Aerial Films for Forest Inventory: Optimizing Film Parameters

L. Fent, R.J. Hall, and R.K. Nesby

Abstract
Recent advances in aerial film emulsions and processing techniques have not been evaluated to determine their suitability to forest inventory operations. Five black-and-white films (Kodak's Double-X 2405, Infrared 2424, and Panatomic-X 2412; Agfa's Aviphot Pan 200; and Ilford's FP3) and two color films (Kodak's Aerocolor 2445, and Aerochrome Infrared 2443 processed as a positive and as a negative) were evaluated for their accuracy and user preference for forestry photo interpretation at a scale of 1:20,000. The black-and-white films were also exposed and processed at three average gradients (1.0, 1.4, 1.8) except for the Panatomic-X (1.8, 2.0, 2.2) and Ilford FP3 (1.4 only). Species composition, crown closure, stems per hectare, and height were examined collectively to determine photointerpretation accuracy for each film/average gradient combination. The highest interpretation accuracies were attained when average gradients produced densitometric range measurements of 0.11 to 0.17 (0.12-mm aperture) in mixed coniferous-deciduous forest stands. The Panatomic-X emulsion achieved the highest interpretation accuracy (83 percent) and Aerocolor 2445 attained the lowest (68 percent). Interpreter preference was highest with Aerochrome I.R. 2443 positive processing (7.2 on a scale of 1 to 10) and lowest with Aerochrome I.R. 2443 negative processing (4.1 on a scale of 1 to 10). Higher interpreter preferences were associated with increasing spectral sensitivity to the infrared. There was no correlation, however, between interpreter accuracy and preference for the 16 average gradient/film combinations. Using Panatomic-X film in forest inventory entails practical trade-offs between gains in interpretation accuracy and its requirements for proper exposure. Panatomic-X is a fine-grained, slow speed film with narrower exposure latitude, narrower photo acquisition windows (day and season) relative to other panchromatic films, and likely requires image motion compensation for optimal exposure at a scale of 1:20,000.

Introduction
Conventional aerial photographs continue to be the major source of remote sensing data used in natural resource assessments despite the many developments in digital remote sensing (Avery, 1977; Meyer and Werth, 1990; Howard, 1991; Driscoll, 1992). Yet the perception exists that digital remote sensing has rendered aerial photography an outdated technology. Aerial photography is often viewed as a relatively stagnant technology with no major improvements foreseen (Leckie, 1990). During the past decade, however, there have been no fewer than eight new emulsions appearing in the aerial photo field. These films have been specifically engineered to address issues such as film speed, spectral sensitivity, resolution, and color rendition in relation to aerial photography (Fent, 1990). One class of these newer emulsions (the Agfa films) will be incorporated in this study in a comparative context with the more established films. In addition, significant developments in aerial camera technology include image motion compensation, lenses with better optics and consequently better illumination uniformity in the negative, integrated geopositioning systems, and exposure systems that combine photo acquisition with controlled laboratory film processing (Fent and Polzin, 1986; Zeiss Jena, 1990; Zeiss, 1990; Leica, 1992). The forestry community is a major user of aerial photographs and can benefit substantially from improvements in this technology. Technological advancements and more specific definition of aerial photo quality parameters such as spectral sensitivity, average gradient[1], and densitometric range will result in a higher quality photo product for interpretation and mapping (Hall and Fent, 1991).

The effects of contrast and film type on forest interpretation have been addressed by Jensen and Colwell (1949), Losee (1951), Schultz (1951), Meyer and Myhre (1961), Meyer and John (1961), Haack (1962), and Vlcek (1972). These early workers established the basic operational parameters relevant to acquiring aerial photographic products for forest interpretation. More recent investigations (Klimes *et al.*, 1987; Ciesla, 1990; Hoppus, 1990; Hall and Fent, 1991) have helped to refine the application of film materials and photo processing for the analyses of forest cover information.

In the government of Alberta's forest inventory program, the optimal film type and contrast in black-and-white processing have not been defined for forest cover interpretation. Previous investigations that analyzed optimal scales and film

L. Fent and R.K. Nesby are with Alberta Environmental Protection, Resource Information Branch, 9945 108 Street, Edmonton, Alberta T5K 2G6, Canada.
R.J. Hall is with Natural Resources Canada, Northern Forestry Centre, 5120 - 122 Street, Edmonton, Alberta T6H 3S5, Canada.

[1]The average gradient indicates the level of contrast given to the film during development. An average gradient of 1.0 will reproduce the object brightness range 1:1 on the resulting image (International Standards Organization 7829, 1986). As a general rule in medium scale aerial photography, average gradients below 1.0 are typically low contrast, values between 1.0 and 1.3 are medium contrast, values above 1.3 are high contrast, and values above 1.7 are very high contrast.

Photogrammetric Engineering & Remote Sensing,
Vol. 61, No. 3, March 1995, pp. 281–289.

0099-1112/95/6103-281$3.00/0

types for forest inventory (Silvacom Ltd., 1987, 1988) produced results that were inconclusive or contradictory due to the effects of varying solar angles, average gradients, and paper printing grades on image contrast. Aerial photographs acquired for forest inventory usually employ the general specifications defined by the Interdepartmental Committee on Air Survey (1982). These specifications were intended to serve the topographic mapping community and not the interpretive fields such as forestry or agriculture (Fleming, 1983), and may be inadequate for producing a high-quality photo product for forestry purposes. It is not uncommon, for example, for an aerial film to pass densitometric evaluation and yet be considered of poor quality for forestry photo interpretation (Lyseng[2] and Stade[3], personal communication). Consequently, improvements in aerial photographs for forestry purposes should be sought in association with the acquisition phase, because corrective measures may be insufficient or even impossible after procurement (Welch and Halliday, 1975; Fleming, 1983).

The concept of defining photo specifications for specific applications such as forestry is not new (Plasker and TeSelle, 1988). Many forestry agencies approach the problem of aerial photography specifications on a trial-and-error basis, often by adjusting and refining the product criteria according to judgments from agency interpreters. Although specifications based on a subjective factor such as preference may help to derive meaningful information from the aerial photograph, a more appropriate process for determining operational specifications is to assess the influence of photo quality on interpretation accuracy.

