# Influence of Aerial Film Spectral Sensitivity and Texture on Interpreting Images of Forest Species Composition

by R.J. Hall • L. Fent

## RÉSUMÉ

*En foresterie, les photographies aériennes constituent la principale source de données de télédétection, mais la qualité de ces photographies est variable. Le contraste d'image, la sensibilité spectrale et la résolution spatiale sont considérés comme des facteurs importants au moment de la définition des paramètres à utiliser en photographie aérienne forestière. Nous avons exposé et développé quatre films noir et blanc présentant diverses caractéristiques spectrales et spatiales au 1/20 000; le gradient moyen était de 1.8. Nous avons soumis à un balayage numérique plusieurs des peuplements photographiés et avons observé que les films présentaient des différences quant aux densités maximale et minimale (contraste utile) et à la texture d'image. Nous avons élaboré et mis à l'essai une technique numérique permettant de contrôler l'expansion ou la compression du contraste, à partir d'une relation densitométrique fondée sur la gamme de gris. C'est le film Panatomic-X qui a permis l'interprétation la plus exacte de la composition en espèces. Les valeurs élevées d'intervalle de densité et d'hétérogénéité de texture que la résolution et les propriétés contrastantes du Panatomic-X nous ont permis d'obtenir se sont avérées très utiles au moment de l'interprétation. Ces résultats ont des répercussions importantes pour les organismes d'exploitation forestière qui utilisent toujours des films aériens sensibles à l'infrarouge dans le cadre d'applications d'inventaire forestier.*

## SUMMARY

*Aerial photographs are the major source of remote sensing data used in forestry, but their consistency in quality has been variable. Image contrast, spectral sensitivity, and spatial resolution are considered important factors when defining parameters for forestry aerial photography. Four black-and-white films of varying spectral and spatial characteristics at a scale of 1:20,000 were exposed and processed at an average gradient of 1.8. Several forest stands imaged on these films were digitally scanned and differences in maximum and minimum density (i.e., density range) and image texture were obtained. A technique for controlling contrast expansion or compression by using a digital grey value-densitometric relationship was developed and demonstrated. Panatomic-X film produced the highest interpretation accuracy results for species interpretation. The study results suggest that Panatomic-X's high spatial resolving and high contrast properties reflected by values of high density difference and textural heterogeneity are important cues that aid the interpretation process. These results have implications for operational forest agencies who continue to use infrared-sensitive aerial films in forest inventory applications.*

## INTRODUCTION

In a forest inventory, aerial photographs are the primary source of remote sensing data used in photo interpretation during the production of forest cover maps (Howard 1991; Driscoll 1992; Gillis and Leckie 1993). Among the forest attributes interpreted during this process include species composition, crown closure, stand height, origin, stand structure, and moisture regime (Alberta Environmental Protection 1991). The extent to which these attributes can be interpreted, particularly tree species, is largely determined by the films used (Fent *et al.* 1995), and the quality of the photographs acquired (Lillesand and Kiefer 1994). In addition, with aerial photographs being increasingly scanned during the generation of digital orthophotos, the amount of information that can be derived from the aerial image is critical (Brandes 1994; Mussio and Light 1995). This is attributed to the quality of the final digital orthophoto image being directly related to the quality of the original aerial photograph (Klimiuk 1994). Thus, the accuracy of the resultant information used in decisions for forest management is influenced by air photo quality.

The interpretation of aerial photographs for mapping of forest cover requires the use of image characteristics that include tone, texture, pattern, shape, size, shadow, and site (Hoppus and Evans 1993; Lillesand and Kiefer 1994). How stands of varying species composition and stand structure will image

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depends on film type and photo quality. The sharpness of an image is an important component of air photo quality because it affects several image characteristics (e.g., size, shape, texture) that relate to image interpretability (Caylor 1989). Texture and tonal variations for example, are often used to distinguish between features with similar reflectance (Lillesand and Kiefer 1994). Determining image sharpness is complex because of the interactions from image motion, camera and lens characteristics, exposure parameters, film type and speed, target brightness and contrast, atmospheric conditions, and chemical processing (Caylor 1989). With the recent improvements in aerial film (e.g., film speed, resolution, spectral sensitivity, contrast characteristics) and camera technologies (e.g., forward image motion compensation, improved lens resolution, integrated computer exposure controls) (Mussio and Light 1995; Light 1996), photo quality can be enhanced to a greater degree because of the better controls now available to the photo acquisition process. Thus, efforts to refine air photo quality parameters such as selecting spectral sensitivity, average gradient and densitometric range could have a significant influence on the resultant accuracy of the information base upon which forest management decisions are made (Fent *et al.* 1995).

