

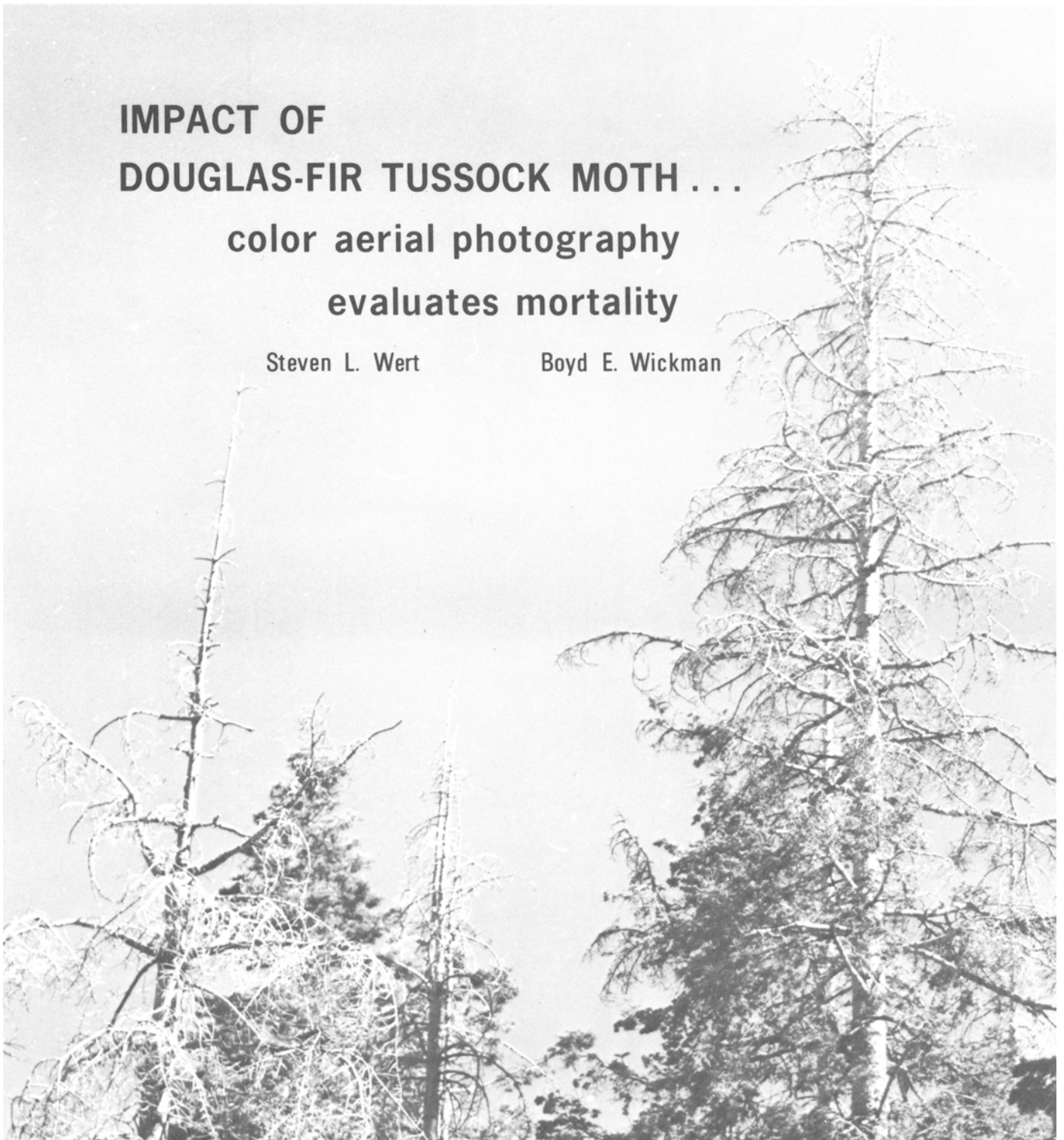
PACIFIC SOUTHWEST Forest and Range Experiment Station.

