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A TEST OF AERIAL PHOTO CLASSIFICATIONS IN FOREST MANAGEMENT-VOLUME INVENTORIES

by

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KARL E. MOESSNER, research forester, Intermountain Forest and Range Experiment Station, has used aerial photos most of his 30-year career with the Forest Service. Since World War II, where he served as a photo interpreter with the 8th Air Force, he has been engaged in photo interpretation research primarily in the field of Forest Survey. Author of more than 40 papers and notes on the various phases of photo interpretation, his experience gives him a unique knowledge of the uses of aerial photos by the land manager.

A TEST OF AERIAL PHOTO CLASSIFICATIONS IN FOREST MANAGEMENT-VOLUME INVENTORIES

INTRODUCTION

The growing interest in combined forest management-volume inventories¹ and continuing developments in aerial photo volume estimating justify a critical look at the forest classifications now used on aerial photos. Most of these classification schemes--whether based on species, stand size, age, stocking, volume, or site--are those which evolved from experience in ground surveys. Conceived primarily as map strata, their basic definitions remain those developed before aerial photos or statistics were considered foresters' working tools. Few of these basic criteria are directly measurable on aerial photos.

These standard classifications, although traditionally recommended in forestry texts, are often inefficient when used on aerial photos. During the past 20 years, many forest photo interpreters have attempted to take the type, stand-size, and density classes used in timber cruising and redefine them in terms recognizable on aerial photos. Some schemes have been based on photo interpretation keys which made use of aerial or ground stereograms; others relied wholly upon written descriptive material. The use of photo interpretation to recognize these familiar but often arbitrary field classifications is subjective to a large extent. This is an important weakness.

The use of aerial photos in a survey usually implies double sampling. In double sampling a large number of plots are classified on the photos and then a subsample of these is measured on the ground to obtain mean volumes. The subsample is subsequently reclassified on the ground in order to adjust the proportions of photo plots on which area estimates are based. Although photo and ground classifications have the same designation, different tree or stand features are measured. For example, in classifying by stand size, tree diameters are measured on the ground, whereas the photo interpreter can only measure height and crown diameter. Although these criteria are related, different classifications often result. These differences are considered photo interpretation errors and are used to adjust the photo estimates of area. As errors, they are assumed to be reflections on the effectiveness of photo stratification.

This roundabout procedure, wherein photo interpretation is expected to classify plots into essentially ground-defined strata, is justified on the assumption that the traditional ground classifications are the most efficient approach to volume estimates; but, are they?

Since the primary purpose of stratification in timber cruising has always been to obtain a good volume estimate, the most effective photo scheme to accomplish this will be one whose criteria are most closely related to ground volume. If the objectives also include an estimate of acres needing cultural or other management treatment, the best scheme may be one whose criteria are also related to these. Before traditional ground classification schemes are recommended for photo use, they should be tested.

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¹ Inventories made to assess cultural and improvement opportunities as well as area, volume, growth, and mortality in forest stands.

THE PROBLEM

Although several studies have tried to determine which of the many possible photo schemes result in strata most closely resembling those used in ground surveys, few seem to question the value of the original ground strata in volume or management estimates. Instead, they concentrate on ways of rating photo-classification schemes by photo-field differences, and on methods of adjusting for these differences.

At least three studies have broken with tradition by testing the usefulness of photo classifications in the light of their improvement of volume estimates. Bickford (3)² reported that cubic-volume classes were more efficient than stand-size classes in estimating cubic volume on plot sampling surveys. Kendall and Sayn-Wittgenstein (4) reported that a combination of cover type, stand height, and cover density gave best results when areas were delineated (mapped) rather than point sampled. Macpherson (5) reported two-way stratification by cover type and volume classes about equal to three-way stratification using cover type, volume, and maturity group. However, it is quite significant that the gains shown by these studies were made without the use of precise photo measurements and aerial photo volume tables.

