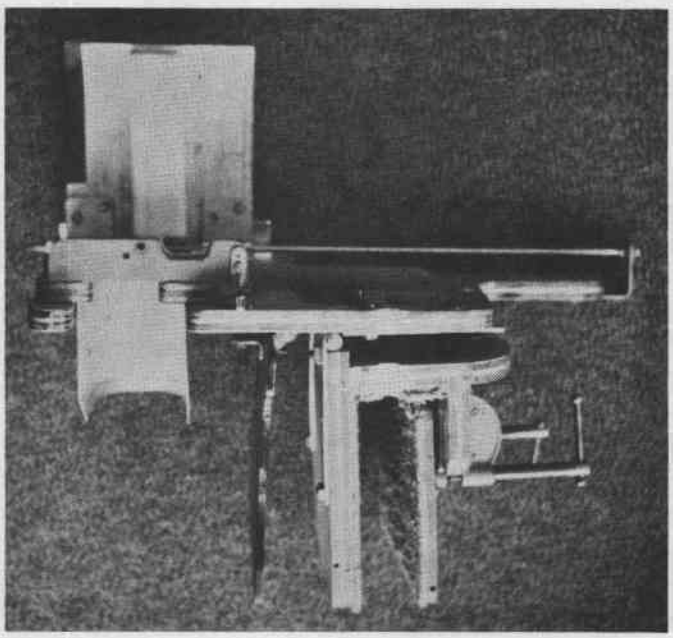
evaluation of 35mm Vertical Aerial Photography for estimating Tree Mortality



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EVALUATION OF 35 MM VERTICAL AERIAL PHOTOGRAPHY FOR ESTIMATING TREE MORTALITY

by

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ABSTRACT

Evaluation of four 35 mm film:lens combinations for estimating conifer mortality showed that large-scale true color images obtained with Kodak High Speed Ektachrome and color infrared images obtained with Kodak Ektachrome Infrared, both exposed through a 135 mm lens were best. Higher correlation coefficients were found for the true color:135 combination than color IR:135 combination.

Correlation between ground counts and photo counts of stereoscopically examined Kodacolor prints was no better and possibly not as good as correlations between ground counts and enlarged images of projected 35 mm transparencies.

This type and format of photography, as with other types and formats, has its advantages and disadvantages, and would be useful in determining mortality rates or making mortality counts on areas where full coverage is not desired. Other innovations are discussed.

Survey designs in which plot selection is based on probability proportional to size (numbers of trees) are apparently more efficient than methods employing simple random selection. An estimated mortality rate of 1.5 trees per acre was indicated, and estimates of 9.8 dead good-topped trees per acre plus an additional 9.5 green high-risk trees per acre were found. Most mortality and tree decline were associated with disease agents, and continuing or accelerated disease-caused decline is expected in the area. Western white pine,lodgepole pine, and Douglas-fir accounted for over 90 percent of the recent and older mortality.

The widespread occurrence of destructive root pathogens, including *Armillariella mellea* and *Poria weirii* (identified on high-risk trees during the survey), indicates that even though tested control measures are unavailable, best available alternatives discussed herein should be considered in management of the area.

INTRODUCTION

Remote sensing techniques, especially aerial photography, are and have been valuable tools for the forest manager. Recently, utility of large-scale color or color IR (infrared) photography for detecting forest damage, primarily mortality, has been recognized (McGregor, et al. 1972; Murtha 1972; Heller and Bega 1973; Williams 1973; Meyer and French 1966, 1967).

Often, however, cost is prohibitive, proper timing cannot be scheduled, or such small areas are involved that large format photography cannot be obtained. Lately, 35 mm aerial photography has been shown to have both practical and wide application in forestry and range work (Klein, 1970; Harris, 1971). Aerial photography using 35 mm film is an inexpensive and accurate method of detecting and quantifying numbers of trees killed by the mountain pine beetle (*Dendroctonus ponderosae*, Hopkins) in specific areas (Klein, 1973b) and may be used operationally and inexpensively to record year-to-year beetle trends over extensive areas (Klein, 1973a). Because of these attributes, plus the ease of obtaining suitable cameras, film, development, camera mounts, and aircraft, 35 mm photography was tested in the Northern Region. The test was in response to a request made by the Priest Lake District, Idaho Panhandle National Forests, to estimate mortality caused by root pathogens over nearly 900 acres in the Binarch Creek drainage.