The study objective was to determine which of the five black-and-white and three color aerial film types were most accurately interpreted and most preferred for the interpretation of Mixedwood Boreal forest cover types (Rowe, 1972). The study objective was addressed by answering the following questions:

- Does forest interpretation accuracy vary between average gradients and within each black-and-white film?
- Does forest interpretation accuracy differ among the five black-and-white and three color film combinations?
- Does forest interpretation preference differ among films?
- Is there a relationship between interpretation accuracy and interpreter preference?

Materials and Methods

Study Area

The study area is located 150 km north of Edmonton, Alberta (National Topographic System map sheets 83 I13 and J16) within the Mixedwood Boreal Forest Region B.18a (Rowe, 1972). A flight line 60 km in length was flown over an area that exhibited a considerable diversity of cover types exemplified by varying stand heights, crown closure, stems per hectare, and species composition, typical of the boreal forest. The species in the study included white spruce (*Picea glauca* [Moench] Voss), black spruce (*Picea mariana* [Mill.] B.S.P.), tamarack (*Larix laricina* [Du Roi] K.Koch), jack pine (*Pinus banksiana* Lamb.), white birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), and balsam poplar (*Populus balsamifera* L.).

[2]L. Lyseng, October, 1991, Alberta Environmental Protection, Timber Management Branch, Edmonton, Alberta.

[3]A. Stade, October 1991, Alberta Environmental Protection, Quality Control Unit, Edmonton, Alberta.

Aerial Photography

Seven aerial films were selected for analysis[4] (Table 1). The Agfa Aviphot PE 200 (A200), Kodak Infrared Aerographic 2424 (BWIR), and Kodak Double-X Aerographic 2405 (DXX) are extended red or near-infrared sensitive aerial films and are typical of films used in operational forest inventories. The other black-and-white films evaluated were Ilford FP3 (ILFD), a true aerial panchromatic emulsion, and Kodak Panatomic-X Aerographic 2412 (PANX), an extremely fine-grained high-resolution emulsion. The color films evaluated were Kodak Aerocolor Negative 2445 (CNEG), and Kodak Aerochrome Infrared 2443 processed to a positive (CIRP) and to a negative (CIRN) (Klimes and Ross, 1993). Both color infrared products were interpreted on paper prints.

For each of the black-and-white films (except ILFD), three average gradients were chosen that represented typical low-, medium-, and high-contrast processing for forestry assessments (Table 1). The high average gradients for PANX were considered operational norms for this emulsion (Eastman Kodak, 1992). All films were subjected to sensitometric evaluation prior to the aerial photo acquisition. The appropriate effective aerial film speed (EAFS) and average gradients were derived for each of the black-and-white films and used to properly expose each film/average gradient combination. Processing was performed in a Versamat 11C film processor using Kodak's 885 chemistry. The CIRP/CIRN infrared balance (i.e., 33) was normal (Fleming, 1979).

The aerial photographs were acquired with a Wild RC20 camera and a 152-mm lens at a scale of 1:20,000. All films except the CNEG were exposed with a Wild 525-nm cutoff filter. The flight line was repeated to expose each of the 16 film and average gradient combinations (Table 1). The time and date of the photo acquisition, during solar noon and close to the summer solstice (10 July), were chosen to minimize the variation of changing solar angle on image contrast. Photo acquisition started at 11:57 MDT and was finished at 14:13 MDT, with each flight line taking approximately eight minutes to complete. Contrast variation was further controlled by printing the black-and-white photos on grade two photographic paper.

Interpretation Procedure

Fifty polygons were selected from the flight line so that each film type would contain an average distribution of three different polygons. The allocation of polygons among the films helped in preventing interpreter learning bias. The polygon sample also provided, for each film type, a representation of forest stand attributes to be assessed. The forest attributes included species composition, crown closure, height, and stems/hectare. A number from 1 to 10 was used to describe each attribute. For example, if the interpreted height of a tree stand in a polygon was 25 m, then a number 9 would be assigned to the height class attribute for that polygon (Table 2).

Thirty-eight interpreters from across Canada and the United States familiar with the boreal forest were solicited. Some means of standardization was required to ensure consistency in the interpreters' approach to the study (Hilborn, 1981). Interpretation key stereograms were developed to aid the interpreters in evaluating the four forest attributes at a scale of 1:20,000. The aerial prints from each of the 16 film/average gradient combinations were assembled and identified

[4]The mention of trade names does not imply endorsement by the authors.

TABLE 1. AERIAL FILMS, AVERAGE GRADIENTS, AND PROCESSING SYSTEMS EVALUATED.

Aerial Films	Average Gradient/Process		
Agfa Aviphot 200 PE	1.00	1.40	1.80
Kodak Double-X Aerographic 2405	1.00	1.40	1.80
Kodak Infrared Aerographic 2424	1.00	1.40	1.80
Kodak Panatomic-X Aerographic 2412	1.80	2.00	2.20
Ilford FP3		1.40	
Kodak Aerochrome Infrared 2443	Positive originals - EA-5		
Kodak Aerochrome Infrared 2443	Negative originals - Modified C-22		
Kodak Aerocolor Negative 2445	Aero-Neg Color		

only by a letter designation (set A to P). Each photo set contained stereo coverage of the three polygons per film combination. The interpreters were asked to interpret the four forestry attributes for each polygon (Table 2), and to rate the photo sets in terms of their relative preference for forestry interpretation from 1 (low) to 10 (high).

Ground Truth and Interpreter Accuracy

The ground reference information was based on interpretation of large-scale, 70-mm (1:500) photographs acquired from a fixed-base camera system with Hasselblad MK 70 cameras (Bradatsch, 1980; Spencer and Hall, 1988). These photos were acquired during leaf-off conditions to facilitate discrimination among hardwood species. A representative description of the stand was obtained by averaging interpretation information of four stereo pairs as sample plots within each forest polygon.