When examining this problem of which stratifications should be used on aerial photos, it is well to remember the limitations of the photo interpreter as well as his strong points. In general, he studies the forest, not the trees. For example: The photo interpreter is limited in the number of direct measurements he can hope to make. He can measure only what he can see on his aerial photos. Direct plot measurements therefore are limited to total height, crown diameter, and crown coverage of the visible trees. On medium-scale photos, he often finds it difficult to measure individual trees; instead, his measurements are plot averages. His conception of stocking must be based on crown coverage of all visible trees; he cannot directly recognize dead or cull trees. He can, however, record measurements for two or more height classes, and the coverage of each in many two-storied stands. Because topographic differences are accentuated on aerial photos, he can often recognize broad soil and site differences and can measure slope and aspect with considerable accuracy. In addition to these reasonably objective measurements, the photo interpreter may be able to deduce from photographic tonal differences many changes in species composition or stand condition due to past history of fire, logging, or insect devastation. These varied photo measurements and interpretations have been combined into numerous classification schemes. Those based strictly upon direct photo measurement are quite objective. Those which rely largely on tonal differences and image shape or appearance are almost wholly subjective.

In management inventories, as in timber estimates, sampling by strata can mean a better estimate at less cost. The amount of gain depends on the type of strata used. These must be defined so that each stratum is fairly homogeneous and so there are real differences between strata. And to afford adequate sampling in each, the total number must be kept quite low. Bickford (2) states: "For timber cruising aerial photos provide the most practical basis for defining classes needed for stratified sampling." He also emphasizes that the most effective classes are those closely related to the data being estimated. When volume is being estimated, the best stratification schemes will be those that are most effective in reducing volume variation within classes.

The stratification problem is further complicated when considering combined management and volume inventory surveys. The photo schemes most valuable for estimating gross cubic

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²Underlined numbers in parentheses refer to Literature Cited.

volume are not necessarily the best for estimating net board-foot volume, and may be weak in selecting acres of high risk timber or acres where thinning is needed. In a single limited study it is hardly possible to test the value of the many photo-stratification schemes for all types of data collected in volume and management inventories. However, it is possible to evaluate a number of photo or field stratification schemes by means of indices based on one or two types of data collected.

The purpose of this paper is not to outline a survey plan, but rather by evaluating a number of photo-stratification schemes, to provide a reasonable basis for selection of a scheme when considering photo stratification in timber cruising or combined forest management volume inventories.

The question to be answered is: Which classification scheme uses this available aerial photo information most effectively in stratifying forest stands for combined forest management and volume inventories?

During the 1960 field season the Intermountain Forest and Range Experiment Station, in cooperation with other Stations and Regions of the U.S. Forest Service, conducted the St. Regis study--a pilot test of a new survey procedure designed to collect basic information to satisfy both inventory and management needs. This was primarily a field study; however, the ground plots measured for this test were also measured on aerial photos and these paired plots furnished the basic data used in this study of aerial photo-stratification schemes.

OBJECTIVES

In general we wanted to know which aerial photo-classification scheme would contribute the most in a combined forest management-volume inventory.

Specifically we wanted to:

1. Evaluate the several methods of photo or map stratification by their ability to increase the efficiency of the estimates of cubic- and board-foot volume.
2. Rank the methods by their ability to segregate areas of high risk sawtimber and young stands needing thinning or other management treatment.
3. Determine which method would best combine these management and volume inventory aims.
4. Estimate the saving in cost possible by use of this method.

THE STUDY

For this study we had available 126 1-acre plots systematically located throughout a 132,000-acre unit in the St. Regis Ranger District of the Coeur d'Alene National Forest, Montana. These plots were first measured and classified on aerial photos and then on the ground during the 1960 field season.

Nominal 1:16,000-scale $8\frac{1}{4}$ -inch focal length USDA photos flown in 1958 were available for the area. Recent 1:62,500-scale USGS quadrangles with 80-foot contour intervals were also available. Mean flying height and photo-scale reciprocals were determined for 200-foot elevation changes from 68 scale lines measured on the maps and photos of the area.

Photo and field plots were located systematically. Plot centers were pinpricked approximately 1,320 feet west of the principal point of each aerial photo lying within the sampled tract. Plot intervals averaged about 1.0 mile east and west and 1.5 miles north and south, throughout the area. Plots were numbered consecutively and marked on the existing type and stand-class map for the area, and on the USGS quadrangles.

AERIAL PHOTO DATA

Photo measurements for the dominant stand consisted of total height and crown diameter in feet, and crown cover in percent. Height and crown cover were also recorded for the under-story in two-storied stands. Stand-height measurements were made under lens stereoscope using parallax wedge. Crown cover was measured by a crown-density scale. Measurements of slope percent were also made through each plot center. These stand measurements were converted to gross cubic- and board-foot volumes per acre using an aerial volume table (6).