OBJECTIVES

Objectives of the study were to determine:

1. Level of mortality
2. If root disease centers could be identified on 35 mm photography
3. Optimum film-lens combinations
4. Whether the system was feasible for use in northern Idaho Forests
5. Systems deficiencies

MATERIALS AND METHODS

Description of Test Site

Test site is located within the Binarch Creek drainage in T. 59 N., R. 5 W, sections 1, 2, 3, 11, 12, Boise Meridian, and ranges from approximately 2,500 to 7,000 feet in elevation. Exposure was generally south. *Tsuga heterophylla/Pachistima myrsinites* was the predominant habitat type (Daubenmire and Daubenmire, 1968).

Photographic Parameters

Vertical photography was obtained with a 35 mm Honeywell Pentax Spotmatic [1/] single lens reflex camera with through-the-lens metering system and equipped with a remote-operated, battery-powered film advance. Two lenses, Super Takumar 1:1.4 50 mm and 1:4 135 mm automatic and three films, Kodak Ektachrome infrared, Kodacolor-X and Daylight Kodak High-Speed Ektachrome were evaluated. A Tiffen #12 yellow filter was used in

1/ Mention of commercial products is for convenience only and does not imply endorsement by USDA.

connection with color IR film. A Pentax polarizing filter was used with High-Speed Ektachrome and no filter was used with Kodacolor.

Film:lens combinations tested were: Kodak Ektachrome Infrared with 135 mm lens (designated IE:135); Daylight Kodak High Speed Ektachrome with 50 mm and 135 mm lenses (designated as EH:50 and EH:135 respectively); and Kodacolor-X with 50 mm lens (designated as CX:50). The camera was held in place in a mount described by Meyer (1973).

A Cessna 182, capable of sustaining a minimum air speed of 90 to 100 miles per hour was used.

Flying altitude above datum was 3,000 feet and 5,000 feet for 50 mm and 135 mm lenses respectively. Approximate photo scales were 1:11,000 for 135 mm lens and 1:18,000 for the 50 mm lens, giving coverage of nearly 28 acres and 60 acres per frame respectively (Meyer, 1973). Exposure interval required for 60% endlap when flying at the desired speed of 90 to 100 miles per hour was approximately 3 and 4 seconds for 135 mm and 50 mm lenses respectively (Meyer, 1973).

Inclement weather delayed photography until the first week of October 1973. At the beginning of the flight, the sky was clear with a few scattered clouds, but when actual exposures were made, a fairly dense haze covered the sky.

Photo Interpretation

Circular 1-acre plots on each slide or Kodacolor print falling within the test site were evaluated for current year mortality (red trees) and older mortality.

Initially, a slide was projected onto a white paper screen and the projection image circumscribed on the paper. Measurements of the image were taken and necessary diameters for 1-acre circular plots for slides exposed through both the 135 mm and 50 mm lenses were delineated in the center of the circumscribed slide image.

All slides were projected onto the paper screen so that projection image of each coincided with the circumscribed image, and all red and older dead trees falling inside the appropriate circular 1-acre plot counted and tallied as either recently dead (red) or older dead. Trees with only a red top, where they could be discerned as such, were not counted. Circular 1-acre plots were systematically delineated on the center of stereo portions of each Kodacolor print, and mortality counts made using a pocket stereoscope.

Two mortality counts were made by the same photo interpreter for each plot and averaged. Total mortality counts including recently dead (red) and older dead trees for each photo plot were then grouped according to lens:film combination. While evaluating plots for mortality, each was assessed for obvious signs of cutting, and each plot tallied as to recently or heavily thinned or unthinned.

Plot Selection and Acquisition of Ground Truth

Twenty percent of the photo plots in each film:lens combination were selected for ground truth data acquisition on a probability proportional to number of total dead (i.e., size) trees, using the computer subroutine, PPSORT for selecting each ground plot (Stage, 1971).