FOREST SERVICE.
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IMPACT OF DOUGLAS-FIR TUSSOCK MOTH . . . color aerial photography evaluates mortality

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Figure 1—Stand of mixed white fir-ponderosa pine forest type near Alturas, California. White patches on hillside are white fir trees defoliated and killed by Douglas-fir tussock moth.



Figure 2—Location and area of white fir type killed by defoliation from the Douglas-fir tussock moth at Stowe Reservoir. The map was produced from the 1:8,000-scale color photography.

In 1964-65, the Douglas-fir tussock moth (*Hemerocampa pseudotsugata* McD.) caused heavy defoliation of white fir (*Abies concolor* [Gord. and Glend.] Lindl.) over thousands of acres of timber stands in northeastern California. Large patches of saplings and pole-sized trees were completely stripped of needles (fig. 1). Trees in areas between these patches were defoliated to varying degrees. Earlier studies have shown that large amounts of tree mortality and top kill can be expected after 2 years of heavy defoliation by the Douglas-fir tussock moth (Wickman 1963) and this infestation bore out the prediction. But large acreages and lack of manpower made a true picture of losses difficult to get with conventional ground survey methods.

Our first thought was to use aerial photography. As a tool in solving land management problems, aerial photography has been accepted for many years. Many films, filters, cameras, and photographic scales are usable, according to specific objectives. We were impressed by results of studies using large-scale color 70-mm. aerial photography to detect insect damage to balsam fir (*Abies balsamea* [L.] Mill) in Maine and Minnesota.¹ The type of insect damage (defoliation)

and the tree species (balsam fir) closely resembled the conditions we faced.

In 1966, we tested 70-mm. color aerial photography, at a scale of 1:1,584, to determine whether we could detect dead and thin-crowned white fir trees (Wert and Wickman 1968). Correlations were high between photo interpretation of tree crown condition and field examination of the same trees.

Encouraged by these results, we decided to test in 1967 an aerial photo technique operationally by thoroughly sampling a small infestation unit. This paper describes the test and appraises the accuracy, economy, and practicality of the technique for evaluating white fir damage from Douglas-fir tussock moth. Specific objectives of the test were as follows:

1. To test operationally large-scale 70-mm. aerial photography as a method of measuring white fir mortality and crown condition after defoliation by the Douglas-fir tussock moth.
2. To examine the use of small-scale (1:8,000) 9-by 9-inch format color aerial photographs to map and stratify insect damage and lay out flight lines for subsequent large-scale (1:1,584) sample aerial photography.

TEST AREA AND DAMAGE

The test area, Stowe Reservoir, is 1 mile east of Cedar Pass in the Warner Mountains of Modoc County, California. The infestation here covers 450 acres in a moderately sloping basin with mainly south and east exposures. The elevation varies from 5,600 to 6,200 feet, with higher elevations and rugged terrain immediately to the north and west. The second-growth stand is predominantly white fir with a scattering of ponderosa pine (*Pinus ponderosa* Laws.), Washoe pine (*Pinus washoensis* Mason & Stockwell), and western juniper (*Juniperus occidentalis* Hook) at the lower elevations and southern exposures. The original stand was predominantly pine

and was heavily logged 60 to 70 years ago. It was logged a second time for the fir overstory 16 years ago. White fir of sapling and pole size is now the predominant species type and is growing in scattered patches throughout the area.

Defoliation by the Douglas-fir tussock moth was first noticed at the Stowe Reservoir Forest Service campground early in summer of 1964. By fall it was obvious that a serious tussock moth infestation had developed on about 450 acres concurrently with similar infestations totaling about 80,000 acres on other areas of the Modoc and Lassen National Forests. The infestation was controlled by DDT spray and natural causes, but not before many of the white fir trees were seriously defoliated by tussock moth larvae in 1964. Many of these trees subsequently died or suffered top dieback in 1965.

