smaller than 3,000 feet to 1 inch is by variation in tone; such photographs are commonly used in regional landform interpretation; the frequently used scale of 1 mile to 1 inch comes in this group. On larger-scale photographs, recognition of species by crown shape is possible. 2,000 feet to 1 inch was found to be the smallest convenient scale for crown shape analysis, and even at this scale recognition of the smaller species must rely on tone differentiation. 1,000 feet to 1 inch is probably the optimum scale, and the smaller species such as Alder show up well. It can be noted that the readily available photographs of 1,320 feet to 1 inch closely approach the optimum.

It must be stressed again that the relationships between forest vegetation and surface material presented above are not definite laws. Rather, they are the averages of a continued series of observations that have been proved valuable in photo interpretation practice. In transition belts between the suggested climatic zones, great care must be used, and all possible topographic data must be incorporated in the final analysis. In areas of considerable vertical extent it must be remembered that there can be a transition of climatic zones upwards as well as laterally. This applies particularly between the mild Northern Hardwood Zone, and the cooler Boreal Forest Zone in the area discussed. Despite these necessary limitations, the method of vegetation analysis in terms of surface material can add substantially to the accuracy of terrain studies; it is submitted as a valid addition to the criteria available for the interpretation of surface material.

Acknowledgement is herewith made to the efforts of the Ontario Department of Lands and Forests and also to Professor K. B. Jackson of the University of Toronto. They have investigated air photo technique for the purpose of increasing tree crown detail in the negative. Resulting photo prints are yielding much greater information on species identification than normal air photography.

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Evaluating Color, Infrared, and Panchromatic Aerial Photos for the Forest Survey of Interior Alaska

PAUL M. HAACK*

(Abstract is on next page)

INTERIOR Alaska has extensive, remote areas of brushland, tundra, and barrens intermingled with scrub timber and better hardwood and softwood stands, both pure and mixed. Congressional authorization for a forest survey of Alaska brought new challenges to the U. S. Forest Service. Time, costs, and practicability pointed to major use of aerial photos for data on area and timber volumes.

With such great emphasis on photo sampling, the choice of scale, focal-length, and film-type are important considerations. A scale of 1:5,000 and a 12-inch focal-length was selected for this project.‡ Raup and Denny,[8]

‡ Wilson, R. C. "Working Plan for the Forest Survey of Interior Alaska." U. S. Forest Service, Washington. 1957. (Unpublished report.)

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Stoeckler,[10] and Stone[11] studied the identification of interior Alaska vegetation on aerial photos but did not compare film-types for interpretation and measurement purposes. No reference to such a study could be found in 1957 for similar conditions, photo-scale, and focal-length.

This report presents and evaluates a study of the three most common types of film emulsions currently being used on forest surveys—panchromatic and infrared (both with a minus-blue filter) and color (Ektachrome).

Study Photography

At three locations, each representing distinct climatic and topographic conditions, a photo strip five miles long at a scale of 1:5,000 was flown, exposing the three film-types. This flying was done early in June 1957 after the hardwoods had attained full foliage.

ABSTRACT: *Vertical aerial photography at a scale of 1:5,000 using a 12-inch focal-length camera was flown over three sample strips in interior Alaska. Infrared and panchromatic, both with a minus-blue filter, and color film were used. This photography was to determine the type best suited for the interpretation of vegetative classes on the proposed Forest Survey.*

Four photo interpreters tested the film types on the basis of land-and-forest-class recognition. Another test compared the ability of five interpreters to measure tree heights on panchromatic and infrared film. Empirical estimates indicating the ease of accomplishing the goal also were made.

Interpreter success is analyzed by a technique involving angular transformations of adjusted per cents as determined from unequal cell frequencies.

No significant difference between film-types was found, but several desirable features of infrared film led to its selection.

All three sample strips were in the Boreal Forest Region. Commercial forest types and species included paper birch (*Betula papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), and spruce, either pure white spruce (*Picea glauca* (Moench) Voss) or mixtures of white and black spruce (*P. mariana* (Mill.) B.S.P.). Noncommercial types sampled were black spruce bogs, offsite hardwoods, and subalpine areas. Nonforest areas include barren mountain tops, willow and alder brush, open bogs, unstabilized river bars, and areas denuded by repeated fires. Forest stand-size classes vary from restocking to old-growth sawtimber with most stands being even-aged due to the past fire history. Topography ranges from river valleys to plains and mountains. On each sample strip a two-man field crew located and visited examples of all land classes represented as defined by the survey plan. The locations of individual trees and stands classified and measured were carefully marked on each type of film.