The confusion error matrix (i.e., contingency table) and Kappa statistic described by Congalton and Mead (1983) can be used to evaluate the correspondence of an interpreted attribute to its actual value, and was initially considered in this study to compute accuracy. The photo interpretation and ground truth values employed, however, were based on a ten-point classification scheme, and the polygons were also not contiguous nor cellularized over the entire study area. Consequently, each polygon was unique in size and shape and only served to characterize a particular forest stand. The process used in this study was to determine the interpretation error as either a 0 (correct interpretation) or 1 to 10, depending on its deviation in classes from its correct value. If

TABLE 2. FORESTRY ATTRIBUTES AND CLASSIFICATION INTERVAL SYSTEM USED IN DETERMINING A POLYGON ACCURACY LABEL.

Species Composition[1]		Crown Closure		Height		Stems/Hectare	
Interval	Class	Interval	Class	Interval	Class	Interval	Class
1–10%	1	1–10%	1	0–3m	1	≤ 200	1
11–20%	2	11–20%	2	3.1–6m	2	201–400	2
21–30%	3	21–30%	3	6.1–9m	3	401–600	3
31–40%	4	31–40%	4	9.1–12m	4	601–800	4
41–50%	5	41–50%	5	12.1–15m	5	801–1000	5
51–60%	6	51–60%	6	15.1–18m	6	1001–1200	6
61–70%	7	61–70%	7	18.1–21m	7	1201–1400	7
71–80%	8	71–80%	8	21.1–24m	8	1401–1600	8
81–90%	9	81–90%	9	24.1–27m	9	1601–1800	9
91–100%	10	91–100%	10	27.1–30m	10	1801 ≥	10

[1]The species attribute is composed of Aspen, Poplar, Birch, Tamarack, Fir, Pine, Black Spruce, and White Spruce.

crown closure was interpreted as 60 percent (i.e., class 6), for example, and its reference value was 40 percent (i.e., class 4), then the absolute value of the class deviation (interpreted minus reference) would be an interpretation error of two classes (i.e., 20 percent). The average of the class deviation errors ($\bar{E}$) for each attribute would provide a measure for the interpretation mean class error of a polygon: that is,

$$\bar{E} = \sum_{i=1}^{n} \frac{|I_i - R_i|}{n}$$

where

$\bar{E}$ = mean class error,
I_i = interpreted class number,
R_i = reference class number, and
n = number of attributes.

Because each class error represents a 10 percent deviation from its actual value, interpretation accuracy percentage would be computed as $100 - (10 * \bar{E})$.

The class deviation error and accuracy percentage for the species attribute required a minor adjustment. The class deviation error values were obtained only for those species that an interpreter identified, or for where the species existed as verified by the reference data. For example, if the interpreter identified coverage of aspen as class 6 (i.e., 60 percent of the stand consisted of aspen), poplar as class 3 (i.e., 30 percent of the stand consisted of poplar), and birch as class 1 (i.e., 10 percent of the stand consisted of birch), while the reference data described aspen as class 6, poplar as class 3, and pine as class 1, then error values would be assigned as follows: aspen = 0 (i.e., no interpretation deviation from the reference), poplar = 0, birch = 1 (i.e., 10 percent deviation), and pine = 1. The values for both birch and pine would be included in the error calculation, because both were identified by either the interpreter or the reference data. The class deviation errors were then summed and divided by the number of species that were identified either in the interpretation or the reference data. For the example noted, the sum of the errors would be 2 and the number of species in either the interpretation or reference data were 4, resulting in a species class deviation error of 0.5 (i.e., 2 errors/4 species) or, likewise, an interpretation accuracy of 95 percent. An example of the complete species composition, crown closure, height, and stems/hectare error calculation, along with the mean class deviation error and interpretation accuracy percentage for a polygon, is outlined in Table 3.

Densitometry

A densitometer (X-Rite model 310) with a specially constructed aperture diameter of 0.12 mm (standard aperture diameters are between 1 and 3 mm) provided an appropriate size for measuring tree crown image highlights on the negatives that were 2 to 7 m in diameter on the ground (Morton et al., 1986). Density maximums for both the coniferous ($D\max_c$) and deciduous ($D\max_d$) tree species were obtained on the photographic negatives in a forest area common to all films in order to determine the density range between the coniferous and deciduous tree species (defined as $Drng_{d-c} = D\max_d - D\max_c$). These values represented a measure of forest stand hardwood-softwood species contrast instead of overall image contrast. The density range values were obtained to associate film densitometric parameters with interpreted accuracy and preference.

TABLE 3. A NUMERICAL EXAMPLE FOR CALCULATING INTERPRETATION ACCURACY.

	Aspen	Poplar	Birch	Tamarack	Fir	Pine	Black spruce	White spruce	Crown Closure	Height	Stems/ha.
Interpretation							3	7	2	1	4
Reference (ground truth)				7			3		3	3	8
Interpretation Errors				7			0	7	1	2	4
Error average for species	7 + 0 + 7 = 14/3 species = 4.7								1	2	4
Error average for polygon	4.7 + 1 + 2 + 4 = 11.7/4 attributes = 2.9 class error										
Accuracy %	Given 10% classes: 2.9 * 10 = 29% error, 100 − 29 = 71% accuracy										

Statistical Analysis

An analysis of variance design is appropriate for comparing the influence of film/average gradient combinations on interpreter performance. Although the training stereograms were helpful in ensuring consistency, a potential influence on interpreter performance existed because of the interpreters' geographic origin. A one-way analysis of covariance[5] (ANCOVA) with interpreter geographic location as the covariate and average interpretation accuracy as the response variable was used to address the first and second questions of the study. The ANCOVA was conducted using the General Linear Model (GLM) program within the Statistical Analysis System (SAS Institute Inc., 1985). The data matrix for the first question consisted of average gradients within each of the four black-and-white films as "treatments" and interpreter responses as "row" observations. The data matrix for the second question consisted of the selected average gradient from each of the black-and-white films yielding the greatest interpretation accuracy percentage, including the Ilford and the three color-film combinations.