In addition to the measurements several photo interpretations were made. These interpretations of species-type, stand size, topographic site, and aspect, were primarily subjective although the stand measurements and volumes were used in making them. Insofar as possible Forest Survey definitions were used for these photo classes.

Photo measurements and interpretations for the 1-acre plot surrounding each pinpricked location were recorded on 3- by 5-inch cards. Also included were plot and photo flight line numbers, elevation, photo scale, and parallax factor.

To assure independent observations all photo interpretations were made and recorded prior to any field examination. All field classifications and measurements were made independently from photo interpretation except that field plots were located by means of the same aerial photos previously measured by the photo interpreter. The pinpointed plot centers were located as precisely as possible on the ground and formed the starting point for location of the 16-point field sample grid described below.

FIELD DATA

Stand volume and tree distribution were obtained from a grid of 16 points located on each 1-acre sample (8). Pole and seedling-sapling volumes and counts were determined on a 1/256-acre fixed plot around each grid point. Sawtimber volume was obtained from variable plots located at each of the 16 points and averaged for the acre location. Detailed description of crop trees, a measure of competition, and a quantitative estimate of excess trees were also obtained from the grid plots. Finally, a qualitative description of sawtimber was recorded as a basis for risk classes.

Using these data and Forest Survey volume tables, we determined cubic- and board-foot volume for each acre sample. These volumes, together with the following data, were also recorded on each 3- by 5-inch photo plot card:

Tree and stand heights (tallest, five tallest, average)	Field category
Total stocking and desirable tree stocking	Field site class
Field stand-size class	Management prescription
	Aspect and slope percent

These field classifications were those used in the original St. Regis study which developed a procedure for collecting basic information for combined volume inventory and management requirements. The definitions of these classes are those standardized by the National Forest Survey, U.S. Forest Service.

STRATIFICATION SCHEMES

The 126 plots were then sorted by means of the previously recorded classifications into each of 18 stratification schemes selected for testing. These schemes include most of the traditional forest classes common to volume inventories plus a few peculiar to management surveys. They included seven schemes based on field classification and measurements, eight schemes based on photo interpretation and measurement, and three schemes based on classifications from a previously prepared type and stand-size map. The following brief description includes the number of strata and the source of the measurements of interpretations used in classifying.

The first seven methods of stratifications are those based upon computed data from field measurement of sample plots:

1. Field stand size and density (10 strata).--Includes sawtimber, poles, seedling-sapling, poor, medium, well stocked, and a catchall stand-size class of nonstocked.
2. Field stand size (4 strata).--Same data as 1--collapsed into sawtimber, poles, seedling-sapling, and nonstocked.
3. Field density (3 strata).--Same data as 1--collapsed into poor, medium, and well stocked.
4. Field species (10 strata).--Plots were stratified into white pine, ponderosa pine, larch, Douglas-fir, grand fir, alpine fir, cedar-hemlock, spruce, lodgepole pine, and nonstocked by plurality of cubic volume.
5. Field site class (6 strata).--Site index from site tree measurements taken on sample plots was used to classify plots into six site classes.
6. Field management category (5 strata).--Includes high risk, low risk, and immature sawtimber; pole and sapling stands not needing treatment, and such stands in need of treatment. This is a management classification. Its efficiency in volume estimating is easily tested, but its relative value in management surveys cannot be determined since these same five categories were used in computing ranks.
7. Field cubic-volume class (11 strata).--Includes 500 cubic-foot classes up to 4,000 cubic feet, and 1,000-cubic-foot classes from 4,000 through 6,000 cubic feet. Relative value for management surveys is easily determined, but volume efficiency cannot be determined since computed plot volumes were used in stratification.

The next eight methods of stratification are those patterned after the traditional field classes but rely on strata identified on aerial photos by interpretation or measurement.

1. Photo stand size and crown cover (9 strata).--Includes classes of sawtimber, poles, seedling-saplings, poor, medium, and well stocked, as identified by measurements of total height, crown diameter, crown cover, and tabular volume.
2. Photo stand size (3 strata).--Same data as 1--collapsed in three stand sizes.