Photo Interpretation and Measurement

Training

The photo interpreters had no previous experience with the identification of vegetative classes of interior Alaska from aerial photos and had never been in the Interior. This factor was of secondary importance, however, as no attempt was made to measure the interpretive ability of individual observers but rather the film type with which the best job could be done. All of the photo interpreters had sufficient experience with aerial photos to recognize homogeneous features, contrasting features, and variations in tone, color, texture, size, and pattern.

The interpreters were oriented and trained in: (1) Why the study was being made, the importance of the study and its relationship to the over-all inventory project; (2) The various land and forest classes of interior Alaska and their ecological relationships; (3) Characteristics of each film-type; (4) Demonstration and use of the Old Delft scanning stereoscope with color transparencies on a light table; (5) Use of the Abrams height finder, on 10 trees previously measured on the ground; and (6) Examination and study of 39 stereograms of various land and forest classes.

The Tests

Land and forest classes.—The basic test was to determine how well four photo interpreters could properly classify 47 photo locations (Table 1).

Separate forms for each film-type were used by the interpreters to record their observations. Only one film-type was studied at a time in a randomly determined order. Each observer also made empirical estimates of the relative ease of interpretation, i.e., resolution, definition, recognition features, and time required to reach a definite conclusion as to classification of each location.

Height measurements.—Spurr and Brown,[9] Pope,[7] and others found that types of film have little to do with the ability to measure heights. However, since accurate height measurements will play a large role in this forest inventory, it was deemed advisable to explore the possibility that film-type might be a factor.

Separate forms for infrared and panchromatic film-types were used to record the parallax differences for 16 field-measured trees—10 softwood and 6 hardwood. Again, empirical estimates of "ease" were listed by the observers for each film-type.

Analysis of Data

SPECIES AND STAND-SIZE CLASS RECOGNITION

To the keen designer of experiments, the unequal distribution of the 47 locations must appear somewhat meager in number and startling in balance. In partial defense, from both a biological and interpretive viewpoint, distinction between poletimber and sawtimber is most crucial for spruce and between poletimber and seedling and sapling stands for the hardwoods. Also, suitable test locations on the three study areas were limited.

The design wasn't considered a problem in the original method of analysis planned for the study. Briefly, that approach was to assign "1's" to correctly identified locations and "0's" to those misinterpreted, using the analysis of variance on the untransformed basic data. For each of the nine species-size class combinations, the sources of variation were: location, film, observer, film × observer, error, and total. The mean square error terms were examined using Bartlett's Chi-square test of homogeneity of variance.[1] Separate tests on all groups, on the eight hardwood and softwood groups, and on the six hardwood groups indicated that no combinations should be made.

Film type was not found to be a significant source of variation for any group. For each group the sum of squares for film type was separated into two orthogonal comparisons: infrared vs. panchromatic, and infrared plus panchromatic vs. color. In no case was any contribution significant. Next, the proportions of correct interpretation for each type-size class were ranked in order of difficulty. Duncan's test of significance,[2] applying Kramer's modifications,[3,4] grouped spruce poletimber and sawtimber, birch poles and "other" into one class; aspen saplings and poles with balsam poplar saplings into a second category; and birch saplings and balsam poplar poles into the most troublesome group. Further analyses of these groupings substantiated individual findings of no significant difference between films or any of their interactions.

Yet, the validity of the analysis of variance when applied to such untransformed "yes" or "no" discrete data has been questioned by many statisticians. Some aspects of this are considered by Olds and Lewis.[6] The author is grateful to Dr. C. I. Bliss* for suggesting an analysis involving angular transformations of adjusted per cents as determined from unequal frequencies within each cell. This method offers a more acceptable solution and stresses the desirability of equal cell frequencies, n', of ten or more. The data for the more troublesome hardwoods will be used to illustrate this procedure (Table 2).

