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Relating forestry interpreter preference to sensitometric parameters of black and white and normal color aerial films

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ABSTRACT

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The photointerpretation accuracy of forest inventory surveys are highly contingent on the sensitometric attributes of aerial films. The sensitometric characteristics of the products that interpreters prefer to work with was determined as a basis for future specifications of 70 mm large-scale photography. Seven black and white and two color films were compared, of which color-positive film was clearly preferred. Of greater significance were the comparison results between the black and white films. Panchromatic films with an average gradient of 0.9 to 1.2 and a density range of 1.0–1.2 were most preferred for forest photo interpretation. Within each black and white film, interpreters preferred the higher contrast images characterized by the higher average gradients. In general, interpreter preference decreased as the spectral sensitivity of the black and white films increased.

1 INTRODUCTION

Assessing aerial photo quality entails the association between the measured variables of average gradient, minimum and maximum density, to the qualifying criteria of air photo interpretation. The focus of the problem has been, and still is, with the intended use of the images. For example, the Federal and most of the Provincial sensitometric specifications in Canada are oriented towards photogrammetric applications (Service de la Cartographie, 1980; Interdepartmental Committee on Air Surveys, 1982; Interdepartmental Committee on Surveying and Mapping, 1990). These specifications have been effective for topographical mapping of photo scales from 1 : 15 000 to 1 : 60 000. Diapositives have been routinely produced from these images for stereoscopic models in various photogrammetric plotters.

For forest and vegetation inventories, would image quality specifications

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be similar to those for topographic mapping? Recent evidence (Fent, 1988) has indicated otherwise. For 70 mm large-scale photography, photo scales range from 1:250 to 1:2000. The vegetative features imaged change from forest stands at medium scales to individual trees at large scales. These images would include sunlit and shaded portions of trees, tree shadows, and ground vegetation that would not be visible at smaller scales. The ground luminosity of such scenes would easily approach ratios of 30:1, as opposed to the ratios of 5:1 usually noted at smaller scales (Carmen and Carruthers, 1951; Lockwood and Perry, 1976).

Fleming (1984) stated that general specifications were rarely "universal" in application, and their determination is of greater concern at larger scales as developments in camera technology, exposure controls and film resolution continue. The user of the aerial photos however, must be considered in determining these specifications. The photo interpreter is the most important factor in influencing the quality of forest inventory surveys. An interpreter knows through experience which black and white image products are preferred for his task. Due to a lack of knowledge of basic aerial film sensitometry however, interpreters are seldom able to provide film exposure and processing specifications. It is proposed that an optimal and consistent photo product can be achieved by determining these specifications. The difficulty, however, would be in quantifying interpreter preferences (Congalton and Mead, 1983). If improvements in aerial photography are to be made, it should be during acquisition, since corrective measures may be insufficient after procurement (Carmen, 1967; Fleming, 1983). The photography must be correctly exposed and processed the first time through. Consistency can be difficult to maintain since the actual time of day, year, and prevailing atmospheric conditions (e.g., haze) under which photography will occur are not known (Horn and Tugwood, 1984). Several brightness exposure systems (Photoscience Research, 1979; Fent and Polzin, 1986) have been developed in response to this need for coordinated exposure and processing control.

A black and white film's average gradient ($\bar{G}$) is perceived by an interpreter as the film's inherent contrast. Film speed usually varies proportionally with average gradient (ISO 7829-1986) (Appendix), which is controlled by processing parameters. The key to optimal specifications is therefore in correlating preferences in contrast to film speed and average gradient to determine proper camera exposure.

Two color films processed under manufacturer's recommendations, were compared with seven black and white films exposed and processed to four average gradients, for forestry interpretative purposes. The intention was to produce results as a basis for determining future specifications for large-scale photography; and to explain them in terms both forestry and natural resource users could understand. An information gap would therefore be filled to assist users in working with aerial photographers and photographic scientists.

The objective of the study in addressing interpreter preferences was to answer the following questions:

(1) Does an interpreter exhibit preference for a particular average gradient or gradients and the resulting density range within a black and white film?

Stated as Hypothesis 1. There were no interpreter preferences between average gradients within each of the seven black and white films.

(2) Including the color films, does an interpreter exhibit preference between films?

Stated as Hypothesis 2. There were no interpreter preferences between the seven black and white and two color films.

(3) What are the sensitometric characteristics of average gradients and resulting density ranges for the preferred black and white films?

2 METHODS

2.1 Study area

The study area was chosen near Whitecourt, Alberta, approximately 180 km northwest of Edmonton. The area is within the mixedwood section of the Boreal Forest Region (B.18a) (Rowe, 1972). A random flight line was chosen that exhibited considerable diversity in species composition, typical of the boreal forest. This facilitated selecting stereopairs which would represent a variety of forest cover types.