The objective was to determine which aerial films produced the smallest interpreter error and, therefore, the most accurate interpretation of forest attributes overall. If there were significant differences between the "treatments," then the Bonferroni multiple mean comparison test (Neter et al., 1990) was employed. If there were no statistically significant differences between films, then the film with the greatest interpretation accuracy was selected to be the best film. This approach is similar to that advocated by Mize and Schultz (1985) because the film most likely to be best is the one producing the highest mean accuracy.

Descriptive statistics (mean, standard deviation, standard error) were used to determine interpreter preference confidence intervals for each film type (question 3). The relationship between interpreter accuracy and preference (question 4) was determined by ranking the film/average gradient combinations by interpreter accuracy and preference, and by computing Spearman's rank correlation coefficient (Mosteller and Rourke, 1973).

[5]All statistical tests in this study were performed at $\alpha = 0.05$ level of significance.

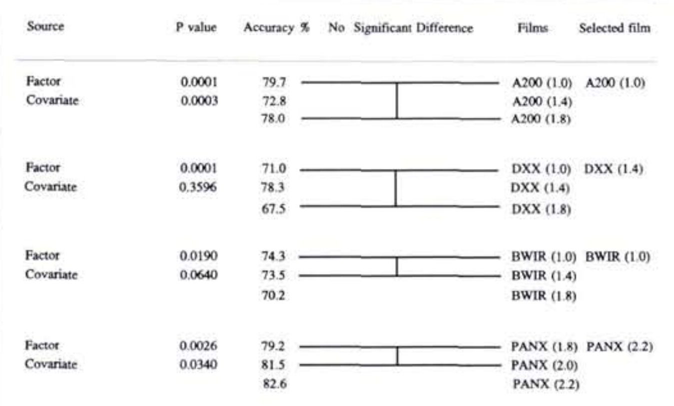

Figure 1. ANCOVA results for each of the four B&W films and three average gradients. The three average gradients are grouped for each film, and no significant difference between the average gradients of a film type is denoted by the vertical bar connector. The average gradient with the highest interpreted accuracy percentage is selected as the best choice within each film type.

Results and Discussion

Interpretation Accuracy and Average Gradient

The first question in this study was to determine if a change in average gradient produced significant changes in interpretation accuracy. The ANCOVA provided the means to evaluate differences between interpretation accuracy percentage for each average gradient within the black-and-white film types. The ANCOVA procedure also aided in determining whether having interpreters from different geographic regions was a significant factor in the study.

The average gradient with the highest mean accuracy was selected as representing the best contrast within each black-and-white film (Figure 1). These average gradients corresponded to densitometric ranges for the maximum density (i.e., the highlights) in the coniferous-deciduous tree stands of 0.11 to 0.17 (Table 4). These results suggest relatively low density differences between coniferous and deciduous *crown highlight* measurement result in higher interpretation accuracy. The covariate term (grouping the interpretation by geographical location) was significant in three of the four film types (Figure 1). The ANCOVA model was therefore appropriate for this study.

Interpretation Accuracy and Film Type

The second question was to determine if interpretation accuracy differed among the five black-and-white and three color films. The four film/average gradients selected in question 1 were grouped with ILFD and the color films. Significant differences between films defined distinct groups of film types

Table 4. Forest Stand Densitometry Obtained with a 0.12-mm Diameter Aperture. The Density Range Is the Difference between the Maximum Density Readings (Tree Crown Highlights) of the Deciduous and Coniferous Tree Species.

Film/Average Gradient	Coniferous-Deciduous Density Range $\|(Dmax_c - Dmax_d)\|$
A200, G = 1.00	0.15
A200, G = 1.40	0.22
A200, G = 1.80	0.38
DXX, G = 1.00	0.03
DXX, G = 1.40	0.11
DXX, G = 1.80	0.11
ILFD, G = 1.40	0.10
BWIR, G = 1.00	0.17
BWIR, G = 1.40	0.39
BWIR, G = 1.80	0.55
PANX, G = 1.80	0.11
PANX, G = 2.00	0.15
PANX, G = 2.20	0.17

(true color, the infrared films and ILFD, and the extended red black-and-white (B&W)) (Figure 2). CNEG film, for example, was significantly lower in interpretation accuracy than all other films. The BWIR, CIRN, CIRP, and ILFD films were not significantly different among each other, but their interpretation accuracy percentages were lower than the extended red B&W film group and higher than the true color (Figure 2). These results suggest interpretation accuracy is higher for extended red films (DXX, A200) and lower for films such as IR-sensitive CIRN, CIRP, BWIR, true color CN, and true panchromatic ILFD. Interpretation accuracy results for the negative (CIRN) and positive (CIRP) color infrared processes were also identical (Figure 3), which suggests that the processing of Kodak Aerochrome Infrared 2443 film to a negative was not a factor in forest interpretation.

The high accuracy obtained with Panatomic-X, a film not generally used in forest inventory, and the relatively poor results obtained with the black-and-white IR, a film often used in vegetative interpretation, warrant some closer evaluation. Height, crown closure, and stems/hectare are dependent on spatial resolution in their interpretation and are more accurately interpreted using a higher spatial resolution film. Because species composition is more dependent on spectral instead of spatial resolution, it is more easily interpreted on infrared films. The other black-and-white films which were between the Panatomic-X and black-and-white infrared films with respect to resolution, granularity, and spectral sensitivity (Ilford, 1982; Agfa-Gevaert, 1990; Eastman Kodak, 1992) were similarly placed in terms of interpretation accuracy (Figure 3).

The color negative film rated the lowest in interpretation accuracy and would seem disadvantageous when used for forest interpretation purposes. Its spectral sensitivity includes the visible spectrum from approximately 400 nm to 670 nm (Eastman Kodak, 1992), and is of little benefit for separating major tree species such as coniferous and deciduous. Color negative films also have lower contrast than black-and-white or color IR films, which may have added to the poor results obtained.