Previous research has addressed the influence of aerial films and photo quality on interpreter preference and interpretation accuracy, by which accuracy was expressed as the average of interpreting species composition, crown closure, stand height, and stems per hectare (Hall and Fent 1991; Fent *et al.* 1995). This investigation focuses on the species attribute of the forest stand and how well different tree species were interpreted among the aerial films.

The ability to identify tree species on aerial photographs has long been a basic requirement for many kinds of forest resource surveys, and it is among the most important of the characteristics that describes a forest stand[1]. Ciesla (1990), for example, reports that interest in tree species identification on aerial photographs is a necessity in forest health surveys. As interpretation demands increase, however, the aerial photographic industry has continued to improve materials and technology, necessitating the evaluation of aerial photographic media that would foster accurate species interpretation. Relying solely on the empirical performance of interpretation accuracy, however, would be insufficient without determining their associated film densitometric, spectral and spatial characteristics, including the reasons for the results that occurred. A digital analysis of scanned forest stands imaged on different films is one approach that may provide this insight. Associating traditional film assessment techniques such as densitometry to the digital environment provides the means for assessing photographic quality, and controlling tonal parameters to optimize the image product for interpretation. Determining the relationship between densitometry of photo products to their digital images also establishes the base that fosters a transition between the analogue and digital air photo environments (Light 1996).

Forest stands of varying species composition were identified and interpreted on four black-and-white aerial films that included Kodak Infrared 2424, Agfa 200, Kodak Double-X, and Kodak Panatomic-X 2412. Except Panatomic-X, these films are also the ones used operationally by the provinces of Quebec in the east through to British Columbia in the west (Leckie and Gillis 1995). The study objective was to determine which of the four black-and-white films were most accurately interpreted for species composition. Selected stands of pure hardwood, pure softwood and mixed wood were also scanned and digitally analyzed to support and explain differences observed on the four films. The study objective was addressed by answering the following questions:

1. Is there a difference in interpretation accuracy among the four black-and-white films?
2. Is there a difference in the interpretation accuracy of hardwood, softwood and mixed wood stands?
3. Is there a relationship between image grey value and photographic density?
4. Are there differences in density range among the hardwood, softwood and mixed wood stands imaged on the four black-and-white films?
5. Is there a difference in image texture for hardwood, softwood and mixed wood stands on the four black-and-white films?

## STUDY AREA

The study area is 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) (**Figure 1**).

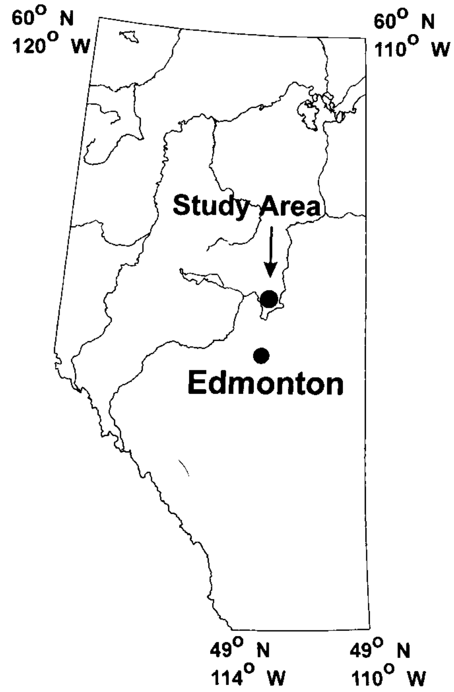

**Figure 1.**
**Map of Alberta showing study area.**

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[1] Morgan, D.J. Alberta Environmental Protection, Lands & Forest Services. Personal communication. February 1, 1995.

A flight line 60 km in length was flown over an area at a scale of 1:20 000 that exhibited a diversity in species composition typical of the boreal forest. The species in the study included white spruce (*Picea glauca* [Mince] Vose), 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.).