The explanation of the steps leading to the

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Table 1

Number of Locations Studied on Each Film Type, by Species (Type) and Stand-Size Class

Species (Type)	*Stand-size Class*					
	Sawtimber	*Poletimber*	*Seedling-sapling*	*Non-commercial*	*Non-forest*	*Total*
Spruce	5	3	—	—	—	8
Aspen	—	7	6	—	—	13
Birch	—	4	7	—	—	11
Balsam poplar	—	5	4	—	—	9
"Other"	—	—	—	3	3	6
Total	5	19	17	3	3	47

TABLE 2

NUMBER OF CORRECTLY INTERPRETED HARDWOOD LOCATIONS BY FILM TYPE, SPECIES AND STAND-SIZE CLASS EXPRESSED IN PER CENT AND ANGLES

Film type	Statistic	*Aspen*		*Birch*		*Balsam poplar*	
		Pole-timber	*Seedling-sapling*	*Pole-timber*	*Seedling-sapling*	*Pole-timber*	*Seedling-sapling*
Infrared	a[1]	20	20	15	19	9	11
	n'[2]	28	24	16	28	20	16
	Adj%[3]	70.87	82.32	91.79	78.28	45.18	67.91
	Angle[4]	57.33	65.14	73.35	62.23	42.24	55.50
Pan-chromatic	a	25	17	15	18	9	9
	n'	28	24	16	28	20	16
	Adj%	88.26	70.20	91.79	63.91	45.18	55.97
	Angle	69.96	56.91	73.35	53.08	42.24	49.59
Color	a	18	19	14	14	11	11
	n'	28	24	16	28	20	16
	Adj%	63.91	78.28	85.82	50.00	54.82	67.91
	Angle	53.08	62.23	67.88	45.00	47.76	55.50

[1] Number correct for all four observers.
[2] Number of locations × number of observers.
[3] Equals $50(8a+3)/(4n'+3)$, used to stabilize variance.
[4] Empirical angle.

analysis of variance and Chi-square test of these data follows.

Success as adjusted per cents and angles.—One of the requirements for validating the use of the analysis of variance is that variances for the various treatments in the experiment be equal. Differences frequently occur in binomial percentage data as herein considered. Transforming percentages to angles generally equalizes the variances so that a plot of frequencies over angle class would approach the normal curve. Tables for this transformation are available in several statistical texts, or can be computed. The sine of the angle is the square root of the percentage in decimal form.

However, variance becomes unstable near the ends of the curve—i.e., around 90° and 0° which correspond to 100% and 0%. This can be shown by plotting variances (in degrees) against degrees. To correct for this, Bliss recommends that the percentages first be adjusted by the approximation. . . .

Adjusted $\% = 50(8a+3)/(4n'+3)$
where a = No. locations correct for all four interpreters
and n' = No. observers × No. locations
giving Angle = arc $\sin\sqrt{\text{adjusted per cent}}$.

Sum of squares.—Working with the angles within each cell of the table and subtotals for all possible combinations (see Table 2), the variation contributed by each is determined. This is done conventionally by finding the sum of squares of deviations from the average in question.

Choice of error terms.—Species and stand-size class are tested by their interaction in this split plot design. The mean squares for the other sources of variation were first compared with that for the interaction $FT \times S \times SSC$. These variance ratios were judged at the 20 per cent points rather than the usual 5 per cent (tables of F) to determine if any interactions might be pooled with $FT \times S \times SSC$. The sums of squares and degrees of freedom for the nonsignificant interactions are added to those of the $FT \times S \times SSC$ interactions forming the pooled-error term. If the variance ratio comparing mean squares of $S \times SSC$ with $FT \times S \times SSC$ had not been significant at the 20 per cent points, this interaction could also have been incorporated into the pooled-error term. In that case, variances for species and stand-size class would have been compared with that of the pooled-error.

