 2. Central portion of equal-area grid displaying different sampling units.

each of the 132 SSU's within the frame. One SSU per frame was chosen with probability proportional to the fader count for the third stage sampling.

In the third stage, one TSU was selected from each of the 80 SSU's based on probability proportional to the fader count. The boundaries of the selected TSU were located on the ground and data collected on the actual number of 1979 faders present, by diameter class.

Detailed sampling and field procedures are presented by Dillman *et al.* (1979b). Fader counts at each stage and on the ground are aggregated using equations as outlined by Eav *et al.* (1980) to arrive at the estimate of the number and variance of faders within the study area.

FIELD VIEWING

To utilize the optical bar camera transparencies in the field, Klein *et al.* (1980) designed a lightweight, solar-illuminated stereoviewer. This viewer permits the use of full-frame transparencies for stereoscopic viewing at 2×, 4×, or 7×. The viewers with the transparencies can be used to locate plots on the ground and establish plot boundaries.

Full-frame transparencies (4.5 by 50.2 inches) were used in the field rather than prints in order to retain the maximum image resolution and prevent unnecessary cutting of the original film.

RESULTS

GROUND PLOTS

The vegetation heterogeneity and the prominent topographic features helped in locating the sides and corners of the plots to within about 5 feet on the ground. In uniform stands or dense expanses of oakbrush, sides and corners were more difficult to locate. In those cases, the boundaries were determined by establishing intersecting lines based upon easily recognizable features and following an azimuth to the probable plot corner. Particular care was taken in placement of the plot boundaries when the line or corner bisected areas containing faders.

Eighty plots were selected for ground examination. Only 75 of the 80 selected TSU's were visited on the ground. Five plots were excluded because either permission from private landowners could not be obtained or the terrain was too steep for accessibility. Using the 75 sets of ground data, the resultant regression line ($y = -0.494 + 1.858x$) was obtained when ground fader counts (y) were regressed on the optical bar fader TSU counts (x). The correlation coefficient (r) between the ground counts and the TSU counts is 0.82. These regression estimates of the ground counts on the photo counts were used to simulate data for these five missing plots.

ESTIMATED NUMBER OF INFESTED TREES

The estimate of the total number of trees killed by mountain pine beetle in 1978 was 167,687, and the standard error of the estimate of the total was 23,206 faders, giving a relative standard error of 13.8 percent. This sampling error is well within the standard currently defined under the USDA

Forest Service, Forest Insect and Disease Information System (Ciesla and Yasinski, 1980).

PROJECTED COSTS

A total of 4,719 hours of labor was expended on the survey. Field work represented 61 percent (2,848 hours) of the total man-hours expended, whereas the photo interpretation was second with 20 percent (965 hours) of the total hours (Table 1).

Detailed in Table 2 are the 965 photointerpretation hours, the plotting of data, the PSU quick count, and the count of faders in the 80 SSU's and TSU's. The detailed fader count of the 80 SSU's required 76 percent of the photointerpretation hours, while the quick count of the 370 PSU's required 18 percent of the total time expended.

A total project cost model was used to calculate representative survey costs. Total costs for the project were $148,379, with wages, photo acquisition, and travel being the major costs. The conventional survey, which covered the entire Front Range of Colorado, had a model cost of $117,291. This figure is based on 3,879 labor hours and 78 person weeks of travel.

DISCUSSION

COMPARISON OF ESTIMATES

The optical bar panoramic camera and conventional surveys were intended to cover the same study area in order to compare estimates of total population and standard error. Because of problems with aircraft scheduling and cloud cover, the optical bar camera survey covered only one-half of the area covered by the conventional survey. Therefore, the two surveys are for two different populations and, consequently, there is no statistical basis for a direct comparison of estimates. However, the estimates for both surveys are presented in Table 3.

The optical bar camera survey estimate of 167,687 faders (for approximately 2.5 million acres) represents 51 percent of the faders estimated by the conventional survey for the entire area. By assuming the timber type is uniform throughout the range, the estimate from panoramic photographs appears to be a reasonable estimate for one-half of the area covered by the conventional survey. In addition, the estimated relative standard error of 13.8 percent for the optical bar survey and 15.0 percent for the conventional survey are comparable.

TABLE 1. LABOR HOURS FOR THE COLORADO OPTICAL BAR SURVEY.

Activity	Hours
Management	33
Survey design	412
Ground data acquisition	2,880
Photo interpretation and data analysis	965
Evaluation of results	246
Documentation	183
Total	4,719

TABLE 2. LABOR HOURS FOR PANORAMIC PHOTOGRAPHIC INTERPRETATION.

Activity	Hours
Training	28
Photographic indexing	8
PSU quick count (370 frames, 28 minutes per frame)	172
SSU count (9 hours per frame)	730
TSU count (20 minutes per SSU)	27
Total	965

Symbol Definition:
PSU-primary sampling unit
SSU-secondary sampling unit
TSU-tertiary sampling unit

COMPARISON OF COSTS

A direct comparison of costs is also difficult. A general comparison of the cost of the two surveys indicated that the optical bar camera survey required more man-hours, mainly for project design and photointerpretation. Also the total cost for photo acquisition was more for the optical bar than the conventional survey (Table 4).

Project design hours can be greatly reduced in subsequent surveys because of the experience gained in this pilot study. The only design considerations would be the refinement of the sampling strategy.