TABLE 1

Aerial films tested

Film	Film type	Description	Average gradients			
			$\bar{G}_1$	$\bar{G}_2$	$\bar{G}_3$	$\bar{G}_4$
1	Agfa 150	Aviophot Pan 150 PE negative, with UV filter	0.8	0.9	1.2	
2	Agfa 200	Aviophot Pans 200 PE negative, with UV filter	0.7	0.8	1.0	1.2
3	Kodak 2424 F.F. 1.0	Kodak infrared aerographic 2424, with UV filter	0.6	0.80	1.0	
4	Kodak 2424 F.F. 1.5	Kodak infrared aerographic 2424, with minus blue filter factor 1.5	0.6	0.7	0.8	1.0
5	Kodak 2403	Kodak Tri-X aerographic 2403, with UV filter	0.7	0.8	0.9	1.0
6	Kodak 2405	Kodak Double-X aerographic 2405, with UV filter	0.9	1.0		
7	Kodak 2424 F.F. 2.0	Kodak infrared aerographic 2424, with minus blue filter factor 2.0	0.6	0.70	1.0	
8	Kodak 2445	Kodak aerocolor negative 2445, with UV filter				
9	Kodak 2448	Kodak aerochrome MS 2448, with UV filter				

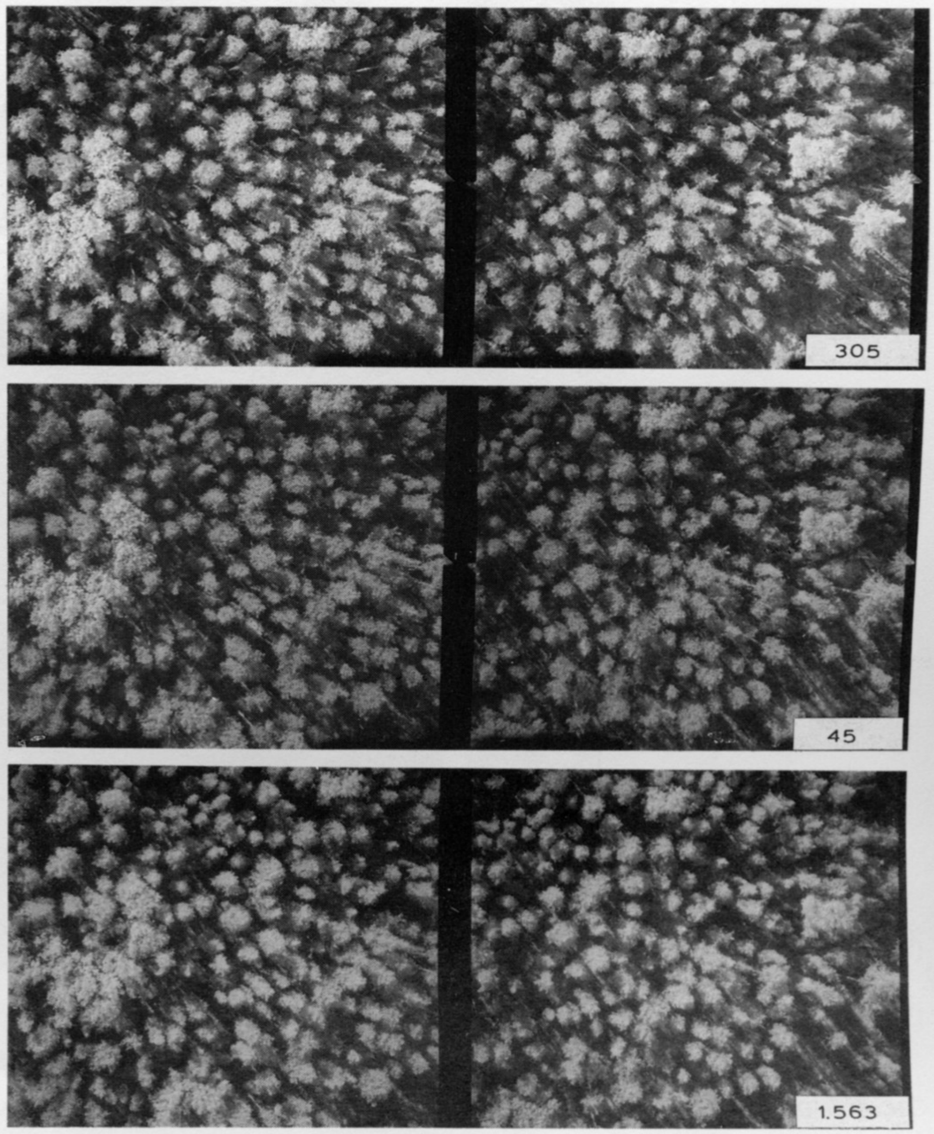
2.2 Aerial photography

The films selected for analysis are summarized in Table 1. Agfa 150 and 200 films are panchromatic emulsions with slight near infrared sensitivity (750 nm). Kodak 2424 infrared film was exposed with no filter, and with a minus blue filter at two different filter factors (F.F. = 1.5 and 2.0). Of interest was to determine if the minus blue filter made a significant difference to interpretability of the image at low altitudes. Also exposed were Kodak 2403 and 2405 panchromatic emulsions, and Kodak 2445 and 2448 color negative and positive transparency films, respectively. Prior to aerial exposure, step wedges were exposed on a National Research Council calibrated sensitometer with appropriate filtration and processed. The film speeds and average gra-

Kodak Tri-X 2403
Spectral Sensitivity:
to 720 nm.

Agfa Aviphot Pan 200
Spectral Sensitivity:
to 750 nm.

Kodak Infrared
Aerographic 2424
Spectral Sensitivity:
to 920 nm.