Interpreter Preference

The third study question was to determine whether interpretation preference differed among the films. When color infrared film was processed to a positive, it was the most preferred film type, but, when it was processed to a negative, it became the least preferred film type (Table 5). This result was likely attributable to interpreter familiarity with one of the two processing types. The CIRP is a standard product familiar to all interpreters, which results in set expectations of how a color infrared film portrays the vegetative landscape. Because the CIRN type is a relatively new approach to color IR photography, the lack of interpreter familiarity with the shift in hues may lead to uncertainty, and to the low preference rating obtained. The true color film (CNEG) was one of the least accurate and least preferred, possibly because of its lower contrast and lack of infrared sensitivity.

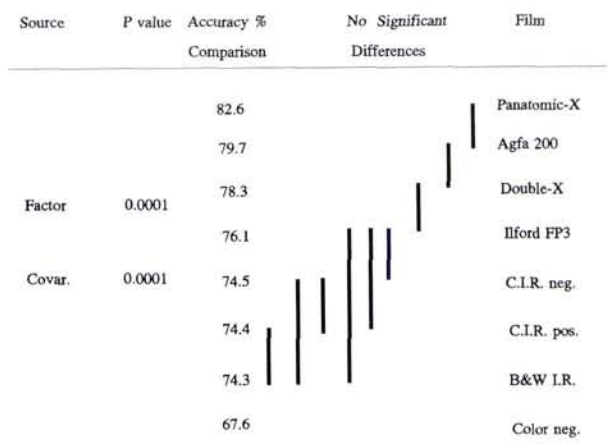

Figure 2. ANCOVA results for the four B&W films, ILFD, and the three color films. The films are listed in decreasing order from the most accurately interpreted film to the least accurately interpreted film. The vertical bars associate films with no significant difference.

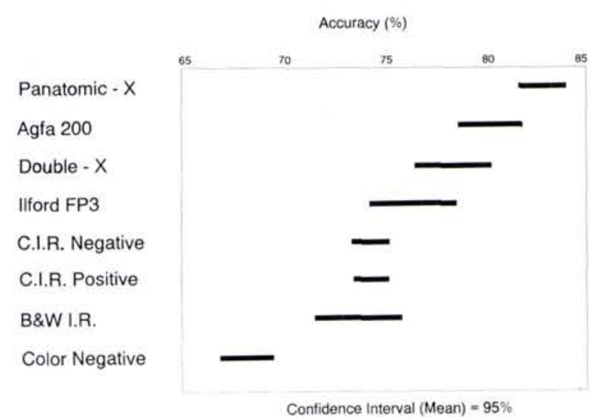

Figure 3. Confidence limits for mean interpretation accuracy for each of the eight study emulsions. The films are listed in decreasing order, from the most accurately interpreted film to the least accurately interpreted film.

Table 5. Mean Interpreter Accuracy and Preference Values Are Associated with the Ranked Accuracy and Preference Values. Spearman's Correlation Coefficient (R_s) is derived for the Ranked Data and Tested against the Null Hypothesis of no Correlation.

Film (Average Gradient)	Preference Mean Value	Preference Standard Deviation	Accuracy Percentage	Preference Rank	Accuracy Rank
PANX (2.2)	5.974	1.71	82.6	7	1
PANX (2.0)	4.974	1.68	81.5	13	2
A200 (1.0)	5.811	1.44	79.7	8	3
PANX (1.8)	5.767	1.70	79.2	10	4
DXX (1.4)	6.263	1.41	78.3	5	5
A200 (1.8)	5.789	1.47	78.0	9	6
ILFD (1.4)	4.810	1.72	76.1	14	7
CIRN	4.135	1.86	74.5	16	8
CIRP	7.079	2.26	74.4	1	9
BWIR (1.0)	6.105	1.60	74.3	6	10
BWIR (1.4)	6.526	1.51	73.5	4	11
A200 (1.4)	6.553	1.41	72.8	3	12
DXX (1.0)	5.684	1.70	71.0	11	13
BWIR (1.8)	6.632	1.46	70.2	2	14
CNEG	4.216	1.97	67.6	15	15
DXX (1.8)	5.370	1.66	67.5	12	16

Null Hypothesis H_0: No association exists between interpretation accuracy and interpretation preference.
$r_s = -0.05$
Critical value at $\alpha = 0.05$ is 0.425 (n=16)
Since $r_s < 0.425$, H_0 is accepted

An average preference rating was given to PANX despite its high interpretation accuracy value. Because preference is highly subjective, those qualities of an aerial photograph that influence interpreter judgement should be characterized. Tone, texture, and color are interpretative properties that influence an interpreter (Colwell, 1960). These interpretation attributes are highly contingent on contrast, and are influenced by average gradient and film spectral sensitivity (Avery, 1977). Wider spectral film sensitivity increases the tonal range for aerial scenes of forests and makes them more visually appealing. The trend between higher density range and higher preference when average gradient is kept constant (1.40) (Figure 4) confirms this observation. Interpreter preference, therefore, increases as the spectral sensitivity of the film increases (Figure 5). PANX film's moderate preference rating appears associated with its equally intermediate spectral sensitivity extension (i.e., 720 nm) relative to the other study films.

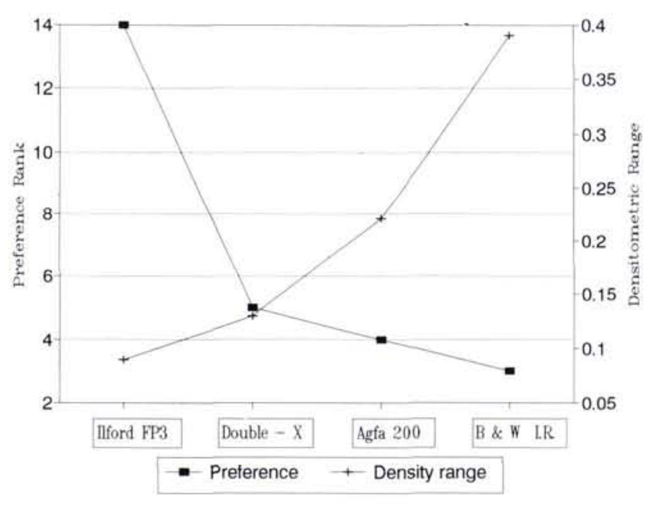

Figure 4. The densitometric range as measured on the negatives and mean interpreter preference ranks are associated for B&W films at 1.40 average gradient. The films are ordered from least infrared sensitive (left) to most infrared sensitive (right).