¹Aldrich 1966; Aldrich and Drooz 1967; Heller, *et al.* 1967; Weber 1965.

METHODS

Obtaining Aerial Photography

A two-stage aerial photographic technique was used in the study. In the first stage, we obtained small-scale (1:8,000) aerial photography over the entire area of study. Anscochrome D/200 color film was exposed in a K-17 Fairchild aerial camera (9- by 9-inch format).²

After the film was developed, areas of contiguous white fir damage were outlined directly on the transparencies. This procedure allowed us to produce a map delineating the damaged white fir stand (*fig. 2*). From this map we planned our second-stage large-scale coverage (sampling photography) and the ground cruise needed to obtain "ground truth" data.

Large-scale (1:1,584) aerial photographs were obtained for four flight lines, flown by using a Maurer 70-mm. aerial camera with Anscochrome D/200 color film (*fig. 3*). Total coverage of the sample photography amounted to about 12.5 percent (75 acres) of the study area (*fig. 4*). This film was processed and returned to the field in about 5 days.

Gathering Ground Data

The previous delineation of contiguous areas of infestation on small-scale photography defined the size of the infestation. We imposed a systematic ground cruise over the area, with cruise lines spaced at 5-chain intervals. This was done so that four of the cruise lines coincided with the flight lines of the large-scale photographic coverage.

Ground crews sampled the area 1/40-acre circular plots established at 2-chain intervals along the cruise lines. Data gathered from the plots served two purposes. They established ground truth for aerial photo coverage, and they provided sample data for an estimate of total white fir damage in the area, taking the place of a 100-percent cruise.

Within each 1/40-acre plot we recorded the following data:

1. D.b.h. of all trees
2. Species
3. Crown condition (alive, dead, thin, or normal, and length of top kill if present)
4. Crown class (dominant, codominant, intermediate, or suppressed)

5. Basal area per acre of live and dead white fir trees (as determined by a 360° sweep of a 40-Basal Area Factor (BAF) optical prism from the plot center)

6. Year of death if caused by tussock moth or secondary insect attack.

Along the cruise lines covered by the large-scale aerial photography, the plots were viewed stereoscopically on the film by means of a portable light table. The location of each plot center examined on the ground was pinpricked on the film. All white fir trees within the plots and visible on the film strip were circled and numbered on a transparent acetate template placed over the film. This provided a count of visible fir trees to compare later with counts made by photo interpreters in the office. Time studies for use in evaluating efficiency were made for each phase of the field operation by a third crew member.

Interpreting Photos

Before photo interpreters looked at the actual plot transparencies, they were trained extensively in identification of tree crown conditions. Stereograms with descriptive commentaries were used to present examples of trees encountered on the infested areas. Interpreters spent about 8 hours studying the stereograms before they began work. The interpreters were also given a tree species identification test from extra coverage film of the same area. Both interpreters were able to identify white fir and associated species within acceptable limits of accuracy.

At each plot location pinpricked on the large-scale 70-mm. photography, the limits of the plot boundaries were plotted on clear acetate templates. Each plot was indexed as to the flight line on which it occurred and numbered in consecutive order. The film was then examined by two photo interpreters.

The photo interpretation procedure was as follows:

1. Each interpreter recorded on a prepared form (*fig. 5*) the tree crown condition of each white fir tree occurring on the plots. Tree crown condition was classified as alive, dead, thin or normal, as for ground data. Top killing was also recorded if it was evident and the length of the killed top in feet was estimated.

2. All white fir trees interpreted were circled and numbered on the templates prepared, according to the number and description of the trees as recorded on the form.

When photo interpretation was completed for all plots, the resulting data were compared with data gathered in the field.

²Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

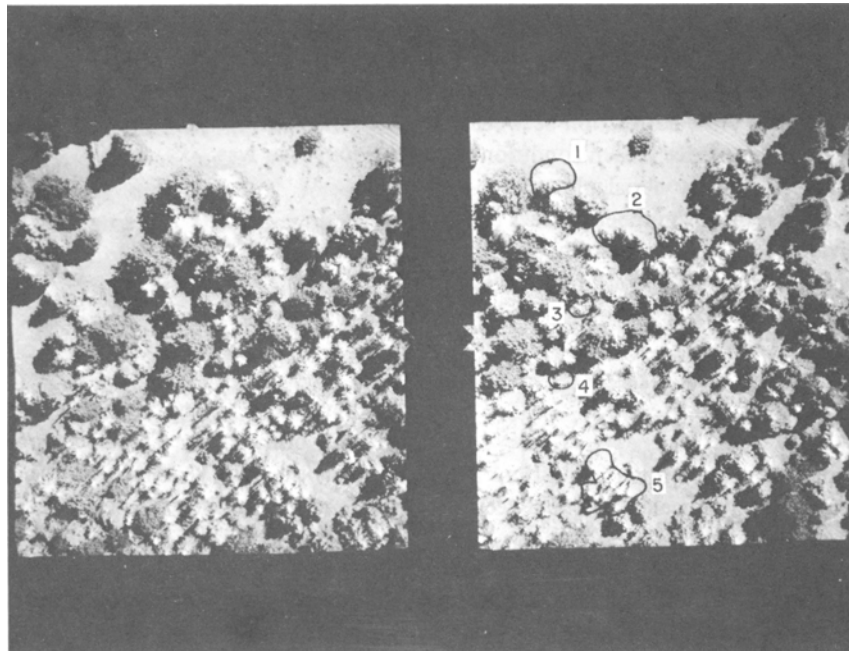
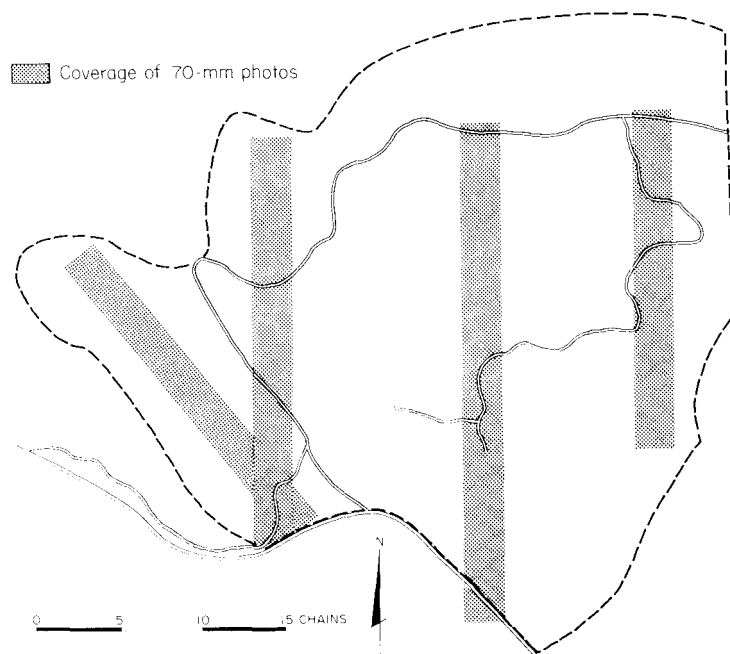


Figure 3—Example of large-scale aerial photography (stereogram) showing white fir mortality from Douglas-fir tussock moth, was photographed in August 1967, at scale of 1:1,584.

1. White fir about 50-60 feet high. Top kill about 20 feet with very thin crown in lower two-thirds of crown. Notice that it is overtopping a green tree on the right.
2. Healthy white fir trees.
3. Two dead white fir trees.
4. White fir, thin top, about 15 feet high.
5. Group of 12 dead white fir trees.

Figure 4—Area covered by the second stage 70-mm. photography at 1:1,584 scale. Four flight lines covered 75 acres.