The photointerpretation hours are dominated by the intensive interpretation of SSU's. If the size of the study area were to be increased by 100 percent (i.e., another 374 nonoverlapping optical bar frames) the time needed to select 80 ground plots would only increase by 18 percent (172 hours). It is only the PSU quick count that would increase for a large area, assuming 80 ground plots were required.

The photographic acquisition cost is higher for the optical bar panoramic camera, but it provides complete coverage of more than 5.5 million acres while the conventional survey photography which samples the infested area covers only about 34,000 acres. This additional coverage provides the basis for additional resource analysis and a permanent record to evaluate change over time.

AIRCRAFT SCHEDULING AND PHOTOGRAPHIC ACQUISITION REQUIREMENTS

The NASA U-2C aircraft did not acquire photos until 7 August because of scheduling priorities

TABLE 3. ESTIMATES FOR THE 1979 COLORADO MOUNTAIN PINE BEETLE DAMAGE SURVEYS.

Survey Method	Area coverage million/acres	Number of faders	Standard Error of Estimate	Relative Standard Error, Percent
Conventional	12.0	327,443	49,027	15.0
Optical bar	5.5	167,687	23,206	13.8

and cloud cover over the target site. 1 September was the final photo date which would permit all necessary project activities to be completed by November. Activities during and after November would likely be adversely affected by the onset of winter weather.

In addition, weather conditions in the Rockies can be severe during August and September. Wind, rain, and snow could begin to remove needles from the 1979 faders and cause them to resemble the 1978 faders. This could increase commission errors on both the fader counts from the panoramic photographs and the counts from the field visits.

Aircraft scheduling and photographic acquisition requirements account for some of the problems encountered in this study. The most logical solution to the scheduling problem is to have a firm committment for the aircraft by reserving the aircraft well in advance of the collection date and having more than one aircraft available.

Photo acquisition requirements can be relaxed. For example, cloud cover over a sensitive area or late faders might be compensated for by designing special sampling procedures into the survey.

PHOTOINTERPRETATION

Ground plots with zero faders contribute to an increased standard error of the estimate in a survey using PPS sampling. Twelve of the 80 ground plots in this survey did not contain any ponderosa pines killed by the mountain pine beetle. Some of these plots contained host and non-host trees killed by other pests which were misclassified by the photo interpreters (commission errors). Eight of the 12 zero count plots had six or less faders counted on the photography. Of the 80 TSU's interpreted, 13 had six faders or less.

To reduce commission errors, photo interpreters should be familiar with the appearance of major types of insect damage activities in the study area, both on the photographs and on the ground. Also, all photo plots with less than six faders should be double checked by photo interpreters to reduce chances of drawing a zero-fader plot.

Not counting faders which are actually present (errors of omission) is evident in the slope of the regression line between faders counted on the photographs and faders actually counted on the ground. The slope of the line in this study is 1.858 and indicates that one fader counted on the photography represents about two faders on the ground. This error is not severe in PPS sampling because the ratio of the counts between stages is used for the calculation of the estimate.

The important thing is that the relationship between photographic and ground counts is consistent. This is reflected in the value of the correlation coefficient (r). In this study r was 0.82 while for the conventional survey the correlation coefficient between low altitude photographic counts and ground count of faders was 0.83. The slope of the regression line in the conventional survey was 1.070 for the combined data.

The effect of scan angle on the photographic counts of faders has not been analyzed exten-

TABLE 4. MAJOR COSTS FOR TWO SURVEYS IN 1979 OF THE COLORADO FRONT RANGE.

Item	Optical Bar Camera Survey		Conventional Survey	
	Hours	Cost	Hours	Cost
Total representative cost		$148,379.00		$117,291.00
Direct labor hours	4,719		3,879	
Cost for photographic acquisition[a,b]		21,000.00		7,440.00
Field survey costs labor and subsistence		47,277.00		49,266.00
Photo interpretation hours	965		429	

[a] The photographic coverage provided by the two surveys are 5.5 million acres for the optical bar survey and 34,917 acres for the conventional survey. The conventional survey covered the entire study area, about 2 million acres, with aerial sketch mapping.

[b] Photographic acquisition for a 1980 operational optical bar camera survey of the Front Range of Colorado will cost $77,000, one original film and two duplicate copies.

sively. Some variation in counts has been noted at scan angles greater than 20° either side of nadir due to increasing obliquity and color shifts.

For the 1979 survey data, an analysis was performed to determine if a change in detection accuracy occurred with increasing distances from nadir. The 80 plots were divided into two groups: one group with plots falling between nadir and ±20°, and the other with plots falling outside that range (±20° to ±40°). The correlation coefficients r between the ground counts and the TSU counts were calculated for both groups, and a test of the significance of the difference between the two correlations was made using Fisher's transformation z. With probability $P = 0.0375$ (the one-sided test), it was concluded that the correlation coefficients are significantly different for the two groups and that the correlation coefficient between the ground counts and TSU counts is higher when the scan angle is below 20°.

The use of stereoscopic viewing may reduce the effects of scan angle on the photographic counts but this would greatly increase the photo interpretation time.

Conclusion

High-altitude photography taken with the Itek KA-80A optical bar panoramic camera is an alternative to conventional survey methods for estimating the number of ponderosa pines killed by the mountain pine beetle. Optical bar panoramic photography offers a potentially cost-effective alternative to the conventional survey.

Acknowledgments

This work was performed under USDA Forest Service Contract 53-3187-8-25 through the Nationwide Forestry Applications Program, Houston, Texas. Dr. F. P. Weber is the contract technical monitor.

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(Received 29 November 1980; revised and accepted 11 December 1981)