Interpretation Accuracy and Preference

The fourth question led to computing the relationship between interpretation accuracy and interpretation preference. The Spearman's rank correlation coefficient between accuracy and preference is −0.05 (Table 5). This suggests that no relationship exists between interpreter preference and interpreter accuracy, and is contrary to a previous study (Scott, 1968). Some associations were observed, however, between accuracy and preference of specific films (Table 5). Color negative film was consistently low in both rating scales. The infrared films (except CIRN) ranked high in preference but were below average in interpretation accuracy (Table 5). This suggests interpreter bias for tonal detail rather than for sharpness, because an interpreter's perception of image tonal characteristics is a factor in preferential judgements (Pfenninger, 1984). The infrared films were the highest in densitometric tonal and hue differences (Table 4), and were, therefore, most preferred. PANX was characterized by below average preference and high accuracy (Table 5). The density range for PANX was moderate relative to the other films (Table 4), which may explain its lower preference rating. The superior spatial resolution of the PANX would have contributed to its high interpretation accuracy rating.

The association of density range with accuracy and density range with preference suggests further differences in how photointerpreters evaluate aerial photographs (Figure 4). The density range corresponding to the highest accuracy of interpretation and measured for crown highlights in the coniferous-deciduous forest stand is 0.17. When density range corresponding to highest preference is measured, the value increases to approximately 0.40 (Figure 4). This density range is also associated with BWIR films for which crown coniferous-deciduous highlights will have maximum contrast. In defining a densitometric specification, the figure associated with accurate interpretation seems to be the goal. If a relationship between interpreter preference and interpretation speed suggests significant cost-benefit advantages, then the density range associated with highest preference should also be considered.

Conclusions

Because many forest inventory decisions regarding aerial film use and contrast specifications are based largely on interpreter preference, results from this study suggest forest interpretation accuracy may be compromised. Several average gradients and film types at a scale of 1:20,000 were compared, and interpretation accuracy increased when the chosen average gradient/film type produced a densitometric range of 0.11 to 0.17 within coniferous-deciduous forest stands. Interpretation of photos from PANX, a high resolution film, was higher than from those films of higher spectral sensitivities.

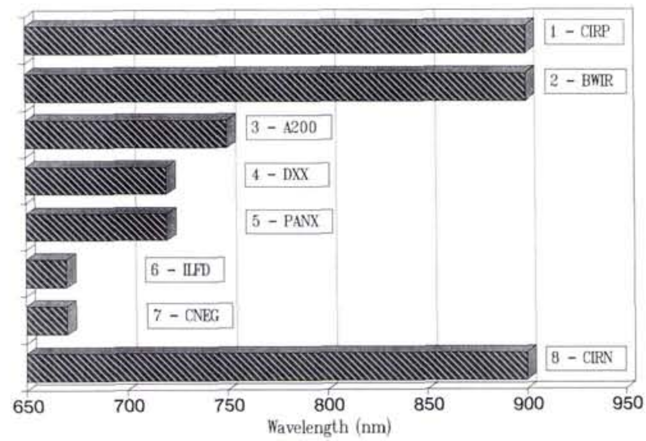

Figure 5. Mean interpreter preference rank for each film and spectral sensitivity of B&W and color films. The films are ranked from most preferred (top) to least preferred (bottom) and the horizontal bars are indicative of maximum spectral sensitivity.

Although PANX was the most accurately interpreted film, it has not been used for forestry assessments in the boreal forest. Film speed, image motion, solar hot spots, and length of photo day and season must be considered when using this film. Its slow film speed, for example, requires longer shutter speeds for proper exposure, and this increases image motion. A slow film speed also requires more light for proper exposure, and reduces the available time for aerial photo acquisition during the day and flying season. The speed problem is a concern for the large and medium scales at which forest inventory photographs are often acquired. A forward motion compensation (FMC) camera compensates for slow shutter speeds while maintaining image sharpness, and is highly recommended if PANX is to be used. An FMC camera also allows photo acquisition in lower light level conditions when slow shutter speeds are necessary to maintain proper exposure.

The PANX's relatively high inherent film contrast will emphasize the solar hot-spot, which is practically uninterpretable and difficult to compensate for during printing. High contrast negatives with a solar hot-spot place extreme demands on the photo laboratory printing process and, consequently, on the interpreter's ability to see detail in the affected area. Solutions include avoiding the solar hot-spot's incursion, or lowering the contrast of the images to achieve more uniform contrast. Exposure errors are also more likely because the film's higher contrast reduces the exposure latitude.

PANX exhibited the best *average* accuracy for the four forestry attributes. If the accuracy of these attributes were assessed independently, then PANX would only rate best for crown closure. PANX's ranking for species composition, stems/hectare, and height was found to be second, second, and third, respectively.

PANX was included in the study as a film with unique high resolution characteristics for comparison with films normally used in forest inventory. If its resolution is favorable for forest inventory, as this study suggests, then the Agfa Aviphot Pan 50, Agfa's higher resolution alternative, should also be evaluated. Although it is a lower resolving film than PANX (Fent, 1991), the Aviphot Pan 50's slightly higher spectral sensitivity and lower contrast may be a benefit for forest inventory.

Previous investigations on the use of high resolution films have focused primarily on survey mapping applications (Fleming *et al.*, 1983; Brindopke and Kolbl, 1984; Becker, 1988). These studies support increased use of these once-regarded "special application" films such as Kodak's Panatomic-X and Agfa's Aviphot 50. Forestry applications using these films are nonexistent because the technology to use the films at medium and large scales has not been available. With improvements in camera and lens technology, there should be less reluctance to use these films. With increased knowledge on the advantages and limitations of aerial films, the forest inventory community should find higher benefits than are presently available with more traditional aerial films presently in use.