3. Photo crown cover (3 strata).--Same data as 1--collapsed in three crown-cover classes.
4. Photo volume (500 cubic feet) class (13 strata).--Classes based on an estimate of cubic-foot volume obtained from photo measurements of total height, crown diameter, and crown coverage used with a previously compiled aerial volume table.
5. Photo volume (1,000 cubic feet) class and topographic site (28 strata).--Classes based on estimated cubic volume obtained from photo measurements and a previously prepared aerial volume table, and photo interpretation of topographic site.
6. Photo volume (1,000 cubic feet) class (7 strata).--Same data as 5--collapsed into volume strata only.
7. Photo topographic site (4 strata).--Same data as 5--collapsed into four sites based on aspect and position on slope.
8. Photo species class (6 strata).--Plots were classified as white pine, ponderosa pine, larch fir, spruce fir, lodgepole pine, and brush by photo interpretation and measurement.

The next three methods of stratification were obtained from a standard forest type map prepared by Northern Rocky Mountain Region, U.S. Forest Service. Original type delineation was on aerial photos, combined with field examination and checking. These delineations were then transferred to a base map of the area to prepare the finished map. Plots were located on this map and classified according to the type in which they fell.

9. Map stand size and density (9 strata).--Includes sawtimber, poles, and seedling-saplings, and poor, medium, and well stocked classifications obtained from the previously prepared type and stand-size class map of the area.
10. Map stand size (4 strata).--Same data as 9--collapsed to stand size.
11. Map density (3 strata).--Same data as 9--collapsed to density.

ANALYSIS

In the analysis all stratification schemes were evaluated for both volume and management use by means of one or two selected indices. For example, net volume by species, by diameter class, and by age group, growth rates, quality, and cull percents are all legitimate requirements in a volume cruise, but evaluation of each scheme by each of these factors would be far beyond the scope or needs of this study. Instead, gross cubic-foot volume and gross board-foot volume per acre were selected as indices to evaluate the strata for volume estimating.

In management inventories, areas of high risk, mature, and immature sawtimber, young stands in need of treatment and others where treatment might not pay off, are usual requirements together with details such as stand size, age, stem counts, and basal areas. Following the above reasoning, areas of high risk sawtimber and young stands in need of treatment were selected as management indices.

Although designed to evaluate photo stratification schemes, this study also evaluates the several field schemes after which most photo schemes are patterned. Classification was accomplished by data from the measured field plots but these field schemes are evaluated by means of the same indices used for the photo schemes, and their value is therefore comparable.

RELATIVE GAIN IN ESTIMATING VOLUME

In volume estimation the most effective schemes are those which reduce variation within and increase variation between classes. Since the number of field samples required to obtain a mean of given reliability is directly related to the variance, each sampling scheme can be evaluated by dividing its pooled within-stratum variance by that of the unstratified sample. When the resulting percentage is subtracted from one, the remainder is an estimate of the reduction in needed field samples. The most efficient scheme is the one with the lowest variance ratio and therefore the greatest reduction in field plots.

For this analysis all methods are considered proportional sampling, that is, strata areas are assumed to be proportional to the number of field samples classified in them. Then:

S^2 = the total variance of the unstratified sample.

$\sum P_i S_i^2$ = the pooled within-stratum variance obtained by weighting the variance of each stratum by the percent of the total area occupied by the stratum.

$\frac{\sum P_i S_i^2}{S^2}$ = the variance ratio obtained by dividing the pooled variance by the unstratified variance.

$1.00 - \frac{\sum P_i S_i^2}{S^2}$ = the expected percentage reduction in required field plots.

While this is not an absolute measure of sampling efficiency, it is a relative and reasonably simple method of rating a large number of stratification schemes for comparison.

The various field stratification schemes are listed in table 1 for comparison with the aerial photo and map schemes listed in table 2. The number of strata, variance ratio, expected reduction in field plots, and rank is shown for each scheme.

Those schemes 4, 5, and 6 (table 2), based on cubic-volume classes, are better than any other photo scheme and even better than any usable ground scheme shown in table 1. Referring again to table 2, photo scheme 5, based on cubic volume in 1,000-foot classes and topographic site, ranks first but cubic volume alone in either 500- or 1,000-cubic-foot classes is nearly as good. To get adequate sampling in each class the number of classes should be kept quite low, and for this reason the scheme using 1,000-cubic-foot classes alone would probably be the most practical even though it ranks third.