RESULTS AND DISCUSSION

Data were compared and analyzed to answer two basic questions: (1) Is there close correlation between photo and field observations of tree crown condition? (2) Is it possible to estimate by aerial photo technique white fir losses in terms of number of trees per condition class (alive, dead, top-killed) within acceptable limits of accuracy on an operational survey basis?

Correlations of Photos and Ground Truth

For each category of tree crown condition a correlation coefficient (r) was calculated between

photo observations and ground truth. The correlation coefficient in this work and in similar work done the previous year was:

Crown condition:	Correlation	
	1967	1966
Dead	0.95	0.98
Alive	.81	.85
Thin	.78	.70
Top-killed	.78	.54

Interpreters were consistent in performance through both years. The differences in correlation between the two years are slight and not significant with one exception—the increase in correlation for

TUSsock MOTH DEFOLIATION STUDY - PHOTO INTERPRETATION FORM

Plot No. 2-3 Location STONE RESERVOIR Time ended 11:10
 Flight line 2 Time begun 11:00
 P.I. by GREENTREE Date 11-67 Elapsed time 10 min.

Tree No.	Crown class	Tree condition		Foliage present		Top-kill (feet)	Crown diam. ^{1/}	Total Ht. ^{1/}	Foliage color-- (gray,yg, y,r,b)	Cause of death ^{2/}	
		Alive	Dead	Thin	Normal					T.m.	Other
1	1	✓		✓		10					
2	1	✓									
3	2		✓							✓	
4	1										
5	3	✓		✓		2					
6	1		✓							✓	
7	4		✓							✓	
8	2	✓									
9	1	✓		✓		1					
10	2		✓							✓	
11	1		✓							✓	
12	3	✓		✓							

^{1/} Only for volume estimates. ^{2/} From field notes.

Figure 5—Form used during photo interpretation of the large-scale (1: 1,584) 70-mm. photography. Measurements of crown diameter and total height were not made on this survey but could be made for larger trees to give volume estimates of mortality.

the crown conditions "top-killed" and "thin." We believe this increase was a result of the more extensive training given interpreters in 1967. During the photo examinations of 1966, interpreters were given few examples of top-killed or thin-topped trees to associate with observations made during their examination of the study sites. In 1967, however, extensive training was given in the recognition of these categories of tree crown condition. We feel it is important that interpreters recognize these categories. Trees that are top-killed or thin-crowned suffer a serious reduction in growth.

Comparison of Field and Photo Cruise

Data from the sample field cruise provided an estimate of the number of white fir trees killed in the area of Stowe Reservoir.

From the field and photo data, we computed a regression equation for each interpreter to provide an aerial photo estimate of tree mortality. The regression equation for interpreter No. 2 was slightly better than for interpreter No. 1 because of the lower standard error of estimate (*fig. 6*). The resulting predicted values from both interpreters are compared with the field estimate of mortality in table 1.

The results show that in this test the photo estimate of mortality was comparable to the field estimate. Photo estimates of top-killed, thin-crowned, and live trees were also comparable (*table 2*).

Only a 100-percent cruise of the area could yield an accurate account of mortality and damage. However, such an undertaking would be impractical for large infestation areas such as this. This study shows that estimates of white fir mortality and tree condi-

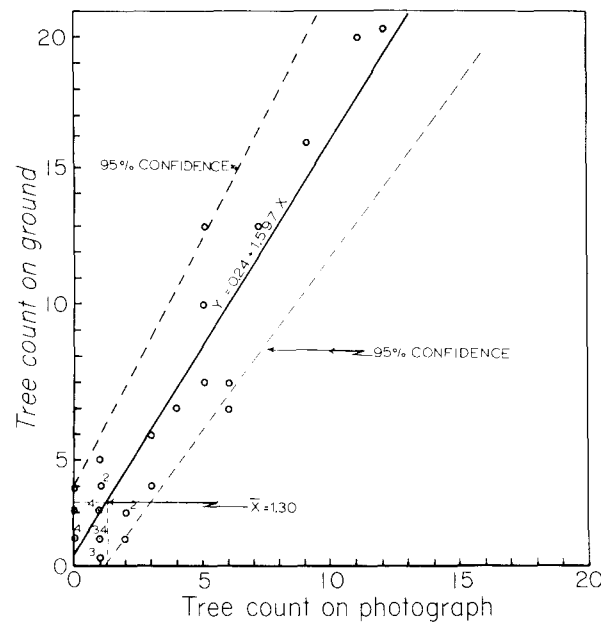


Figure 6—Plotting of regression equation $y = 0.24 + 1.597X$ in which X is the number of dead trees counted on the photo.