(a)

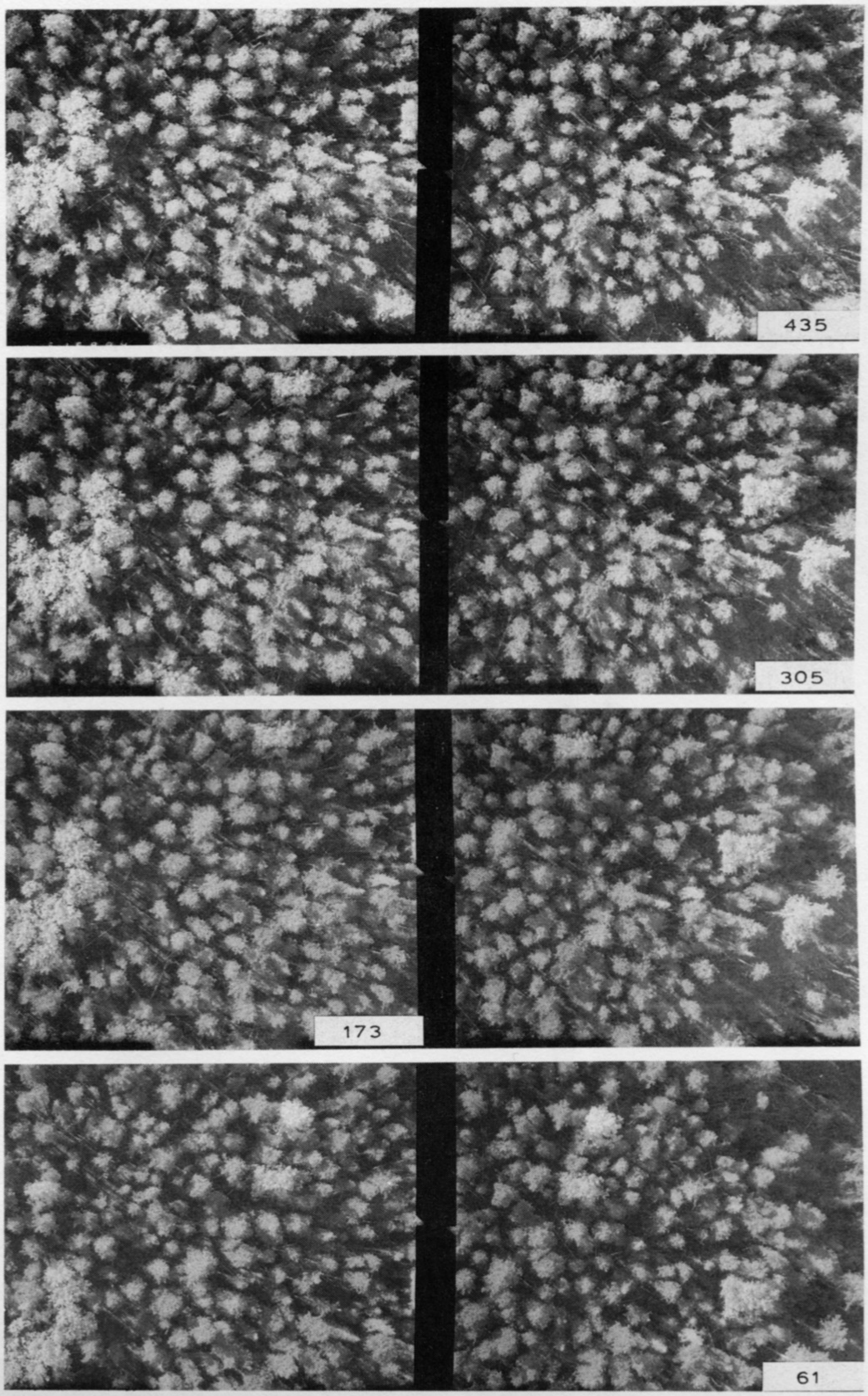
Fig. 1. (a) Spectral differences in black and white films. (b) Contrast differences denoted by average gradient.

Kodak Tri-X 2403
Average Gradient:
1.0

Kodak Tri-X 2403
Average Gradient:
0.9

Kodak Tri-X 2403
Average Gradient:
0.8

Kodak Tri-X 2403
Average Gradient:
0.7



(b)

Fig. 1b. continued.

dients attainable for the black and white emulsions were then determined (Table 1). Following aerial exposure, each film was processed from 2 to 4 average gradients depending on the range easily available under 1 rack Versamat IIC processing and Type A chemistry. Positive transparencies were produced from each emulsion for the interpretation test. This facilitated an interpreter's ability to ascertain differences between the average gradients and film types which might otherwise have been lost from viewing paper prints. A montage of photo prints (Fig. 1) provides a sample of the photography that was acquired.

The Northern Forestry Centre two-Vinten 70 mm aerial camera system (Hall, 1984; Spencer and Hall, 1988) with radar altimeter were used to procure the photos. Both Vinten cameras had 150 mm lenses mounted which permitted exposure to two films at the same scale simultaneously. Photographs were acquired on September 18 and 19, 1987, under similar illumination conditions between 10.30 and 14.30 at a scale of 1:1000. A random flight line of 2 km length was reflown several times until all combinations of film type and average gradient were completed. The differential brightness computer exposure system by Fent and Polzin (1986) was utilized to control exposures for the appropriate film speed and average gradient. Due to the complexity of exposing a large number of film and average gradient combinations, some human errors in exposure occurred which resulted in less than four average gradients being exposed for some films (Table 1).