Table 2 indicates that, compared with volume classes, much less gain can be expected from stand-size and crown-cover classification and still less from species and topographic site. Crown cover, using only three classes, appears to be worthless in volume estimating. In general, classifications taken from existing type maps appear even less useful. Since these maps were prepared by photo interpretation, but not measurement, we must assume that subjective photo methods complicated by drafting limitations, add up to much poorer stratification than would be possible from use of aerial photo volume tables.

Comparison of the ratings shown in tables 1 and 2 indicates stratification by means of ground measurements results in stand-size and density strata only a little better than those

Table 1.--Variance ratio, expected reduction in field plots, and rank of the field-stratification methods for volume estimating

No.	Stratification method		Cubic volume			Saw log volume		
	Description	Number	Variance ratio	Reduction	Rank	Variance ratio	Reduction	Rank
		of		in field			in field	
		strata		plots			plots	
- - - -Percent - - - -								
	None		100	--		100	--	
1	Stand size and density	10	46	54	2	49	51	3
2	Stand size	4	53	47	3	52	48	4
3	Density	3	91	9	7	96	4	7
4	Species	10	91	9	6	89	11	6
5	Site	6	90	10	5	87	13	5
6	Management category	5	56	44	4	48	52	2
7	Cubic volume--500-cubic-foot class	11	1	99	1	14	86	1

¹Total unstratified variance: Cubic, 2,122,100; Saw log, 69,451,100.

NOTE: Method 7 is academic for cubic volume since the stratification was made by the same volumes used in computing variance.

obtained from photo measurement. In the case of species, field classification showed even less gain than that made on photos. Quite obviously, stratification by these traditional schemes even through use of field measurements does not equal the gain possible by use of volume strata and aerial photo measurements. Comparison of cubic and saw log volume data (table 2) indicates cubic-volume classes are just as useful for saw log volume, and therefore the following comparisons will be made on the basis of cubic-volume classes only. Since this study considers combined management and volume inventories, the next step is to evaluate the methods used in estimating the areas needing management.

RELATIVE VALUE IN ESTIMATING AREAS NEEDING HARVEST OR OTHER MANAGEMENT TREATMENT

For this purpose there is no readily measured unbiased index comparable to the variance used in volume estimating. A widely accepted method of evaluating photo stratification for area estimating compares photo and field classifications by means of Chi-square test. This test assumes the traditional field classifications are more closely related to the desired management classifications than are any made on aerial photos. In the light of the volume analyses this assumption seems unwarranted.

A second less familiar approach assumes the superior stratification scheme will be that one which confines the plots on which management treatment is needed to the fewest possible strata. This evaluation made through use of Bartlett's test for homogeneity of variance can be used equally well on both field and photo schemes. For example: Assume two photo-classification schemes each having 10 strata are used to classify an area. Each scheme is sampled

proportionally on the ground, and each field sample is classified as needing or not needing management treatment by means of field measurements and observations. Nearly all plots needing treatment are classified in only one or two of the 10 strata set up by the first photo scheme. In the second scheme the plots needing treatment are found to be distributed through five or six of the 10 strata used. The first scheme would be most valuable for use on aerial photos since it eliminated eight of the 10 possible strata as a likely source of area needing management.

Bartlett's test ranks these two schemes by means of the corrected sum of the squares obtained from the numbers of plots needing treatment. The scheme with plots needing treatment concentrated in the fewest strata will have the highest sum of the squares and consequently will be ranked first. We recognize that this test offers no means of determining whether any of these techniques is better than no stratification at all, and that the ranking obtained is relative and not on a consistent mathematical scale. Also that the ranks are likely to be nonsignificant particularly in the lower ranks. Nevertheless, it does offer some indication of the better method and has the unique advantage of comparable evaluation for both field- and photo-stratification schemes.

Table 2.--Variance ratio, expected reduction in field plots, and rank of the aerial photo and map stratification methods for volume estimating

No.	Stratification method			Cubic volume			Saw log volume		
	Description	Number: of strata	Variance ratio	Reduction: in field plots	Rank		Variance ratio	Reduction: in field plots	Rank
			- - - -Percent- - - -				- - - -Percent- - - -		
	None		¹ 100				¹ 100		
1	Stand size and crown cover	9	58	42	4		66	34	5
2	Stand size	3	59	41	5		65	35	4
3	Crown cover	3	99	1	11		100	--	11
4	Cubic volume-- 500-cubic-foot class	13	34	66	2		30	70	2
5	Cubic volume-- 1,000-cubic-foot class and topo- graphic site	28	31	69	1		30	70	1
6	Cubic volume-- 1,000-cubic-foot class	7	35	65	3		31	69	3
7	Topographic site	4	95	5	10		97	3	10
8	Species group	6	83	17	8		77	23	8
9	Stand size and density (map)	9	76	24	6		76	24	6
10	Stand size (map)	4	77	23	7		77	23	7
11	Density (map)	3	92	8	9		97	3	9

¹Total unstratified variance: Cubic, 2,122,100; Saw log, 69,451,100.