Slides of each selected ground plot were enlarged to a scale of 1:1000-1:1200 on 3-inch x 5-inch format color Polaroid film for orientation of ground crews. Plot center points were designated on each plot.

Plot boundaries were laid out on the ground by measuring off radii 117 feet horizontal length from plot center. At the outer edge flagging was tied to designate the plot circumference. Enough radii were measured on each plot so that one could see from one flag to another on circumference.

For each plot, all dead trees over 5 inches in diameter were counted, species determined, d.b.h. (diameter at breast height) estimated to the nearest 2-inch d.b.h. class, and probable cause of mortality determined. Although numbers of "red" trees could not be ground checked, since ground evaluations were not made until the following summer, an effort was made to correlate most recent mortality to red trees observed on photos. In addition, any high-risk live trees, including suppressed, root diseased, thin-crowned, or western white pine, *Pinus monticola* Dougl., with blister rust (*Cronartium ribicola* J. C. Fischer) bole infections, were tallied by size class and species.

To determine closeness of photo plot size to actual ground plot size, points on photo plot boundaries were compared to actual ground points for six plots ground checked.

Data Analysis

Simple correlation coefficients (Freese, 1967) were calculated to determine the degree of linear association between ground and photo mortality counts for plots in each film:lens combination.

Total and per acre populations of dead trees were estimated for each grouping of plots selected by PPSORT for ground evaluation. Estimates were made with a selection probability based data expansion system developed for PPSORT (Stage, 1971) and adapted for computer usage by Wayne Bousfield. [2/]

2/ Impact evaluation specialist, Foest Env. Prot., State and Private Forestry, USDA, Forest Service, Missoula, Montana.

Total dead photo counts were used for comparison with ground truth data in all cases.

Plot information not totally related to probability of selection (e.g., green high-risk tree data) was analysed to determine the basic statistics: mean (X), standard deviation (S), and standard error (Sx). Expansion of this data was accomplished by multiplying population means by designated acreage factors to obtain estimated total or per acre populations.

Confidence limits for all population estimates were established at the 95% level of confidence; i.e., tabled t value with n-1 degrees of freedom for 95% confidence limit multiplied by standard error (Freese, 1967). Confidence interval (CI) sometimes referred to as percent sampling error is defined as the confidence limit divided by the estimated total or per acre population multiplied by 100. It was calculated for all estimated populations to facilitate comparison of standard errors about different sized total or per acre population estimates.

Usefulness of the PPSORT method of sampling was evaluated by comparing population statistics determined by the PPSORT method for thinned and unthinned plots to corresponding population statistics of a simple random sample of the same number of thinned and unthinned ground checked plots.

Paired or unpaired t-tests were used to test differences between populations of recent dead trees (red), green high-risk trees, and size classes and species occurrence in thinned or unthinned plots. The 95% level of confidence was used in all cases.

Study area was stratified into recently or heavily thinned or unthinned areas, and total acreages in each stratum determined with a Martin-Kuykendall area calculator. Area in the thinned stratum was 580 acres and that in unthinned areas was 320 acres.

RESULTS

System Evaluation and Image Quality

Certain problems with the system were immediately obvious. The most important was that of following or tracking a designated flight line. Due to the scarcity of easily identifiable landmarks, the closeness of predetermined flight lines, and wind, tracking was difficult at best. However, once an observer became acquainted with his job and layout of the country, tracking of established lines improved.

Because of the tracking problem some of the area was photographed twice and some not at all. Sidelap was nonexistent unless by accident and insufficient endlap for 100% stereo coverage was obtained.

Shutter activation was not accomplished about one-fifth of the time, indicating faulty connections somewhere within the electrical system or mechanical drive advance attached thereto.

Although one of the objectives of this study was to evaluate different films, which required much reloading, constant reloading of film was inconvenient and time consuming.

Photos derived from exposure through the 50 mm lens were clear and resolution good as indicated by the Polaroid enlargements. Many photos obtained with the 135 mm lens had blurred images indicative of inadequate shutter speed.

Red trees were more easily identified on color photos (EH) than on color infrared (IE) photos, because differences between red trees and red shrubs were more distinctive on EH than on IE films. Yellowing larch were also confusing on color infrared photos.