Table 1.—Comparison of field and photo estimates of white fir mortality

Source of estimate	Estimate of dead trees per acres ¹	Regression equation ²
Field cruise	105.60 ± 7.6	—
Photo interpreter 1	111.60 ± 8.6	$y = -0.42 + 1.454x$
Photo interpreter 2	111.44 ± 8.1	$y = 0.71 + 1.597x$

¹Standard error of estimates at ± 1 S.D.

²Value x is number of dead trees counted on the photo.

Table 2.—Comparison of field and photo estimates of white fir tree condition

Crown condition	Estimate of trees per acre ¹		Regression equation for photo estimate ³
	Field	Photo ²	
Top-killed	50.27 ± 17.4	58.21 ± 17.2	$y = 0.49 + 0.26x$
Thin-crowned	96.11 ± 8.0	119.41 ± 18.0	$y = .41 + .51x$
Live	214.23 ± 11.6	252.52 ± 21.0	$y = 1.52 + .67x$

¹Standard error of estimates at ± 1 S.D.

²Averages for two photo interpreters.

³For each class, value x is number of such trees counted on the photo.

tion can nevertheless be made from large-scale sample aerial photography so as to be comparable with estimates obtained with an extensive ground cruise such as we undertook here.

Comparisons of photo and ground estimates would

not be complete without consideration of the time required to produce each estimate.

The average time spent per plot evaluating white fir condition was 9 minutes for photo interpretation and 27 minutes for the ground cruise. This includes

setup time, note-taking, and travel between plots. To complete the ground cruise and compute the estimate required 60 man-hours. The photo cruise estimate was available in 20 man-hours. The photo cruise thus represents about a 67 percent savings in man-hours to obtain comparable mortality data on white fir.

This study shows that large-scale color aerial photography has value as part of a sampling technique to evaluate insect-caused mortality in white fir stands. More elaborate statistical sampling schemes incorporating double sampling with regression or probability sampling would be appropriate on larger acreages. Besides being adaptable to many statistical sampling schemes, this aerial photographic technique has other significant advantages:

- One man can efficiently perform a mortality

cruise on a number of photo plots. To be as efficient on the ground, at least two men would be required.

- Aerial photography supplies a permanent photographic record of a particular date and set of stand conditions. This allows further, more detailed examination of plots at the convenience of the investigator.

- The technique as described in this paper is not out of reach financially for the forest manager. The cost of such surveys in dollars spent for labor is either less than or equal to that of field surveys taken to estimate losses. For larger areas the savings may be greater than the 67 percent figure quoted earlier. And the efficiency of such surveys would increase on larger acreages.

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Thorough evaluation of insect impact on forest stands is difficult and expensive on the ground. In a study of tree damage following Douglas-fir tussock moth defoliation in Modoc County, California, large-scale (1:1,584) 70-mm. color aerial photography was an effective sampling tool and took less time and expense than ground methods. Comparison of the photo interpretations with a sample ground cruise gave high correlations (0.78 to 0.095) for tree mortality top kill, and an estimate of mortality made from photos was within 5 cut of the ground cruise estimate.

OXFORD: 453 -145.7 X 18.77 *Hemerocampa pseudotsugata* -587.2:174.7
Abies concolor (7041:587.2.

RETRIEVAL TERMS: *Hemerocampa pseudotsugata*; *Abies concolor*; insect damage evaluation; aerial photography; California.

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