NOTE: Map stratifications were taken from existing type map rather than directly from photo.

Bartlett's test was used to rank both field and photo schemes as to their ability to select stands classified by field crews as high risk sawtimber, and to select those classified as young stands needing management treatment. The field schemes are listed and ranked in table 3. Field-stratification method 6 based on management categories could not be ranked by this method. The photo and map techniques are ranked in table 4. These data show that photo stratification by 1,000-cubic-foot volume classes ranks first in selecting both high risk sawtimber and young stands needing treatment. Detailed examination of the limited basic data lends credence to this ranking since most high risk sawtimber was confined to the higher cubic-volume strata, and most young stands in need of thinning were confined to the lower cubic-volume strata. Species group appeared next in value for management strata with stand size and crown cover next. Crown cover appears to have value in locating young stands needing thinning. The wholly subjective map classifications even though checked for accuracy on the ground are ranked below the measured photo-volume strata.

Study of table 3 indicates the ranking of the field methods is somewhat different from the ranking of corresponding photo method. Cubic-volume strata are again best in segregating high risk sawtimber. Stand density leads as a method of segregating young stands needing thinning with species classification second.

Table 3.--Field-stratification schemes ranked by ability to segregate high risk sawtimber and young stands needing management treatment

No.	Stratification method		High risk sawtimber Category 1	Young stands needing treatment Category 5
	Description	Number		
		of		
		strata		
----- Rank -----				
1	Stand size and density	10	2	4
2	Stand size	4	5	3
3	Density	3	6	1
4	Species	10	3	2
5	Site	6	4	6
6	Management category ¹	5	--	--
7	Cubic volume-- 500-cubic-foot class	11	1	5

¹This classification used in making the test.

NOTE: Ranks are not on a consistent numerical scale.

Table 4.--Photo and map stratification schemes ranked by ability to segregate high risk sawtimber and young stands needing management treatment

No.	: Stratification method :		High risk sawtimber Category 1	: Young stands needing treatment Category 5
	Description	: Number :		
		: of :		
		: strata :		
-----Rank-----				
1	Stand size and crown cover	9	6	7
2	Stand size	3	9	10
3	Crown cover	3	10	4
4	Cubic volume-- 500-cubic-foot class	13	4	5
5	Cubic volume-- 1,000-cubic-foot class and topo- graphic site	28	3	6
6	Cubic volume-- 1,000-cubic-foot class	7	1	1
7	Topographic site	4	7	11
8	Species group	6	2	3
9	Stand size and density (map)	9	5	8
10	Stand size (map)	4	8	2
11	Density (map)	3	11	9

NOTE: Ranks are not on consistent numerical scale.

RELATIVE VALUE FOR COMBINED MANAGEMENT AND VOLUME INVENTORY

The photo-classification method rated best for volume estimating is not necessarily the best for estimating management prescription. In order to visualize how these methods affect both jobs, we prepared a summary, table 5, which ranks each photo or map method according to its ability to segregate stands classed as field category 1 (high risk sawtimber) and stands classed as field category 5 (young stands in need of treatment). The relative efficiency in volume inventory (probable percentage reduction of field plots) is shown directly below the method number. Although the index of relative volume efficiency is numerically reliable, the ranks used in this table should not be interpreted as having consistent numerical meaning. Lack of data precludes not only rating the efficiency for management purposes but in most cases even the testing of significance among ranks. However, this table does indicate that stratification by 1,000-cubic-foot photo volume classes obtained from measured plots and aerial volume tables is superior to any other photo method in combined management and volume inventories. Other schemes combining cubic volume and other strata rate above average for combined surveys, but may be less valuable than stand size or density or species in segregating young stands needing management treatment.

