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Douglas-Fir Beetle Survey With Color Photos

Aerial color photography and probability sampling techniques applied to an epidemic in California yielded important forest mortality data quickly and economically.

(*Abstract on next page*)

Introduction

The Douglas-fir forest subregion in northwestern California is a major contributor of raw materials to timber and wood products manufacturing—the State's third largest industry. Protection and management of these forest stands is essential to the economy of the State and particularly of the local communities.

By early 1966, it became evident that an old enemy of these timber stands—the Douglas-fir beetle (*Dendroctonus pseudotsugae* [Hopk.])—had reached sufficient numbers to cause widespread tree mortality. The epidemic was a direct result of the storms that brought 1964–65 winter floods.

Faced with heavy losses, forest managers looked for some means of determining the amounts and location of the damage. This information is important for salvage operations, inventory revisions, cutting budgets, and tax adjustments.

An impact survey that combined aerial photography and ground survey was designed to obtain the information needed by forest managers. Similar surveys made by Wear et al. [9, 10, 11] and Ciesla et al. [1] had proved successful. But in this impact survey a new probability sampling technique devised by Langley [2] was used. This technique more effectively directs the photo interpreters and field crews to the areas of greatest mortality. As a result the survey was made at less cost and in less time than if other methods had been used.

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History of the Epidemic

To lend some insight into the survey design we will describe briefly the conditions leading up to the epidemic.

1964. In December, heavy snow and rain storms caused severe flooding and a large unestimated volume of Douglas-fir to be uprooted or damaged throughout northcoastal California.

1965. In April and May, Douglas-fir beetles attacked large amounts of downed material. The storm-caused slash provided ideal conditions for brood establishment, and the number of insects greatly increased during the year. Managers attempting to salvage downed

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material were hampered by widespread damage to road systems during the floods.

After forest entomologists had examined the overwintering beetle population in the autumn, they predicted that green trees would be attacked in 1966.

1966. The first evidence of beetles attacking standing green trees was observed in early May. Weather conditions throughout summer favored beetle development during their critical emergence period. Standing trees began to *fade* or change color in large numbers by late July. In November an aerial flight was made to sketch-map the area of the outbreak. The area was found to cover about 1.6 million acres. A reasonable estimate of mortality could not be made at this time because many attacked and dying trees would not show signs of fading until the early summer of 1967.

ABSTRACT: *Large-scale color aerial photographs (1:8,000) and a stratified two-stage probability sampling design together provided an efficient survey of trees killed by the Douglas-fir beetle. The survey showed that a net total of 535 million board feet cf timber had been killed over an area of 1.6 million acres. The survey cost about $0.005 per acre. Compared to other methcds of obtaining mortality data the survey technique proved to be the best on the basis of accuracy, time required, and costs.*

SURVEY PROCEDURES

DESIGN

Foresters and statisticians examined the sketch-map prepared from the fall 1966 reconnaissance flight (Figure 1). A sampling procedure was then formulated for use in this survey. Briefly, it was a stratified, two-stage, cluster sampling design. The first-stage units consisted of a systematic sample of aerial photographs with multiple random starts [5]. The second-stage units were drawn at random with probability proportional to number of dead trees as estimated by photo interpretation. An integral part of the survey design was the use of large-scale stereo triplets—three overlapping color aerial photographs (transparencies) at a scale of 1:8,000, taken over sample locations within the survey