Acknowledgments

The participation of the following agencies in the data collection was invaluable: Aerial Image Technology (Portland, Oregon), British Columbia Ministry of Forests (Inventory Branch), Indian and Northern Affairs Canada (Forest Resources Yukon), Manitoba Natural Resources (Forest Management), Minnesota Dept. of Natural Resources (Resource Assessment Unit), Newfoundland and Labrador Dept. of Forestry and Agriculture (Inventory), Ontario Ministry of Natural Resources (Natural Resource Inventory), Saskatchewan Parks and Renewable Resources (Forestry Branch), and United States Dept. of Agriculture (Forest Service, Salt Lake City, Utah). Mr. A. Stade (Alberta Environmental Protection) provided assistance with the polygon descriptions on the air photos and with the computer data entry. Mr. D. Morgan's (Alberta Environmental Protection) agency contacts, encouragement, and support throughout the project were highly valued. Preliminary review of the manuscript by Dr. W.A. Befort, Mr. J.M. Brouwer, and Mr. B. Huberty was greatly appreciated.

References

Agfa-Gevaert N.V., 1990. *Aviphot Pan 200 PE1 Technical Information*, 708(Li), B-2640 Mortsel, Belgium, 6 p.

Avery, T.A., 1977. *Interpretation of Aerial Photographs, Third Edition*, Burgess Publishing Company, Minneapolis, Minnesota, 392 p.

Becker, R., 1988. Very High Resolution Aerial Films, *Photogrammetria*, 42(3):183–302.

Bradatsch, H., 1980. Application of Large Scale Fixed-Base Aerial Photography with Helicopters to Forest Inventory in B.C., *Proc. of Workshop: Practical Applications of Remote Sensing to Timber Inventory*, Edmonton, Alberta, Canada Forest Service, North. For. Res. Cent., Inf. Rep. NOR-X-224, pp. 75-82.

Brindopke, W., and O. Kolbl, 1984. Optimal Emulsions for Large Scale Mapping, *Proc. XVth Congress ISPRS Commission I*, Rio de Janerio, Brazil, pp. 6-14.

Ciesla, W.M., 1990. Tree Species Identification on Aerial Photos: Expectations and Realities, *Proc. of the 3rd Forest Service Remote Sensing Conference*, Tuscon, Arizona, pp. 308-319.

Colwell, R.N. 1960. *Manual of Photographic Interpretation*, American Society of Photogrammetry, Washington D.C., 868 p.

Congalton, R.G., and R.A. Mead, 1983. A Quantitative Method to Test for Consistency and Correctness in Photo Interpretation, *Photogrammetric Engineering & Remote Sensing*, 49(1):69–74.

Driscoll, R.S., 1992. Remote Sensing - An Invaluable Ally for Assessing and Managing Renewable Natural Resources, *GIS World*, 5(4):66–69.

Eastman Kodak, 1992. *Kodak Data for Aerial Photography*, Publication No. AS-29., Rochester, New York.

Fent, L., 1990. A More Discriminating Use of Aerial Photographic Emulsions and Processing Techniques, *Proc. of the Symposium on Global and Environmental Monitoring , Techniques and Impacts*, I.S.P.R.S. Commission VII, Victoria, B.C., pp. 759–778.

———, 1991. *Alberta Small Scale Aerial Photography 1980-1990: Influences, Changes, and Evolution of Image Quality*, Resource Information Branch Report No. 373, Edmonton, Alberta, 20 p.

Fent, L., and T. Polzin, 1986. A Differential Light Metering System for Aerial Photography, *Proc. of the 10th Canadian Symposium on Remote Sensing*, Edmonton, Alberta, pp. 221–231.

Fleming, E.A., 1983. ICAS Specifications for Aerial Photography: A Look at Their Influence on Manufacturers, Contractors, and Users, *Canadian Surveyor*, 37(3):145–155.

Fleming, E.A., M. Landreville, and E. Nagy, 1983. A Study of the Effect of Standard Laboratory Processing on Speed and Resolution of Three Black and White Aerial Films, *Canadian Surveyor*, 37(1):3–10.

Fleming, J.F., 1979. *Standardization Techniques for Aerial Color Infrared Film*, Interdepartmental Committee on Air Surveys, Ottawa, Canada, 27 p.

Haack, P. M., 1962. Evaluating Color, Infrared, and Panchromatic Aerial Photographs for the Forest Survey of Interior Alaska, *Photogrammetric Engineering*, 28:592–598.

Hall, R.J., and L. Fent, 1991. Relating Forestry Interpreter Preference to Sensitometric Parameters of Black and White and Normal Color Films, *ISPRS Journal of Photogrammetry and Remote Sensing*, 46(4):328–345.

Hilborn, W.H., 1981. Evaluation of Forest Inventory Classification in Airphoto Interpretation, *Proc. of a National Workshop on Inplace Resource Inventories; Principles and Practices*, University of Maine, Orono, Maine, pp. 170-175.

Hoppus, M.L., 1990. Selecting the Best Film Product for Identifying Port Orford Cedar and other Plant Species on Aerial Photos, *Proc. of the 3rd Forest Service RIS Applications Conference - Protecting Natural Resources with Remote Sensing*, Tuscon, Arizona, pp. 356–359.

Howard, J.A., 1991. *Remote Sensing of Forest Resources*, Chapman and Hall, London, England, 417 p.

Ilford, 1982. *Technical Information, FP3 Medium Speed Fine Grain Film for Aerial Survey*, Publication No. 82.75.2.GB, Brentwood, Essex, England, 12 p.

Interdepartmental Committee on Air Surveys, 1982. *Specification for Air Survey Photography*, Ministry of Energy Mines and Resources, Ottawa, Canada, 25 p.

International Standards Organization 7829, 1986. *Photography - Black and White Aerial Camera Films Determination of ISO and Average Gradient*, International Organization for Standardization, Ref. No. ISO 7829-1986(E), 9 p.

Jensen, H., and R. Colwell, 1949. Panchromatic versus Infrared Minus Blue Aerial Photography for Forestry Purposes in California, *Photogrammetric Engineering*, 15:201–223.