Table 5.--Photo-stratification methods ranked by ability to segregate areas
needing management treatment

Management category 1: --high risk sawtimber	Management category 5--young stands needing treatment										
	Rank										
	1	2	3	4	5	6	7	8	9	10	11
Rank											
1		6									
		0.65									
2			8								
			0.17								
3						5					
						0.69					
4					4						
					0.66						
5								9(M)			
								0.24			
6							1				
							0.42				
7											7
											0.05
8			10(M)								
			0.23								
9										2	
										0.41	
10				3							
				0.01							
11										11(M)	
										0.08	

NOTE: Percentage indicates probable reduction in needed field plots based on cubic-volume variance. Ranks for management purposes are not on a consistent numerical scale.

Key--Photo-stratification methods

1	Stand size and crown cover	6	Cubic volume--1,000-cubic-foot class
2	Stand size	7	Topographic site
3	Crown cover	8	Species group
4	Cubic volume--500-cubic-foot class	9	Stand size and density (map)
5	Cubic volume--1,000-cubic-foot class and topographic site	10	Stand size (map)
		11	Density (map)

A primary objective of this study has been to rate selected photo-stratification schemes as simply and as directly as possible. Although complete cost data were not obtained on this study, no discussion of stratification methods would be complete without some reference to costs.

RELATIVE COSTS

In mountainous regions, field plot costs depend more on travel time than on time actually spent in plot measurement. Based on the St. Regis study, total field measurement time can be expected to average about 14 man-hours per location. The Forest Survey records for this area indicate average costs of \$70 per location with some locations exceeding \$100.

Photo interpretation costs are affected little by topography, but depend almost entirely on the kind of measurements and classifications made. In commercial forest stands where cubic- and board-foot volumes are estimated by means of precise photo measurements and these estimates and measurements are used to stratify the plots, studies (7) show that experienced photo interpreters can average about five plots per man-hour. Where classifications are made without measurement, or in areas where many plots are nonforest, much higher averages are possible and sustained rates for stereo classification may reach 200 plots or more per man-day. The skill and precision expected of a good photo interpreter may require a year or more of intensive training and experience, but this interpreter should then be able to measure and classify plots for about 70 cents each or 1 percent of the cost of fieldwork.

The cost of aerial photos can generally be ignored in any evaluation of survey methods. Aerial photos are working tools of the forester. They are obtained for many purposes in addition to forest inventory, and are readily available on most forests. In this particular case, the photos used were originally purchased for field plot location in the St. Regis field study. Since all photo methods were based on one set of photo measurements and classifications, and were tested by field data taken on the same plots, the cost of aerial photos can have no significance in these results. The same may be said for such routine chores as trimming and filing photos, determining photo scale, and marking plots on both photos and maps. They are needed equally in every method used. For example, no qualified photo interpreter would suggest plot classification by any scheme in mountainous areas without knowing photo scale.

Both photo and field plot measurements used in this study were made by personnel with pay scales considerably above average. A comparison of costs is therefore more meaningful when based on man-hours. Photo interpretation including stand heights measured by parallax wedge, crown cover by comparison, and again by dot count, slope percent computed from horizontal and vertical photo measurements, cubic- and board-foot volumes read from aerial tables, and finally, classification of all plots by six different methods was performed at a rate of about 30 plots per man-day.

As this study indicates, merely sorting these measured plots by different methods can result in widely different field plot requirements for reliable volume estimates and corresponding savings in overall costs. These costs can be compared in a simulated problem. Assume 100 unstratified field plots are required to obtain a reliable volume estimate and that measuring the plots on the ground would require 1,400 man-hours of field time. To stratify these plots by stand size and density using photo interpretation without measurement would cost 4 man-hours. The gain is similar to that shown for map stand size and density (table 2) and should reduce the needed field plots to 76 and the field cost to 1,064 man-hours. Measuring the plots on aerial photos and then stratifying them into stand size and density would cost 27 man-hours. However, when these strata are sampled in the field, the required plots could be reduced to 58 and the

field time to 812 man-hours. But if cubic-volume strata are used at the same cost of 27 man-hours, the needed field plots could be reduced to 35 and the required man-hours on the ground to 490. Unfortunately this example is based entirely on the gain in volume estimating. The basic data are inadequate for such an analysis of gain in estimating management needs. Nevertheless, the rank given the various photo methods is at least an indication that the use of photo-volume strata may result in cost savings for these surveys also.

APPLICATION

The use of aerial photos in volume and management inventories involves some form of double sampling. Development of a complete sampling plan for a specific project using both aerial photo and ground sampling requires consideration of both accuracy and cost. The statistical methods used have been well developed in several publications (1, 3).