Plot center points were easily located on the ground using Polaroid or Kodacolor prints where openings or other easily identifiable landmarks were present. However, on photographs which included only a dense closed canopy, location was very difficult and may not have been accurate. The latter case occurred with two or three plots.

Actual plot circumferences laid out on the ground for six plots were compared to corresponding plots delineated on Polaroid or Kodacolor prints. Three comparisons were made for exposures made through the 50 mm lens and three through the 135 mm lens. Fifty percent of the time ground points and photo points matched exactly; the other half, measurements were off slightly. Where differences were noted, ground plot and photo plot circumferences were not over 3 to 5 feet different from each other. In every case, where one side was long, the opposite side was short indicating that plot centers were slightly mislocated, rather than plot size being incorrect.

DATA ANALYSIS--Film:lens Combinations

A total of 94 photo points were included in the core study area, 38 for IE:135, 9 for EH:50, 32 for EH:135, 15 for CX:50. Sixty-four plots were designated as unthinned, and 30 as heavily or obviously thinned. Of the 94 photo points, 33 were selected for ground evaluations. Units selected, photo counts, and ground truth data including high-risk live and dead trees are listed in Table 1.

Because broken-topped trees would probably not be included in salvage operations, only dead trees with unbroken tops are included in all analyses pertaining to dead trees.

Table 1.--Data obtained from photo and followup ground evaluations.

Unit no.	Lens:film	Photo count data: Old Dead	Photo count data: Recent Dead (Red)	Ground evaluation data: High risk live trees by diameter class: 5-10	11-15	16-20	21-25	26-30	Dead trees without broken tops by diameter class: 5-10	11-15	16-20	21-25	26-30	Total live	Total dead	Dead with broken top	Thinned	Unthinned
*1	IE:135	3	2	5	4				4	1				9	5	4		X*
*3		5	1	2	6	1			9	8	1			9	18	3	X	
*4		3	0	4	3				5	3	1			7	9	1		X
*8		7	3	4		1	1		4	1				6	5		*X	
14		16	2			2	1		7	7	4			3	18	1		X*
*22		11	2	3	4	4	2	1	1	5	1	2		14	9	1		X*
*25		18	2	3	3	7	2	2	6	8	1			17	15	2		X
*27		5	3	4	5	1		1	4	4				11	8	4		X
*29		14	1	1	17	6	3		15	5	4	1		27	25			X*
36		3	1	1	4		1		6	2	2	1		6	11	8	*X	
39	EH:50	7	3	4	5	5	1	1	9	11	1			16	21	0		X
*42		9	2	4	6	4			3	5	2			14	10	0		X
*43		7	2	8		3	1		4	7	1	2	1	12	14	4		X*
44		9	0	4	4	3	2		2	5	7	2		13	16	2		X*
*45		5	0	1	4	7			10	5	2			12	17	4		X
46		5	0		1	2			7	5	1			3	13	1	*X	
*49	EH:135	20	2	4							24	7		4	31	2		X*
*50		4	1	2					4					2	4			X
*52		0	0	3					1					3	1	1		X
*54		8	1	8	1				12	2				9	14	1	X	
59		5	2	10	3	1			5	3				14	8	2		X*
61		7	3		1				8	4	1			1	13			X*
*69		2	1	3	1	3			2	1			1	7	4	1	X	
*70		5	2		1	4	1	1	1	2			1	7	4	3		X
*72		9	3		1	4	1		1	8	6	1	1	6	17			X
79		6	1	8		1			6	6	1			9	13			X*
*80	CX:50	9	2	8	7				15	6	1			15	22	4		X*
81		2	1	5	1				7	3				6	10	6		X*
82		9	0	2	2	1			8	4				5	12	4	*X	
*83		13	1	10	2				8	11	2			12	21	3	*X	
84		2	0	6	2	4			3	2				12	5	1	*X	
*87		5	0	11	2	1			11	17	1	1		14	30	6	X	
93		13	3	2	2	4			11	15	2	1		8	29			X

1. Asterisk by unit number denotes PPSORT selection for film:lens combinations.
2. Asterisk by thinned or unthinned designation denotes PPSORT selection for thinned or unthinned variations.