Chi-square test.—This affords a convenient way to determine if the pooled-error mean square agrees with its binomial expectation. If the observed Chi-square is less than the tabular value at the 5 per cent level for the degrees of freedom in the error term, agreement is indicated. Thus, Chi-square,

$$\chi^2 = \frac{s^2 n}{\hat{\sigma}^2}$$

where

s^2 = M.S. or variance for error term

n = degrees of freedom for error

$\hat{\sigma}^2$ = expected error variance, working in degrees

$$= \frac{820.7}{n_m'}$$

n_m' = harmonic mean determined from individual $n''s$

$$= \frac{6 \text{ groups}}{\frac{1}{n_1'} + \frac{1}{n_2'} + \cdots + \frac{1}{n_6'}}$$

$$= 20.8264$$

then

$$\chi^2 = \frac{351.5563}{39.4067}$$

$$= 8.921 \text{ on 10 degrees of freedom.}$$

Observer as an additional source of variation.—Chi-square in the above calculations for the $3 \times 3 \times 2$ design is not exact because the same four observers were used throughout. The advantage, of course, was keeping n' large. Resulting underdispersion is even more evident when observers are considered an additional source of variation. In this $3 \times 4 \times 3 \times 2$ arrangement, n' within cells become distressingly small.

TREE HEIGHT MEASUREMENTS

Parallax differences were converted to tree heights in feet by the conventional formula. The standard error of estimate was used to compare photo measurement with ground measurements made by Abney level and chain.

Results and Discussion

INTERPRETATION OF VEGETATIVE TYPES AND STAND-SIZE CLASSES

Both analyses of the transformed data confirm that there is no significant difference between film-types or their interactions (Tables 3 and 4). With their interaction as the error term, neither species nor stand-size class is significant. Since observers depict Model II (i.e., represent similarly trained photo interpreters, not named individuals), ranking by orthogonal comparisons or Duncan's test is not appropriate. Chi-square tests for pooled error mean squares for both analyses indicate agreement with the binomial expectation, though underdispersion is very pronounced in the second with a Probability, $P > 0.975$.

Considering the empirical estimates of the relative ease of interpretation, infrared was rated best by three of the four observers individually and by all four collectively.

At this point it was clear that no one film-type was outstandingly superior, but that a satisfactory job of classification could be ac-

TABLE 3

ANALYSIS OF VARIANCE OF ANGULAR TRANSFORMATIONS GIVEN IN TABLE 2

Source of variation	*d.f.*	*S.S.*	*M.S.*	*Variance ratios*	
				F_1	F_2
Species, S	2	666.4897	333.2448		—[1]
Stand-size class, SSC	1	26.9134	26.9134		—[1]
S×SSC	2	600.4605	300.2302	12.503	1.000
Film type, FT	2	49.6230	24.8115	1.033[1]	—[1]
FT×S	4	147.5299	36.8825	1.536[1]	
FT×SSC	2	107.9739	53.9870	2.248[1]	
FT×S×SSC	4	96.0525	24.0131	1.000	
Total	17	1,695.0429			
Correction, C	1	59,210.4342			
Pooled error	10	351.5563	35.1556[2]		1.000

[1] Not significant at 20 per cent points.

[2] Expected error variance, $\hat{\sigma}^2 = 39.4067$; $\chi^2 = 8.921$, $n = 10$, $0.60 > P > 0.50$.

TABLE 4

ANALYSIS OF VARIANCE OF ANGULAR TRANSFORMATIONS WITH OBSERVERS AN ADDED SOURCE OF VARIATION

Source of variation	*d.f.*	*S.S.*	*M.S.*	*Variance ratios*	
				F_1	F_2
Species, S	2	1,686.4699	843.2350		—[2]
Stand-size class, SSC	1	275.4600	275.4600		—[2]
S×SSC	2	2,071.4636	1,035.7318	12.208[1]	1.000
Film type, FT	2	98,6600	49.3300	—[2]	—[2]
FT×S	4	484.5951	121.1488	—[2]	
FT×SSC	2	238.6245	119.3122	—[2]	
FT×S×SSC	4	347.7502	86.9376	—[2]	
Observer, O	3	2,391.6147	797.2049	9.396[1]	—[1]
O×S	6	2,478.0374	413.0062	4.868[1]	—[1]
O×SSC	3	116.7813	38.9271	—[2]	
O×S×SSC	6	556.1721	92.6954	—[2]	
O×FT	6	582.2953	97.0492	—[2]	
O×FT×S	12	1,246.7539	103.8962	—[2]	
O×FT×SSC	6	618.1949	103.0325	—[2]	
O×FT×S×SSC	12	1,018.1252	84.8438	1.000	
Total	71	14,210.9981			
Correction, C	1	221,577.1350			
Pooled error	55	5,209.2925	94.7144[3]		1.000

[1] Highly significant at 1 per cent points.
[2] Not significant at 20 per cent points.
[3] Expected error variance, $\hat{\sigma}^2=157.6238$; $\chi^2=33.049$, $n=55$, $P>0.975$

complished on all three. It should be noted, that only one softwood location was incorrectly classified for each film-type. Yet, the number of hardwood locations incorrectly classified as softwood was 0 for infrared, 5 for panchromatic, and 3 for color.