In this study aerial photo-stratification schemes have been compared and rated by the simplest and most practical methods available. These data indicate that photo-volume classes are best in volume estimating and probably best in management inventory.

In spite of numerous studies made during the last decade in aerial photo estimating and the use of photo-volume strata, several reasons are repeatedly given for not capitalizing on this technique. These include:

1. Cubic-volume strata may be of little value in estimating board-foot volume or management needs.
2. Skilled photo interpreters and necessary aerial volume tables are not available when needed, and therefore photo-volume strata are unusable.
3. The number of measured field plots has reached an irreducible minimum in management plan inventories, and therefore additional photo effort will not pay off.

All these make good excuses but poor reasons. The analysis of these data indicates that cubic-volume strata are even more valuable in estimating board-foot volume than in estimating cubic-foot volume. And of all strata tested, cubic-volume strata rank highest in segregating both high risk sawtimber volume and young stands where management prescription is required. No such analyses exist to prove the superiority of the stratification schemes now in use.

Inability to hire photo interpreters skilled in forest measurement techniques is no justification for ignoring the possibilities of these techniques. When unskilled foresters are hired for field plot measurement, they are not only given on-the-job training but are expected to precisely measure almost all items reported in the belief that their measurements will be better than their estimates. Equally unskilled foresters assigned to photo interpretation receive little on-the-job training and are asked to estimate everything without measurement. Yet, the same laws of accuracy apply equally to field and photo measurements and skilled personnel must be developed in the same manner.

Aerial volume tables are not quite as common as ground volume tables, but generalized aerial tables are available. When used for volume stratification as described in this paper, composite tables published in 1956 and compiled from field plots measured in southern Idaho, Wyoming, and Utah, gave satisfactory results in this study in northwest Montana.

While it is true that the number of measured field plots used on extensive management and volume inventories is approaching an irreducible minimum, it is also true that accuracy on the area figures to which data from these plots are applied could certainly be improved through photo measurement. Interpretation of additional photo plots, particularly if these were stratified by the best possible method could improve the reliability of the entire survey.

Finally, the many considerable photo estimating studies made during the past decade have opened the door to better and less costly methods of localizing extensive management and volume inventories. The opportunity for this use alone should justify more consideration of photo measurements and cubic-volume strata.

SUMMARY

A number of photo-and map-stratification schemes were studied using data from the St. Regis test area. Primarily, we concluded:

In volume estimating, photo-volume classes offer the best means of stratification. Volume classes also appear to offer distinct advantages in stratifying for management purposes. Photo cubic volumes obtained from direct photo measurement and aerial volume tables, and stratified into 1,000-cubic-foot classes appear to offer the most practical photo approach to combined management and volume inventories. Some additional findings were:

1. Photo cubic-volume strata were found to be at least as efficient in board-foot volume estimates as in cubic-foot volume estimates.
2. The familiar and widely used stratifications of photo or map stand size and density contributed much less to either survey than did cubic-volume strata.
3. Stand-size and density stratifications based on field data, though somewhat better than their counterparts made on photos, still contributed much less than did photo stratification by cubic volume.
4. Stand density and site strata, whether obtained from photo, map, or field data, contribute little to the efficiency of volume estimates. Density is helpful in selecting young stands in need of treatment, but both density and site probably contribute most in estimating priority and the amount of work required.
5. Photo measurement cost 0.27 per man-hour and field measurement 14 man-hours per location. On a survey requiring 100 unstratified field locations, photo stratification by cubic-volume class could reduce field measurement time from 1,400 to 490 man-hours. Forest Survey records indicate dollar costs for field plot measurement may easily be 100 times the cost of photo measurement at the same location. For this reason substantial savings are possible in double sampling based on cubic-volume strata.

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Stand classifications traditionally recommended in forestry texts are often inefficient when used on aerial photos. In this study, a number of photo and map stratification schemes are compared by means of data from 126 plots measured in the St. Regis test area of northern Montana. Findings indicate that in volume estimating, photo volume classes offer the best means of stratification. They also offer distinct advantages for other management data. Photo cubic volumes obtained by aerial photo measurement and photo volume tables were found to be more useful in combined inventories than any of the other 18 stratification schemes tested. Use of volume stratification could reduce field survey time about 60 percent.

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