Information from PPSORT analyses of film:lens combinations of dead tree data indicates that smallest confidence intervals on the mean are found for EH:135 and IE:135 combinations each with a 53% interval. The EH:50 combination had a 93% interval and CX:50 had a 118% interval. Correlation coefficients varied from strongly negative (CX:50, EH:50) to strongly positive (EH:135) (Table 2).

Table 2.--Population estimates correlation coefficients (R) and confidence intervals (CI) for film:lens mortality data.

Film:lens	R value	Est. population per acre	Est. total population per acre	CI
EH:135	0.971	5.83 ± 3.09	5249.78 ± 2778.3	53%
EH:50	-.963	11.51 ± 10.71	10363.00 ± 9645.6	93%
IE:135	.449	9.97 ± 5.25	8970.16 ± 4725.0	53%
CX:50	-.973	22.162 ± 26.12	19946.00 ± 23507.3	118%

Even though large differences between photo counts and actual ground counts (Table 1) often were found, paired t-tests indicated no significant difference between ground counts and photo counts for any of the film:lens combinations.

DATA ANALYSES--Evaluation of the PPSORT Sampling Method

Narrower confidence intervals for both thinned and unthinned plots were found with PPSORT sampling than with simple random sampling (Table 3), and were considerably less than those for any of the film:lens combinations (Table 2). While numbers of dead trees per unit appear to be less for thinned than for unthinned plots, statistical analyses indicate that this difference is not significant.

Table 3.--Comparison of mortality estimates determined by PPSORT or simple random sampling of thinned and unthinned plots.

Selection	Est. population per acre	CI
Unthinned		
Random	12.17 ± 3.94	32%
PPSORT	11.62 ± 2.90	25%
Thinned		
Random	12.67 ± 5.42	43%
PPSORT	8.86 ± 3.30	37%

DATA ANALYSES--Populations of Dead Trees

For this study, population estimates of dead trees will be based on those obtained from PPSORT analysis of thinned and unthinned grouping of data (Table 3). It was determined that 320 acres had not been recently or heavily thinned, while 580 acres had been recently or heavily thinned.

Expanding PPSORT analysis data to these acreages gives an estimated total population of 8,857.36 $\pm$ 2,862.6 dead good-topped trees or 9.8 trees per acre.

Western white pine and lodgepole pine accounted for the majority of mortality. With the exception of lodgepole pine, differences between species occurrence on thinned and unthinned were nonsignificant (Table 4).

A negative correlation between size class and frequency of occurrence was indicated. Size class distributions were not significantly different for thinned or unthinned variations (Table 4).

Table 4.--Percent mortality occurrence by size class and species in all ground-checked plots.

Size class	Percent occurrence in thinned (10) plots	Percent occurrence in unthinned (23) plots
5-10"	53	48
11-15"	40	38
16-20"	5	11
21-25"	2	3
26-30"	1	1
Species*		
Western white pine	41	61
Lodgepole pine	39	15
Larch	3	4
Douglas-fir	10	15
Grand fir	4	3
Ponderosa pine	2	1
Cedar	0	1
Spruce	0	1
Western hemlock	1	1

*Scientific names for conifer species are listed in Appendix I.

Although diagnosis of older mortality is difficult, it appeared as though white pine blister rust caused by *Cronartium ribicola* was primary problem in western white pine, and root disease caused primarily by *Poria weirii* (Murr.) Murr., and/or *Armillaria mellea* (Vahl ex Fr.) Kimm. was the primary problem in Douglas-fir and grand fir. No obvious agent was consistently associated with mortality in lodgepole pine.

DATA ANALYSES--Mortality Rate

Red (recent dead) trees are indicative of mortality for a given year. Counts listed in Table 1 indicate that 48 red trees were observed on photo plots.

Unpaired t-tests indicate that a significantly greater number of red trees were found on unthinned than on thinned plots. Analyses of red tree data (Table 5) from all 33 plots show an annual mortality rate of 0.80 ± 0.65 tree per acre for thinned and 1.7 ± 0.44 trees per acre for unthinned areas.