Klimes, D., and D.I. Ross, 1993. A Continuous Process for the Development of Kodak Aerochrome Infrared Film 2443 as a Negative, *Photogrammetric Engineering & Remote Sensing*, 59(2):209–213.

Leckie, D.G., 1990. Advances in Remote Sensing Technologies for Forest Surveys and Management, *Canadian Journal of Forest Research*, 20(4):464–483.

Leica, 1992. *Wild RC30 Aerial Camera*, Publication No. U1 643 e - V11.92, Heerbrugg, Switzerland, 6 p.

Losee, S. T., 1951. Photographic Tone in Forest Inventory, *Photogrammetric Engineering*, 19:752–62.

Meyer, M. P., and D. W. Myhre, 1961. Variations in Aerial Photo Image Recovery, Resulting from Differences in Film and Printing Technique, *Photogrammetric Engineering*, 27:595–599.

Meyer, M. P., and H.H. John, 1961. Comparative Forest Aerial Photo-Interpretation Results from Single Contrast and Variable Contrast Paper Prints, *Photogrammetric Engineering*, 27:697–703.

Meyer, M.P., and L. Werth, 1990. Satellite Data: Management Panacea or Potential Problem ?, *Journal of Forestry*, 88(9):10–13.

Mize, C.W., and R.C. Schultz, 1985. Comparing Treatment Means Correctly and Appropriately, *Canadian Journal of Forest Research*, 15:1142–1148.

Morton, R.J., R.J. Hall, R.K. Nesby, and I. Sutherland, 1986. Large Scale Black and White and Natural Color Photographs for the Measurment of Tree Crown Areas, *Proc. of the 10th Canadian Symposium on Remote Sensing*, Edmonton, Alberta, pp. 133–140.

Mosteller, F., and R.E.K. Rourke, 1973. *Sturdy Statistics: Nonparametrics and Order Statistics*, Addison-Wesley, Reading, Massachusetts, 395 p.

Neter, J.W., W. Wasserman, and M.H. Kutner, 1990. *Applied Linear Statistical Models, Third Edition*, Irwin, Boston, Massachussetts, 1181 p.

Pfenninger, U., 1984. Image Quality Evaluation by Subjective and Objective Criteria of Sharpness and Gradation with B/W Transparencies, *Journal of Photographic Science*, 32:207–217.

Plasker, J.R., and G.W. Teselle, 1988. Present Status and Future Applications of the National Aerial Photography Program, *Proc. of the 1988 ACSM-ASPRS Annual Convention*, St. Louis, Missouri, 3:86–92.

Rowe, J.S., 1972. *Forest Regions of Canada*, Publication 1300, Environment Canada, Canadian Forest Service, Ottawa, Canada, 172 p.

SAS Institute Inc., 1985. *The GLM Procedure. SAS Users Guide: Statistics*, SAS Institute Inc., Cary, North Carolina, pp. 433–506.

Scott, F., 1968. The Search for a Summary Measure of Image Quality - A Progress Report, *Photographic Science and Engineering*, 12(3):154–164.

Schultz, O. W., 1951. The Use of Panchromatic, Infrared, and Color Aerial Photography in the Study of Plant Distribution in Quebec, Canada, *Photogrammetric Engineering*, 17:688–714.

Silvacom Ltd., 1987. *Hardwood Differentiation on Aerial Photos*, Resource Evaluation and Planning Division, Alberta Forestry, Lands and Wildlife, Report No. 165, Edmonton, Alberta, Canada, 38 p.

———, 1988. *Hardwood Species Differentiation on Small Scale Photos*, Land Information Branch, Alberta Forestry, Lands and Wildlife, Report No. 282, Edmonton, Alberta, Canada, 24 p.

Spencer, R.D., and R.J. Hall, 1988. Canadian Large-Scale Aerial Photographic Systems (LSP), *Photogrammetric Engineering & Remote Sensing*, 54(4):475–482.

Welch, R., and J. Halliday, 1975. Image Quality Controls for Aerial Photography, *Photogrammetric Record*, 8(45):317–325.

Vlcek, J., 1972. *Tonal Adjustment of Aerial Photographs: Problems and Provisional Solutions*, Canadian Forestry Service, Information Report FMR-X-47, Ottawa., 27 p.

Zeiss, 1990. *RMK TOP Survey Camera System for Aerial Photography*, No. 51-758-e, Oberkochen, Germany, 25 p.

Zeiss Jena, 1990. *Zeiss LMK 2000*, Publication No. 14-329-2, DEWAG Berlin/Leipzig, Germany, 25 p.

(Received 16 December 1992; revised and accepted 8 June 1993)

Livio Fent

Livio Fent completed his undergraduate studies in climatology at McGill University, and graduate studies in photographic science at Concordia University. He headed the analytical photochemistry department at Quebec Film Laboratories in the early 80s, and has since been involved in quality control and applications research with aerial photographic films, climatology, and GIS applications with Alberta Environmental Protection. Livio also teaches photographic science courses at the University of Alberta. He enjoys swimming, cycling, and skiing, and maintains an avid interest in cosmology.

Ronald J. Hall
Ronald Hall completed a Bachelor of Science in Forestry degree from the University of British Columbia, and a Master of Science degree in Remote Sensing and a Doctor of Philosophy degree in Forestry from the University of Alberta. He has been conducting research studies in remote sensing at the Northern Forestry Centre of Natural Resources Canada since 1978. His other research interests include the integration of digital remote sensing and GIS technologies for forest resource inventories.

Richard K. Nesby
Richard Nesby studied Biological Sciences at the Northern Alberta Institute of Technology. Employed by the government for over 20 years, Richard has been the senior air photo interpreter in charge of the Alberta Phase 3 Forest Inventory. He has evaluated various remote sensing technologies ranging from large-scale photography to satellite, and designed the Integrated Alberta Vegetation Inventory (AVI) (forest, wildlife, grazing) standards now in operational use by the public and private sector.

To Participate in Your Local Region Activities:
Contact: Anne Ryan
301-493-0290, (fax) 301-493-0208,
anneryan@asprs.org