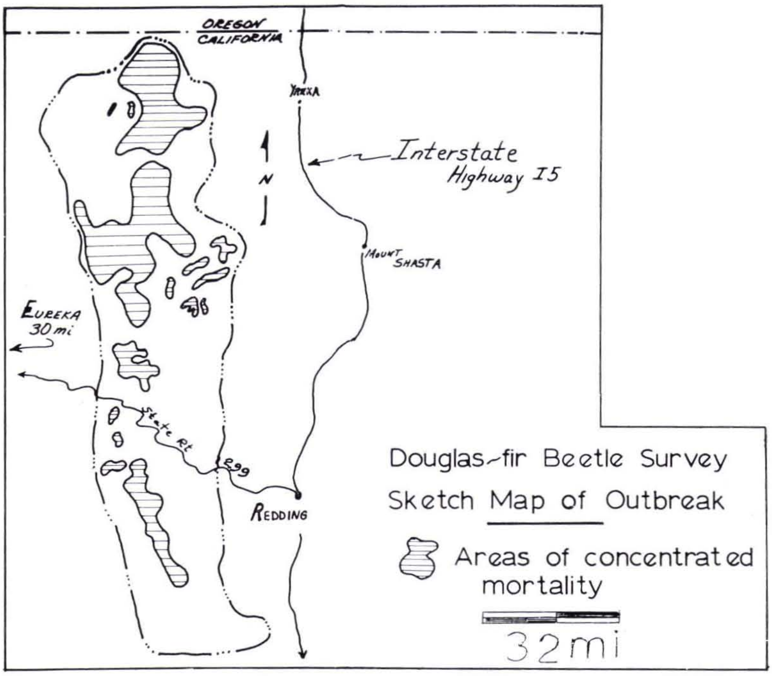

FIG. 1. Sketch-map prepared from aerial reconnaissance survey of Douglas-fir beetle infestation made in November 1966.

area. A detailed account of the statistical theory of the design and computer programming requirements will be found in forthcoming papers by Langley [2] and Norick [4].

The outbreak area was divided into five strata of varying degrees of tree mortality and geographic locality (Table 1). These strata are illustrated in Figure 2.

Two starting points were selected at random within the starting block of each stratum. Each random start specified the location of all photos in the systematically arranged cluster [5].

A cluster is the total number of stereo triplets on alternate flight lines within the stratum. Two clusters were needed to obtain an estimate of variation within each stratum. The large clusters in effect transferred a large portion of the total variance from the between-cluster variance to the within-cluster component. The within-cluster variance was reduced by counting groups of dead trees by the photo interpreters.

TABLE 1. SUMMARY OF FLIGHT LINE AND STEREO TRIPLET INTERVALS, BY STRATA

Strata	*Concentration of Tree Mortality*	*Distance*	
		Between flight lines	*Between stereo triplets*
		Miles	
I & II	Light	12	12
III & IV	Medium	9	9
V	Heavy	6	6

AERIAL PHOTOGRAPHY

Before the aerial photographs were taken the locations of the flight lines and stereo triplets were put onto USGS 1:31,680 scale topographic maps. The maps were then cut into strips and placed in map rollers designed by Merkel et al. [3] to aid in navigation during photography.

The photo mission was made by an Aero Commander 500B and a Cessna 180. Both airplanes were equipped with K-17 aerial cameras (focal length, 12 inches) loaded with Anscochrome D/200 color film. The scale of photography was 1:8,000, camera format 9×9 inches. A flight navigator aided the pilot and the photographer in determining the position on and along each flight line. He instructed the photographer when to take the stereo triplets and marked their location on his flight maps.

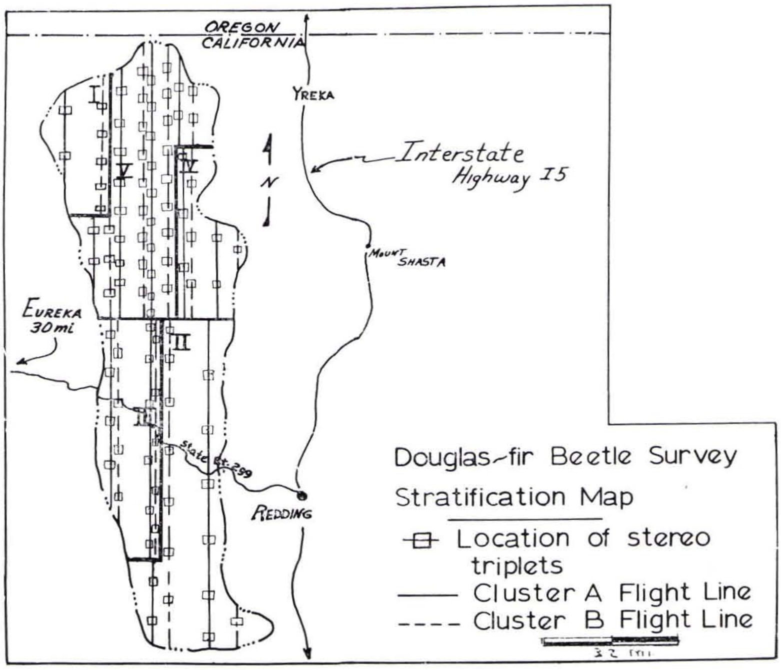

FIG. 2. The infested area was divided into five strata of varying levels of tree mortality. Stereo triplets and flight lines in each cluster were marked on the map.