Total population of red trees on mortality plots is estimated to be 1,242.4 ± 460.1 trees on the core study area.

The same disease agents implicated in old mortality are involved with recent mortality.

Table 5.--Population statistics and estimates of recent mortality.

Thinned	Unthinned
$\bar{x}$ = 0.80	$\bar{x}$ = 1.7
S = .92	S = 1.02
$S_{\bar{x}}$ = .29	$S_{\bar{x}}$ = .21
Est. Population per Acre .80 ± .65	Est. Population per Acre 1.7 ± .435
Est. Total Population on 320 Acres 256.0 ± 208.0	Est. Total Population on 580 Acres 986.0 ± 252.13
CI = 81.3	CI = 25.6

DATA ANALYSES--Populations of Green High-Risk Trees

Number of green high-risk trees varied from 1 to 27 per plot and totaled 313 trees for the 33 plots ground checked (Table 1).

Because plots selected for ground checking were not selected on the basis of green high-risk live trees, expansion factors used in the PPSORT analysis cannot be used for estimating total numbers of high-risk live trees. Except for possible positive or negative factors associated with mortality, it can be assumed that little bias was present in selecting plots to determine green high-risk trees.

Unpaired t-tests showed no significant differences between total numbers of high-risk trees on thinned and unthinned plots. Therefore, all 33 plots were used in estimating total populations of green high-risk trees (Table 6).

Estimated population of green high-risk trees was 9.48 trees per acre or a total of 8,532 trees over the entire test site. Confidence interval was very low, being 20.3%.

Table 6.--Population statistics and estimates of green high-risk trees.

$\bar{X} = 9.48$
$S = 5.40$
$S_{\bar{x}} = .94$

Estimated population per acre
9.48 ± 1.92

Estimated total population (900 acres core area)
8,532 ± 1,728

CI = 20.3

Western white pine and Douglas-fir were the most frequently observed high-risk green trees and accounted for nearly 90% of the total (Table 7). Differences between numbers of each tree species on thinned or on unthinned plots were significant only for lodgepole pine. In general a negative correlation between size class and frequency of occurrence was noted, with over 90% of all green high-risk trees being less than 20 inches d.b.h.

Table 7.--Percent occurrence of green high-risk trees by size class and species in all thinned and unthinned plots.

Size class	% occurrence in all plots	% occurrence in thinned (10) plots	% occurrence in unthinned (23) plots
5-10"	41.5	57	36
11-15"	29.0	26	31
16-20"	22.0	16	24
21-25"	5.0	2	6
26-30"	2.0	0	3
Species			
Western white pine*	42.0	35	45
Lodgepole pine	15.0	34	8
Larch	1.0	2	1
Douglas-fir	37.0	30	39
Grand fir	4.0	0	5
Ponderosa pine	.5	0	1
Cedar	1.0	0	1
Engelmann spruce	1.0	0	1

*Scientific names for conifer species are listed in Appendix I.

White pine blister rust was the primary problem in western white pine, and root disease caused primarily by *P. weirii* and/or *A. mellea* was largely responsible for decline of Douglas-fir and grand fir. Suppression was the major factor contributing to high risk in lodgepole pine.

DISCUSSION

For surveys requiring 100% photographic coverage, 35 mm photography is not the answer unless possibly ultra-small scales are required. Even then, transparencies are not easily handled, viewed, and/or evaluated. But, if a survey involves evaluation of a certain number of randomly taken photos relatively evenly distributed throughout a study area, e.g., on a grid, 35 mm photography should be very useful as indicated by Klein (1973b).

The problem of tracking could be partially alleviated by pre-photographic flights to familiarize the tracker with the terrain. Other minor problems such as endlap, erratic shutter activation, reloading inconvenience, and blurred imagery could be easily overcome by shortening exposure interval (and using a timer), a critical evaluation under simulated conditions of the shutter activation and film advance system, using bulk film, and increasing shutter speed respectively.

These studies indicate that, using any film:lens combination and with a little effort, very low variation between size of photo and ground plots can be obtained; and that given good landmarks on photos from which to navigate, plot centers can be accurately located. In virgin or densely reforested areas with few roads or other landmarks, plot location may be difficult on 35 mm photos, but this could also be the case with larger format photography.