2.3 Interpretation procedure

Participating in the study were ten interpreters having a broad range in interpretation experience. Five stereopairs representing a variety of forest cover types were selected for each average gradient. This meant an interpreter was viewing up to twenty stereopairs for each film. The identical range of cover types were reflected in the five stereopairs for each film. To avoid learning bias, the order for film selection was randomized, and the interpreters did not discuss their results with each other.

A numeric ordinal ranking scale from 1 to 6 (pertaining to very poor, poor, average, good, very good, and excellent) was employed to judge a particular film and average gradient combination for interpreting forestry features. These features included but were not limited to, tree species identification, tree crown detail, and ground vegetation, if present. These features reflected the film parameters of highlights, contrast, tone, texture, and shadow.

2.4 Statistical analysis

To address the first hypothesis, the data matrix for each film consisted of average gradients within a film as column "treatments" and interpreter responses as row "observations." There was a data matrix for each of the seven films. To address the second hypothesis, treatments consisted of the most preferred average gradient from each black and white film and the two color films. The usual parametric method of testing the null hypothesis of no treatment differences is the two-way analysis of variance (ANOVA). Since the interpreter judgements were qualitative, however, the ranked ordinal data could not be analyzed by standard parametric statistical procedures. The nonparametric analogy depends only on the rank of the observations within each block, and may be considered a two-way ANOVA on ranks (Conover, 1980). The rationale for employing nonparametric procedures for this experiment was drawn from Siegal (1956):

(1) Probability statements produced are exact probabilities, regardless of the shape of the population distribution from which the random sample was drawn.

(2) If sample sizes as small as $N=6$ are used ($N=10$ for this study), there is no alternative to using a nonparametric statistical test unless the nature of the population distribution is known exactly.

(3) Nonparametric statistical tests can treat data which are inherently in ranks as well as data whose numerical scores have the strength of ranks, without having to say how much more or less.

2.4.1 Friedman's test

Siegal (1956) provided a description of the Friedman test for which the rows represent the individuals, and the columns represent the treatments. The data for the test are ranks. Scores in each row are ranked separately. That is, with k conditions being studied, the ranks in any row range from 1 to k. The Friedman's test determines whether it is likely that the different columns of ranks (samples) came from the same population. If the individual scores were independent of the conditions, the set of ranks in each column would represent a random sample, under the null hypothesis that the mean ranks of the treatments would be about equal. With the Friedman test, only treatment differences are analyzed with no comparisons made between blocks (row observations) (Conover, 1980). Friedman's test was, therefore, most suitable, as it provided control on variation between interpreters, and permitted focus on the differences between average gradients (hypothesis 1) and films (hypothesis 2) as treatments.

The formulas for Friedman's nonparametric two-way ANOVA by ranks using an approximation of the F-distribution (Conover, 1980), was written into an interactive computer program to calculate within and between film interpreter preferences at an alpha (α) probability level of 0.05. If any of the hypotheses were rejected, a rank sum difference T-test at an $\alpha=0.05$ was employed for multiple mean comparisons (Conover, 1980). This test was based on comparisons between an absolute difference of all pairwise film types or average gradients (treatment rank sums) and calculated reference T-values.

2.4.2 Interpretation of statistical results

Although an alpha probability level of 0.05 was employed, some latitude was necessary to interpret the results and assess its information value. The difficulty arises from the difference between a significant result and a statistically significant result. Although a value of 0.05 is commonly used, there is no logical reason for this (Warren, 1986). The impression in many published results is that tests conducted at very small α levels are less prone to erroneous results than are tests conducted at a less conservative level (Gregoire and Driver, 1987). This is true only when the null hypothesis of no difference is true. When this condition fails, Type II error probability increases with decreasing α levels (Gregoire and Driver, 1987). The answer to what is a sufficiently small probability is therefore dependent on the data, prior knowledge, conditions of the experiment, and purpose of the test (Warren, 1986).

A rule was devised for interpreting the statistical results. If more than one preferred average gradient within a black and white film resulted, then the highest mean preferred average gradient was selected to be representative of that film. Similarly, if there were statistically no significant differences between films, then the films with the highest preferred rank sum were selected to be the preferred films. Since the objective was to find the most preferred average gradient within each film, and the most preferred films, the one with the highest mean can generally be considered the best choice. Even if it was not significantly better statistically than the next one, it is the one most likely to be the best because it produced the highest mean (Mize and Schultz, 1985).

2.5 Sensitometric methods

The purpose of the sensitometric analysis was to determine the characteristics of the preferred films and average gradients. The sensitometric data were compiled from the negative originals and the printed positive transparencies using a X-Rite 310 digital densitometer with an aperture diameter of 1 mm. The densitometer was interfaced to an IBM PC to facilitate the measuring and recording of density readings.

The sensitometric parameters derived from the positive transparencies included the minimum image density (D_{min}), maximum image density (D_{max}), and image density range (D_{range}). Each of these variables related to a qualitative parameter. The positive image D_{min}, for example, characterized highlight detail, while the positive image D_{range} reflected contrast and tonal range.