Color film was eliminated from further consideration because of the following adverse factors: (1) the high cost of color film, which could be justified only if there proved to be a decided gain in accuracy of interpretation over black and white photos; (2) more critical limitations on exposure of color film; and (3) cost of special viewing and handling equipment, such as light tables and scanning stereoscopes required for interpretation of color transparencies, and related increased time for handling them.

Thus, the choice of the film-type best suited for the inventory was narrowed to either infrared or panchromatic.

Tone or color differences, crown shape, and site are features of greatest importance in identifying vegetative types. The degree of accuracy in identifying forest types is usually influenced by film type. Yet this fact was not found to be significant in Alaska. One possible explanation is that there are so few commercial tree species—one softwood and three hardwoods—and therefore only four major tones in the gray scale are possible (no separation is made between white and black spruce on commercial forest land). This greatly simplifies the problem of species recognition on black-and-white film. Color photography would probably be more desirable in regions containing more tree species, as the human eye can differentiate many more tints and shades of color, as it can shades of gray on black-and-white photography.

Losee[5] found that at a scale of 1:1,200, softwood species in northwestern Ontario can be identified better by crown than by tone. At this scale the advantages of the tone distinctions of infrared over panchromatic photography were eliminated. At the test scale of 1:5,000 the four major Interior species have recognizably different crown shapes. But shape is not apparent on hardwood trees of less than poletimber size. This may be partly due to the interpreters' unfamiliarity with interior Alaska forest conditions. A decided improvement may be expected with further on-the-ground training.

TABLE 5

STANDARD ERROR OF ESTIMATE[1] FOR HEIGHT MEASUREMENTS OF 16 TREES BY ESTIMATOR AND FILM TYPES

Estimator	*Film type*	
	Infrared	*Panchromatic*
	feet	*feet*
1	±18.9	±14.8
2	9.0	10.9
3	12.8	13.1
4	13.0	10.2
5	5.6	5.4

[1] Equal to $\pm\sqrt{\frac{\text{Sum (actual ht.—photo ht.)}^2}{(N-1)}}$.

TABLE 6

STANDARD ERROR OF ESTIMATE FOR HEIGHT MEASUREMENTS OF 10 SOFTWOODS AND 6 HARDWOODS BY ESTIMATOR AND FILM TYPE

Estimator	*Film type*			
	Infrared		*Panchromatic*	
	Softwood	*Hardwood*	*Softwood*	*Hardwood*
	feet	*feet*	*feet*	*feet*
1	±20.0	±18.5	±16.6	±12.8
2	8.1	11.0	9.5	14.0
3	13.0	13.7	12.2	15.7
4	5.3	21.3	7.2	14.8
5	5.8	5.8	5.9	4.9

MEASUREMENT OF TREE HEIGHTS

No significant difference between infrared and panchromatic film types involving measurements of 16 sample trees by five interpreters was evident (Table 5). The same holds true for the softwood vs. hardwood breakdown (Table 6). The fact that standard errors are rather large indicates the need for continual practice and supervision.

Empirical estimates of the relative ease in accomplishing height measurements on these 16 trees also favored infrared.

Although color transparencies were not tested, practice measurements indicated that they, too, were very suitable for this purpose.

CONCLUSIONS

Under interior Alaska conditions, this study has shown that distinguishing between vegetative types and stand-sizes, and the measurement of tree heights, are more readily accomplished on modified infrared film, though not significantly so. Each film type has certain desirable features. Ground detail, such as down logs and animal trails, is best defined on panchromatic. Color transparencies best bring out minute tonal details. The superiority of infrared is shown in differentiating between softwood and hardwood components of mixed stands.

With estimates of commercial forest area and timber volumes as foremost aims of the extensive forest survey of interior Alaska, evidence points to infrared film with a minus-blue filter as the type best suited for the inventory.

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