The large amount of thinning, the occurrence of root disease primarily as individuals or in small centers, and the small photo scales were not conducive to identification of root disease centers. Undoubtedly 35 mm photography could be used to identify and perhaps survey for root disease centers, but other systems using 9- by 9-inch format are currently being used with excellent success.

The utility of color Polaroid prints made from the 35 mm slides was very worthwhile. They were easy to carry and use, and photos could be blown up so that plot centers could be more easily located. Polaroid enlargements or other prints for precise plot location could also be easily made for specific points on 70 mm or 9- by 9-inch format photos.

Although few exposures were made through the 50 mm lens, comparisons between data from film:135 mm combinations and film:50 mm combinations in every case showed the 135 mm combinations to have lower confidence intervals than 50 mm combinations, and to be positively correlated with ground truth data, while film:50 mm combinations were negatively correlated with ground truth data. In the case of EH:135 a highly significant correlation coefficient of 0.971 was found while that for IE:135 was not as good, being 0.449. In spite of the often blurred imagery of 135 mm photos, perhaps the nearly one-third larger scale of photos taken through 135 mm lens was the factor responsible for better correlations, and would indicate, to a certain extent, the larger the scale the better for making mortality counts.

Confidence intervals for both IE and EH 135 combinations were the same, but the correlation coefficient for the EH:135 combination was much better than that for IE:135 combination. This, however, does not prove that one film is better than the other, and a series of points photographed with the two films would shed further light on the subject.

A wide variation in estimated populations exists between film:lens combinations, but because of the lower confidence interval on the mean and the very high positive correlation coefficient with the EH:135 combination, within the limitations of this study that combination is probably best.

Mortality counts made with a stereoscope on Kodacolor prints were negatively correlated with ground truth data for PPSORT picks for that film:lens combination. Even when data for all seven Kodacolor:50 mm plots in Table 1 were analyzed, photo counts and ground counts were not strongly correlated. This plus the fact that the two film:135 mm lens combinations had positive correlations while the EH:50 mm lens combination had a high negative correlation similar to that of the Kodacolor: 50 mm combination would indicate that stereoscopic analysis used for Kodacolor prints was no better and possibly worse than the two-dimensional enlarged projection analysis used for the 35 mm transparencies.

Recent dead coniferous trees were easily identified on EH films, but yellowing larch could be less reliably identified, because of the abundance of yellowing deciduous individuals. On color infrared film (IE), red trees appeared as yellowish images. Yellowing larch and deciduous individuals also appeared to have yellowish images. Because of the interference by both yellowing larch and deciduous individuals as well as low sun angle and high probability of inclement weather in the fall, it is recommended that photography be taken prior to autumn color change unless for some specific purpose, such as to identify distribution and quantity of larch component, or conifer coverage data. Because of the interference of both larch and deciduous trees on IE film, perhaps with earlier photography, IE film would be better than EH film.

Confidence intervals calculated for estimated population means may have been due to (1) population variation, (2) variation between actual ground plot and photo plot size, and (3) variation between photo and ground plot locations. In these studies the very good correlation between photo plot and ground plot size and location suggests that very little variation in mortality counts is accounted for by these differences. This indicates that sampling procedures were good and that the majority of variation in mortality between plots is accounted for by population variation.

Except for possible discrete factors associated with high mortality in PPSORT selected plots, the method used for calculating numbers of live high-risk trees seems valid. Of the total ± 8,500 live high-risk trees, nearly 50% fell into the 5- to 10-inch diameter class and nearly 95% were western white pine, Douglas-fir, or lodgepole pine. The occurrence of greater numbers of larger trees in unthinned areas undoubtedly reflects the removal of larger trees in salvage logging operations.

Risk rating was directly tied to disease, primarily white pine blister rust or root disease. Some 40% of the green high-risk trees, or 3.8 trees/acre (mostly grand fir and Douglas-fir) were apparently affected by root pathogens and will probably drop out of the forest canopy within the next 5 to 10 years.