Three sample measurements of D_{min} and D_{max} were obtained for each positive transparency by the use of a sensitometric scanning computer program. The highest of the three D_{max} values and the lowest of the three D_{min} values

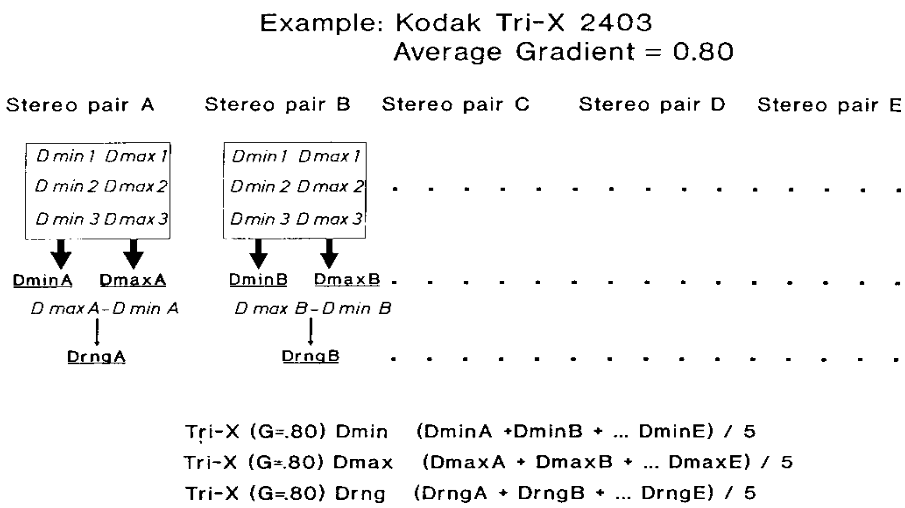


Fig. 2. Schematic of sensitometric data sampling.

were then selected to compute the D_{range} value. This procedure was replicated for the five stereo pairs. Average D_{max}, D_{min} and D_{range} values were then computed from the five stereopairs to represent each film and $\bar{G}$ combination (Fig. 2).

A Log E MK IV printer was used with Agfa Avitone P3P positive transparency film. Image contrast was not influenced by either electronic dodging or processing variations. Since the $\bar{G}$ of the positive process was kept constant at 1.1, the resultant positive transparencies exhibit the density range characteristics of the original negative. Exposure of the transparencies, however, was modified to minimize the influence of variation in exposure densities from the negatives. These negatives exhibited an exposure variation of approximately a half and one stop. Associations between rank preferences and the sensitometric quantities of D_{min}, D_{max} and D_{range} were computed using Spearman's rank correlations (Mosteller and Rourke, 1973) at a probability level of 0.05.

3 RESULTS AND DISCUSSION

3.1 Interpretation test

The first question in this study was to determine if there were any interpreter preferred average gradients within each film. The Friedman's ANOVA with multiple mean comparisons provided an empirical and objective determination and ranking of interpreter preferences. The means and standard deviations of the interpreter responses by film and average gradient are summarized in Table 2. Kodak films 2448, 2405, and 2445 were the most preferred films for forest interpretation across all average gradients for the other films.

TABLE 2

Interpreter responses by film and average gradients

Film type	Statistic[1]	Average gradient			
		$\bar{G}_1$	$\bar{G}_2$	$\bar{G}_3$	$\bar{G}_4$
Agfa 150	$\bar{x}$	3.5	4.3	4.2	
	s	0.67	0.45	0.87	
Agfa 200	$\bar{x}$	3.2	3.6	3.7	4.3
	s	1.23	0.68	0.82	0.67
Kodak 2424 F.F. 1.0	$\bar{x}$	3.2	3.1	3.3	
	s	0.98	0.70	0.78	
Kodak 2424 F.F. 1.5	$\bar{x}$	3.1	3.2	3.3	3.7
	s	0.94	0.60	0.90	0.78
Kodak 2403	$\bar{x}$	3.7	3.6	4.3	3.1
	s	0.90	0.80	0.64	0.94
Kodak 2405	$\bar{x}$	4.4	4.4		
	s	0.80	0.66		
Kodak 2424 F.F. 2.0	$\bar{x}$	2.7	2.9	3.9	
	s	1.10	1.04	1.04	
Kodak 2445	$\bar{x}$	4.2			
	s	1.33			
Kodak 2448	$\bar{x}$	5.0			
	s	0.77			

[1] $\bar{x}$ = arithmetic mean interpreter response.
s = standard deviation of interpreter response.

In answering hypothesis 1, there were interpreter preferences for a particular average gradient or average gradients within each black and white film. The interpreters preferred the higher, but not necessarily the highest, average gradients ranging from 0.9–1.2 across all black and white films (Tables 2 and 3). There was no significant difference for the two average gradients tested for Kodak 2405. This was expected, as both average gradients were similar ($\bar{G}_1 = 0.9$ and $\bar{G}_2 = 1.0$) and no discernable difference could be seen between the images.