FIG. 3. A photo interpreter uses an Old Delft stereoscope and desk-type fluorescent light table to study an aerial photograph.

PHOTO INTERPRETATION

After the film was processed and edited, it was given to three photo interpreters: two forest entomologists and a forester. All three men were relatively inexperienced in aerial photo interpretation. Both entomologists previously had been in the area on the ground and were familiar with the timber types, terrain, and appearance of beetle-killed trees. The forester, however, had no previous experience in the area of the outbreak. Each interpreter was briefed on the job to be done and given some training in identifying healthy and beetle-killed Douglas-fir trees on the aerial photographs.

The interpreters examined all of the sample photography using desk-type fluorescent light tables and Old Delft scanning stereoscopes (Figure 3). The center photo of each triplet was examined stereoscopically. A transparent overlay of 81 one-inch squares enabled the interpreters to examine systematically the entire photograph. All groups or individual dead trees killed by the beetle in 1966 were circled with red opaque ink and numbered. Trees suspected of dying before this date had to be separated from the 1966 killed trees but were not recorded. The number of dead trees in each group was counted and recorded. Each group was indexed according to the stratum, flight line, and photo numbers on which it occurred.

When all photo interpretation was completed (about 25 man-days) the data on numbers of trees in each group and the total number of groups interpreted (1,380) were given to the statistician. A computer program had been written to provide a listing of groups in order of their size (number of trees counted on aerial photographs) in the cluster [2]. From this list, groups to be visited on the ground were selected at random with probability proportional to their tree count. A minimum of two groups from each cluster was selected to provide a valid estimate of the within-cluster variance. Additional selections were made to supplement the minimum requirements of 20 groups (4 per stratum $\times 5$ strata). A total of 53 groups was selected for visit on the ground.

GROUND CRUISING

The ground checks of the selected groups provided the volume data and actual tree counts needed to complete the survey. A field force of 8 two- and three-man crews was organized. Each crew used color aerial transparencies placed in acetate holders and local area maps as guides to reach the selected group locations (Figure 4). At each group the species, diameters and cull indicators were recorded for each tree. Two or three dominant trees in each group were measured for height and age to determine site index. Finally, the green infested trees within and next to the boundary of the group were counted if they were present.

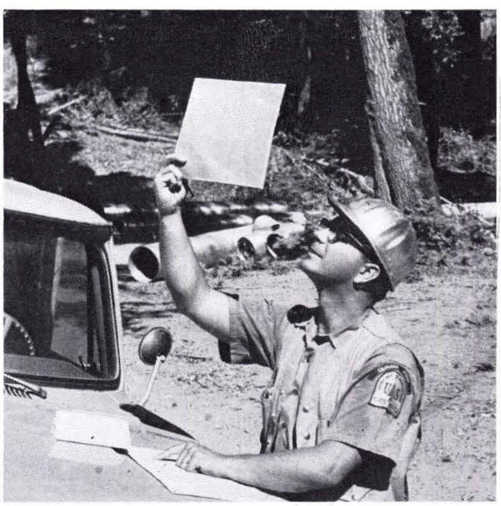

FIG. 4. Color photographs and local area maps enabled survey crews to reach selected areas quickly and efficiently.

TABLE 2. ESTIMATE OF TREE MORTALITY

Mortality	*Amount**
Number of dead Douglas-fir trees	249,000 ± 13%
Gross volume mortality	796,000,000 bd.-ft. ± 12%
Net volume mortality	535,000,000 bd.-ft. ± 11%

* Sampling error is placed at 1 standard deviation.