While *Armillaria mellea* may be attacking stressed trees and may or may not be a problem in future stands in the area, the presence of *Poria weirii* presents a distinct, continuing problem for at least Douglas-fir and grand fir growing in disease centers. Shortened rotations, natural reproduction, and/or artificial reforestation with seedlings from proper seed sources may circumvent the *A. mellea* problem. Proven management alternatives are not available for areas infected with *P. weirii*; however, empirical observations suggest that species other than Douglas-fir or grand fir should be propagated in and around *P. weirii* infection centers. Since blister rust is a problem in white pine, and lodgepole pine has problems with *Fomes pini* ([Brot.] Fr.) Karst., perhaps in root disease centers a mixed stand of rust-resistant white pine, ponderosa pine, hemlock, cedar, and/or larch could be propagated.

The significantly greater numbers of red trees (e.g., mortality rate) on unthinned plots than in thinned plots suggests that current mortality rate may have been reduced by recent thinning, while the lack of significant difference between high-risk trees on recently thinned and unthinned plots suggests continuing long-term decline of the residual stand.

Another alternative explanation concerning mortality rate is that rates per plot are equal but stocking density is reduced in thinned plots.

Regardless of the implications, mortality rates of nearly 1.5 trees per acre per year plus 9.5 high risk trees per acre seems significant. Furthermore, considering the tremendous amount of salvage logging already done in this area in prior years, perhaps stocking is reduced, resulting in reduced mortality or decline rates as compared to adjacent stands.

Because more sample points and lower confidence intervals about the mean are involved in the thinned vs. unthinned evaluations, they were used to estimate populations of old dead trees, which amounted to 8,860 $\pm$ 2,860 trees or nearly 9.8 $\pm$ 3.2 trees per acre.

As with high-risk live trees, a large portion of dead trees fell into the 5- to 10-inch diameter class. While most dead trees were white pine, as with high risk trees, percent of Douglas-fir was only about a third of the composition. Perhaps the impact of root diseases is only recently being expressed.

These studies were not designed to specifically consider the benefit of probability sampling systems (PPSORT), but manipulation of data for thinned and unthinned variations suggest that they are beneficial in survey systems involving two or more stages.

CONCLUSIONS

In conclusion, these evaluations concerning utility of 35 mm photography suggest that:

1. Minor problems encountered with the system should be easily alleviated.

2. To a point, larger scales; i.e., those obtained with a 135 mm lens, were best for estimating mortality.

3. Color film (EH) in these studies may be somewhat better than color infrared film (IE) for counting dead trees, but time of year is important.

4. Unless for specific purposes, autumn photography should be avoided.

5. Stereoscopic evaluation is no better than evaluation of enlarged projected two-dimensional images from transparencies.

6. The use of enlarged Polaroid or other prints for plot location is beneficial and adaptable for other formats.

7. 35 mm photography should not be used when 100% coverage is desired but may be valuable in survey designs involving photo points not requiring sidelap.

8. Survey systems employing probability-based selections seem to be beneficial.

On the 900-acre study area, there were approximately 8,800 dead good-topped stems, and 8,500 high-risk green trees, the majority of which were western white pine and were affected by disease agents. Data also indicate that annual mortality rate is around 1.5 trees per acre, that decline of residual green trees is continuing, and that rate is higher in unthinned than in thinned stands. High-risk impending mortality could and should be salvaged prior to dying so that "green" prices rather than minimum prices can be obtained. With the current demand for dead material and with high lumber recovery from dead white pine, salvage of existing mortality should also be accelerated.

Because of the root disease problem in the area, management should require more than just routine planning. For the time being, recommendations for management of root disease areas, discussed earlier, should be employed.

APPENDIX I

Common and Scientific Names of Conifers

Common Name	Scientific Name
Western white pine	*Pinus monticola* Dougl.
Lodgepole pine	*P. contorta* Dougl.
Ponderosa pine	*P. ponderosa* Dougl.
Western larch	*Larix occidentalis* Nutt.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Grand fir	*Abies grandis* (Dougl.) Lindl.
Western redcedar	*Thuja plicata* Donn
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Engelmann spruce	*Picea engelmanii* Parry ex. Engelm.

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