There was some interpreter variation for the Kodak 2424 black and white infrared film depending on the use of the minus blue filter and the exposure filter factor employed (Table 2). Kodak recommends a minus blue filter with a filter factor of 1.5 (Eastman Kodak Company, 1982). There was no interpreter preference over any of the average gradients tested when no filter, or when a minus blue filter and a filter factor of 1.5 was used (Table 3). The highest average gradient of 1.0 was preferred for the Kodak 2424 film with a minus blue filter and a filter factor of 2.0. (This is equivalent to an additional exposure of half a stop.) This suggests that for Kodak 2424 infrared film, a higher minus blue filter factor of 2.0 should be employed if this film is used for large-scale photography.

TABLE 3

Friedman's ANOVA results and multiple mean comparisons for interpreter preferences within each panchromatic film

Film type	Calculated F	F table value	Multiple mean comparisons[1] and rank sum scores				Most preferred gradient[2]
			$\bar{G}_1$	$\bar{G}_2$	$\bar{G}_3$	$\bar{G}_4$	
Agfa 150	5.36[3]	3.55	14	24	22		$\bar{G}_2$
Agfa 200	2.31	3.01	16.5	20.0	22.0	30.5	$\bar{G}_4$
Kodak 2424 F.F. 1.0	0.68	3.55	20.5	18.5	21.0		$\bar{G}_3$
Kodak 2424 F.F. 1.5	0.71	2.96	23.0	23.0	25.5	28.5	$\bar{G}_4$
Kodak 2403	6.84[3]	2.96	25.0	24.0	34.5	17.0	$\bar{G}_3$
Kodak 2405	0.0	5.12	15.0	15.0			$\bar{G}_2$
Kodak 2424 F.F. 2.0	8.55[3]	3.55	15.5	17.5	27.0		$\bar{G}_3$

[1]Horizontal bar indicates significant difference at 0.05 probability level. Multiple mean comparisons performed only if significant difference between $\bar{G}$.
[2]If there is more than 1 preferred gradient with no significant difference, then the highest interpreter preferred gradient (Table 2) is selected.
[3]Significantly different at 0.05 probability level.

In answering hypothesis 2, the seven black and white films and preferred gradients were compared with the two color films to determine which films were most preferred by forestry interpreters. Color film Kodak 2448 was the most preferred film (Fig. 3) and was attributable to the film's finer grain (Eastman Kodak Company, 1982), and viewing of the original color transparencies in the interpretation test. Kodak 2445 is a color negative film from which diapositives were produced. Interpreters were therefore viewing a second generation product. Although interpreter film preferences were exhibited, the rank sums for comparisons with Kodak 2405, 2445, 2403, and Agfa 200 were all very close (Fig. 3). This suggests interpretation results from either of these four films would be similar. This observation is commensurate with the result of no statistically significant difference between these four films (Fig. 3). The Kodak black and white films of 2405 and 2403 were, however, preferred by interpreters over the Agfa films. The Kodak 2424 infrared films fared poorly in interpreter preference.

Agfa 200 and 150 are black and white films with extended spectral sensitivity into the near infrared (750 nm). Its inherent features include high resolv-

Film and average gradient number

	2448	2405	2445	2403	200	150	2424 F.F. 2.0	2424 F.F. 1.5	2424 F.F. 1.0
		$\bar{G}_2$		$\bar{G}_3$	$\bar{G}_4$	$\bar{G}_2$	$\bar{G}_3$	$\bar{G}_4$	$\bar{G}_3$
Rank sum scores	63.0	52.5	51.0	50.0	49.5	40.5	40.0	34.0	24.5

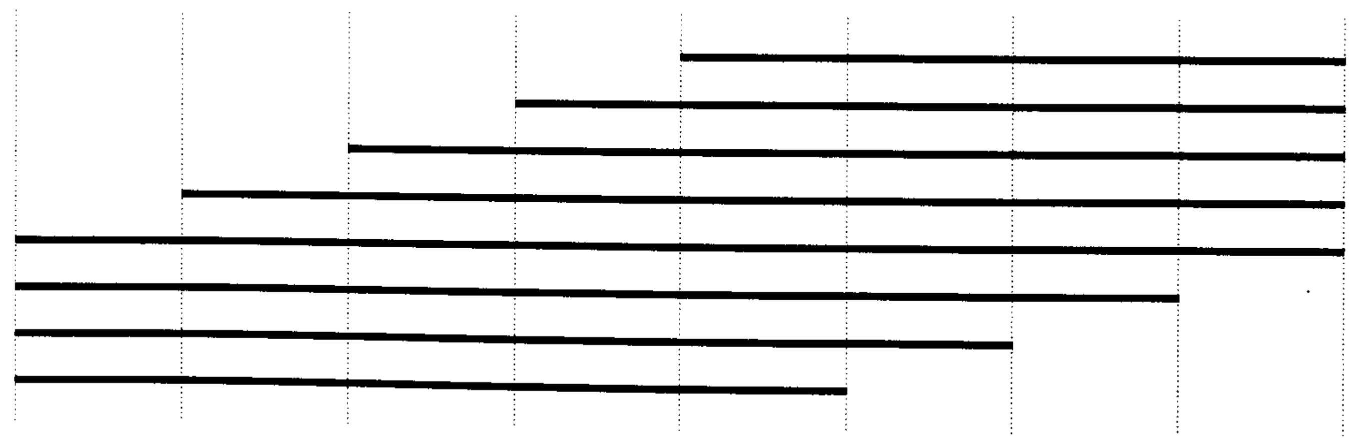


Fig. 3. Multiple mean comparisons for panchromatic and color films ordered by decreasing treatment (film type) means. Horizontal bar indicates significant difference between films at 0.05 probability level.

ing power, haze penetration, and a wide exposure latitude (Agfa-Gevaert, 1983). At the low altitudes that large-scale photos are acquired from, haze is generally not a problem. The advantages of the Agfa films are therefore greater at the smaller film scales. From a forestry interpretive perspective, the interpreter prefered the Kodak black and white emulsions, followed by the Agfa 200 and 150 (Fig. 1).