RESULTS AND DISCUSSION

Gross and net tree volumes were calculated by using appropriate volume tables [7]. The computer program analyzed the photo and ground data and produced an estimate of tree mortality as shown in Table 2.

The net volume *mortality* of 535,000,000 board-feet represents 30 percent of all timber *harvested* on National Forest lands in California in Fiscal Year 1967 (July 1, 1966, to June 30, 1967) [6]. Salvage operations can reclaim at least 50 percent of the dead trees, but the remainder may be lost, mainly because of inaccessibility and other economic limitations of salvage logging.

By using the survey design we could inform forest managers of the extent of their losses in a relatively short time and at minimal expense (Table 3).

For comparison let us consider two other methods by which the survey might have been made:

Ground-aerial observation. An aerial sketch-map would have been used as the basis for locating sample plots for collection of field data. No photography would be used. About four times as many field visits would have been required to obtain the same error of estimate. This would also require an additional 350 man-days of field checking or a total of 500 man-days to do the job. The estimated cost: $21,230 (Figure 5).

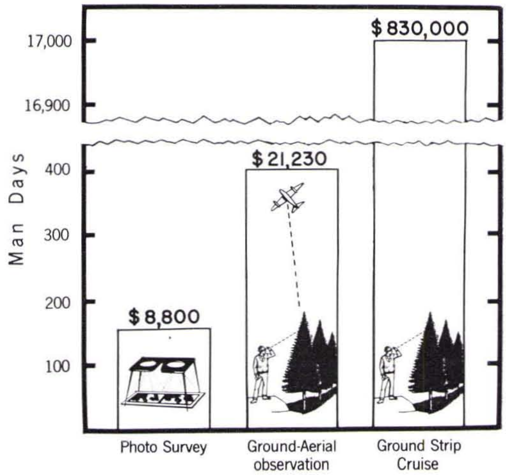

FIG. 5. Man-days of work and costs of three survey techniques are compared. The Cost-Benefit is in favor of the photogrammetric method by a ratio of 100:1.

Ground-strip cruise. Let us assume that only the general area of the outbreak is known as indicated on the map (Figure 1). To obtain an estimate we might imagine a series of cruise lines, one chain wide, across the length and breadth of the survey area. Such an operation would involve about 8,240 miles of cruise line to cover as many acres as was photographed in our photo survey. The cost of such an operation, requiring about 17,000 man-days, is about $830,000 (Figure 5).

Besides the savings in dollars and time, the photo survey method has these other distinct advantages:

TABLE 3. PHOTO AND GROUND COSTS IN DOUGLAS-FIR BEETLE MORTALITY SURVEY

Photo costs		*Ground costs*	
Aircraft	$1024.00	Preparation of field maps (6 man-days)	$204.00
Film processing and editing (6 man-days)	500.00	Cruising (98 man-days)	3332.00
Per diem for photo crew	150.00	Helicopter use[1]	825.00
Salaries (40 man-days for photo crew and photo interpreters)	1425.00	Per diem for field crews	1252.00
Miscellaneous	50.00	Miscellaneous	20.00
Total costs	$3149.00	Total costs	$5633.00
Number of groups interpreted	1380	Number of groups visited	53
Cost per group	$2.28	Cost per group visit	$106.28

Total Cost of Survey	$8,782.00
Cost per Acre	$ 0.005
Total Man-Days	150

[1] Actual cost of helicopter time exclusive of ferrying costs.

- Many other insect damage patterns can be sampled with equally accurate results.
- The survey design is readily adaptable to more sophisticated sample-tree measurement techniques with the use of an optical dendrometer [4].
- The large-scale color aerial photography (1:8,000) results in very high correlations (0.97) of ground-to-photo tree counts. Smaller scale color or panchromatic photography will not obtain as high a correlation with field conditions.
- Other survey methods that do not use aerial photography cannot be seriously considered because of their prohibitive costs and time requirements.

The aerial photo survey method fulfilled the needed requirements of obtaining important mortality data in a short time and at minimal costs. Other types of visual or ground methods could not cover an area the size of this outbreak as efficiently as the method we used. Its flexibility should enable future impact surveys to be made at low cost and with a high degree of accuracy.

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