3.2 Sensitometric analyses

The third question in this study was to determine if there were consistent sensitometric characteristics of the preferred black and white films. Three relationships were portrayed from the graphical representation of D_{min}, D_{max}, and D_{range} (Fig. 4) of the interpreted positive images:

(1) the similar tendencies of the maximum density and density range variables;

(2) the random nature of the minimum density variable;

(3) The relation between interpreter preferred average gradient and the peak values of D_{max} and D_{range}.

Items 1 and 2 above result from the negative originals' inherent quality and the method of reproducing the originals to positive transparencies. Since the

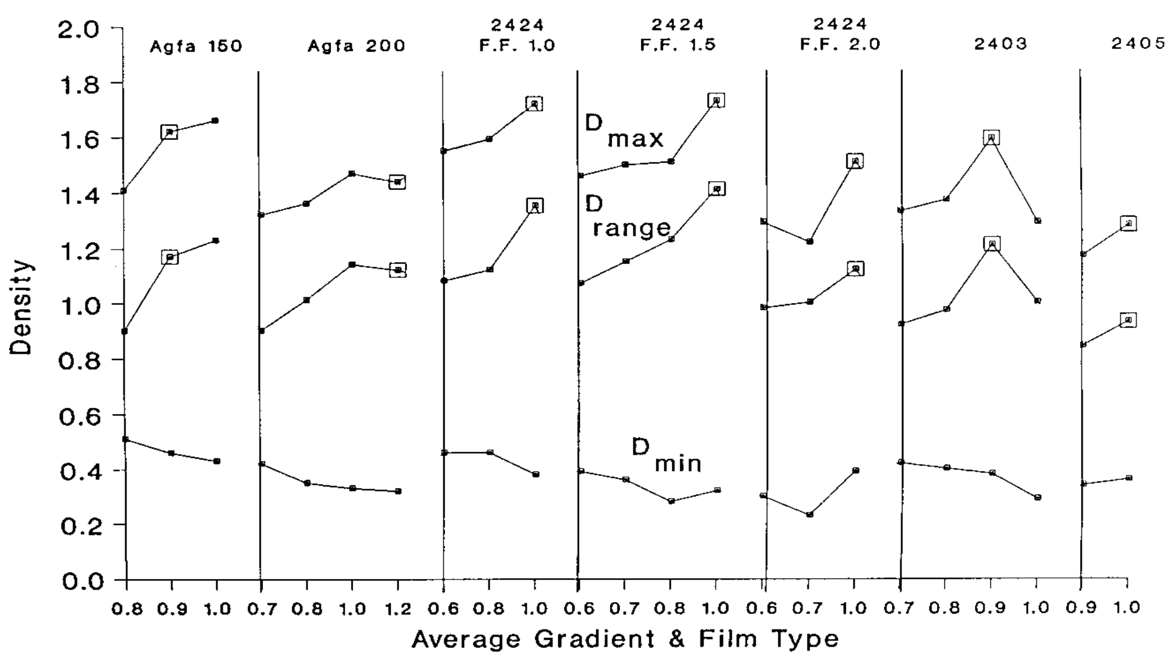


Fig. 4. A graphical plot of density versus black and white film type and average gradient.

exposure levels during printing were controlled by varying the D_{min} density level, the D_{min} of the positive did not vary according to the negative originals. The D_{max} and D_{range} were not influenced by autododge or processing changes, and exhibited the same variations found on the original negatives. The D_{max} and D_{range}, therefore, exhibited similar tendencies due to their related nature (i.e., $D_{range} = D_{max} - D_{min}$). If D_{min} was controlled or held constant, then D_{max} and D_{range} would change proportionally.

For item three, there was a definite interpreter preference for those films with higher D_{range} values. This condition was true for all but the Agfa 150 and 200 films. The preferred $\bar{G}$ for the Agfa films were within one $\bar{G}$ of the peak $\bar{G}$ values (Fig. 4).

There was no correlation between interpreter preference and minimum density (Table 4). This lack of correlation was due to D_{min} being used as a control for equalizing exposure variations in the production of the positive transparencies.

The rank correlations of interpreter preference with maximum density and

TABLE 4

Sensitometric data, ranks, and correlation analysis of preferred films

Film Type	$\bar{G}$	D_{min}	D_{max}	D_{range}	Ranked preference
Preferred films—sensitometric attributes					
Agfa 150	0.90	0.46	1.62	1.17	4
Agfa 200	1.20	0.32	1.44	1.12	3
Kodak 2424 F.F. 1.0	1.00	0.38	1.72	1.35	7
Kodak 2424 F.F. 1.5	0.80	0.28	1.51	1.23	6
Kodak 2424 F.F. 2.0	1.00	0.39	1.51	1.12	5
Kodak 2403	0.90	0.38	1.59	1.21	2
Kodak 2405	1.00	0.36	1.28	0.93	1
Preferred films—ranked data					
Agfa 150	0.90	7	6	4	4
Agfa 200	1.20	2	2	2	3
2424 F.F. 1.0	1.00	4	7	7	7
2424 F.F. 1.5	0.80	1	4	6	6
2424 F.F. 2.0	1.00	6	3	3	5
2403	0.90	5	5	5	2
2405	1.00	3	1	1	1
Rank Correlation (rs)		−0.036	0.607	0.750	

Null hypothesis of population independance (0.05 confidence) is:

Parameter	Statistic	z-value	Probability	Condition
D_{range}:	$z = rs*\mathrm{sqrt}(n-1)$	$= 2.121320$	$= 0.017$	**REJECTED**
D_{min}:	$z = rs*\mathrm{sqrt}(n-1)$	$= 0.101823$	$= 0.96$	**ACCEPTED**
D_{max}:	$z = rs*\mathrm{sqrt}(n-1)$	$= 1.716855$	$= 0.043$	**REJECTED**

density range were statistically significant at the 0.05 probability level (Table 4). Interpreter preference increased as maximum density (D_{max}) decreased. There was a similar trend with interpreter preference increasing as density range (D_{range}) decreased. These results contrast to those depicted in Fig. 4 where the preferred films were characterized by high density ranges. This discrepancy is explained by the information that density range represents.

Density range was an indicator of image contrast influenced by both the average gradient at the time of processing, and the film's spectral sensitivity. For the latter, this governed the film's response to the spectro-photometric qualities of the objects being photographed. For example, holding the average gradient constant, a panchromatic image of a deciduous and coniferous tree stand would produce a lower density range compared with an infrared image of the same stand. Figure 4, therefore, presents interpreter preference when D_{range} is a function of average gradient, whereas Table 4 presents interpreter preference when D_{range} is a function of film spectral sensitivity.

3.3 Sensitometric comparisons between black and white and color films

There was a major problem when sensitometric comparisons between black and white and color films were made. The sensitometric color responses achieved by the yellow, magenta and cyan dye layers were different from black and white films. Although a color sensitometric analysis of the dye layer densities (i.e., color balance) could have been performed, its use to rationalize preference of color over black and white films was not appropriate (Powers and Millar, 1963; Langford, 1977).

4 SUMMARY

The role of the photo interpreter is paramount in governing the quality of forest inventory surveys. The interpreter knows by experience which image products are preferred. Specifications are rarely given, however, due to a lack of knowledge of aerial photographic sensitometric variables such as average gradient and D_{range}. The purpose of this study was to correlate interpreter judgments and preferences to film sensitometric characteristics as a basis for determining future specifications. This provides important basic information to the photo interpreter, aerial photographer and the film processor with respect to their roles in producing the aerial image to be interpreted.

Although there may be several acceptable average gradients that a black and white aerial film may be processed to, there were definite preferences by interpreters. Relative to the 0.6–1.2 average gradient range evaluated, average gradients from 0.9 to 1.2 were preferred, which corresponded to the relatively higher contrast images. The density ranges were between 1.0 and 1.2 for the Kodak 2405 and 2403, and Agfa 200 and 150 films. For Kodak black and white infrared 2424 film, the preferred density ranges were between 1.2 and 1.4.

The most preferred film was the Kodak 2448 color positive film followed by Kodak 2405 extended red panchromatic, 2445 color negative, and 2403 extended red panchromatic emulsions. Next on the preference list were the slightly infrared-sensitive, panchromatic Agfa films 200 and 150. Agfa 150 was a fairly slow speed, fine grain film, but its perceived utility for low-altitude work was somewhat low. Kodak 2424 black and white infrared film rated the lowest of all films. There was little reflectance and therefore little information in the shadow areas. Details required for interpretation of large-scale photos included both the tree crowns and ground features. These conclusions were similar to a visual analysis of the average interpreter preferences in Table 2. A decrease in interpreter preference was observed with an increase in film spectral sensitivity.

In conclusion, interpreters preferred the lower contrast range, narrower spectral sensitivity panchromatic films, over the higher contrast, wider spectral sensitivity infrared films for forestry interpretation at large scales. Within the panchromatic black and white films however, interpreters preferred those processed to higher average gradients.

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APPENDIX

Definition of sensitometric terms used:

Average Gradient: The tangent angle subtended between line of two defined points on the characteristic curve of the emulsion of the x-axis. According to ISO 7829, point 1 is defined by measuring the base density + the fog density + 0.3 and locating it on the characteristic curve, this value is also called the speed point. Point 2 is defined as 1.0 + the value of the speed point and locating it on the characteristic curve. The slope of the line between these two points will also provide the average gradient. D_{min}, D_{max}, D_{range}: the measured minimum, maximum, and calculated density range of individual images.

Minimum density is associated with shadow areas and maximum density is associated with highlighted areas. Density range provides a quantitative expression of image contrast.

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