## METHODS

### *Aerial Photography*

The four black-and-white films selected are described in **Table 1** (Agfa-Gevaert 1990; Eastman Kodak 1982). The BWIR is a near infrared sensitive aerial film and both A200 and DXX are extended red aerial films that are often used in operational forest inventories. PANX is also an extended red aerial film, but it has an extremely fine-grained, high-resolution emulsion that results in a slow film speed. Its slow film speed has prevented its application to medium scale forest inventories until the relatively recent availability of cameras with forward motion compensation (FMC) capabilities.

The photography was experimentally planned and conducted to minimize the influence of the following factors that could otherwise mask the differences among films and affect interpretation accuracies:

1) **image motion**: All aerial photographs were exposed with a Wild RC-20 camera and 15/4 UAG-F 152 mm lens, using FMC and the PEM exposure control system.
2) **exposure conditions**: All aerial photographs were exposed on the same day within a two- hour period at solar noon.
3) **film processing and printing**: The black-and-white films were processed at 1.80 average gradient and printed on grade two photographic paper.

Any differences observed among the forest stands imaged were therefore attributed to differences in film spectral sensitivity and spatial resolution and not because of photographic conditions.

### *Interpretation Procedure*

Forest stand polygons were selectively chosen along the flight line and among the different films for the interpretation procedure. This ensured each film type would consist of different polygons to prevent any interpreter learning bias from interpreting the same stand more than once. Thirty-eight interpreters from across Canada and the United States familiar with the boreal forest were solicited. To ensure consistency in the interpreters' approach to the study, interpretation key stereograms were developed to aid the interpreters in assessing species composition at a scale of 1:20 000. Species composition for each polygon was assessed for the one or more tree species, and its percent (%) occurrence within the stand, in one of ten classes consisting of 10 % intervals ranging from 0 to 100 %.

Table 1
Black-and-white aerial film Characteristics.

| Films | Abbreviation | Film resolution (lp/mm) | Spectral sensitivity (ηm) |
|---|---|---|---|
| Kodak Infrared 2424 | BWIR | 50 | 900 |
| Agfa Aviphot PE 200 | A200 | 50 | 750 |
| Kodak Double-X 2405 | DXX | 50 | 720 |
| Kodak Panatomic-X 2412 | PANX | 125 | 720 |

The ground reference information was based on interpretation of large-scale, 70-mm (1:500) photographs acquired for a previous study (Fent *et al.* 1995). A representative description for each polygon was obtained by averaging interpretation information from four stereo pairs that served as sample plots within each polygon. Interpretation error was then computed as the average of the 10 % class deviations between reference and interpreted, with interpretation accuracy being computed as 100 - (10 × average interpretation class error) (Fent *et al.* 1995). For example, if the interpreter identified coverage of aspen as class 6 (i.e. 60% of the stand consisted of aspen), poplar as class 3 (i.e. 30% of the stand consisted of poplar) and birch as class 1 (i.e. 10% of the stand consisted of birch), while the reference data denoted the coverage for aspen as class 6, poplar as class 3, and pine as class 1, then error values would be assigned to aspen = 0 (i.e. no interpretation deviation from the reference), poplar = 0, birch = 1 (i.e. 10% deviation), and pine = 1. The values for both birch and pine would be included in the error calculation, since 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 identified in the reference data. Further details and a numerical example are available in Fent *et al.* (1995).

### *Statistical Analysis*

A two-way analysis of covariance (ANCOVA)[2] using the province where the interpreter resides as the covariate, was conducted to determine if statistical differences in terms of accuracy existed. The response variable was interpretation accuracy and the factors tested included accuracy differences among films, species (hardwood, softwood, mixed wood), and film by species interaction. The model for the experimental design is (Neter *et al.* 1990):

$$Y_{ijk} = \mu_{..} + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma(X_{ijk} - \bar{X}_{...}) + \xi_{ijk}$$

*where* $\alpha_i$ = *factor A (film)*
$\beta_j$ = *factor B (species)*
and $(\alpha\beta)_{ij}$ = *interaction effect of film, species.*

If there were significant differences between films or species, then the Bonferroni multiple mean comparison test (Neter *et al.* 1990) was employed.

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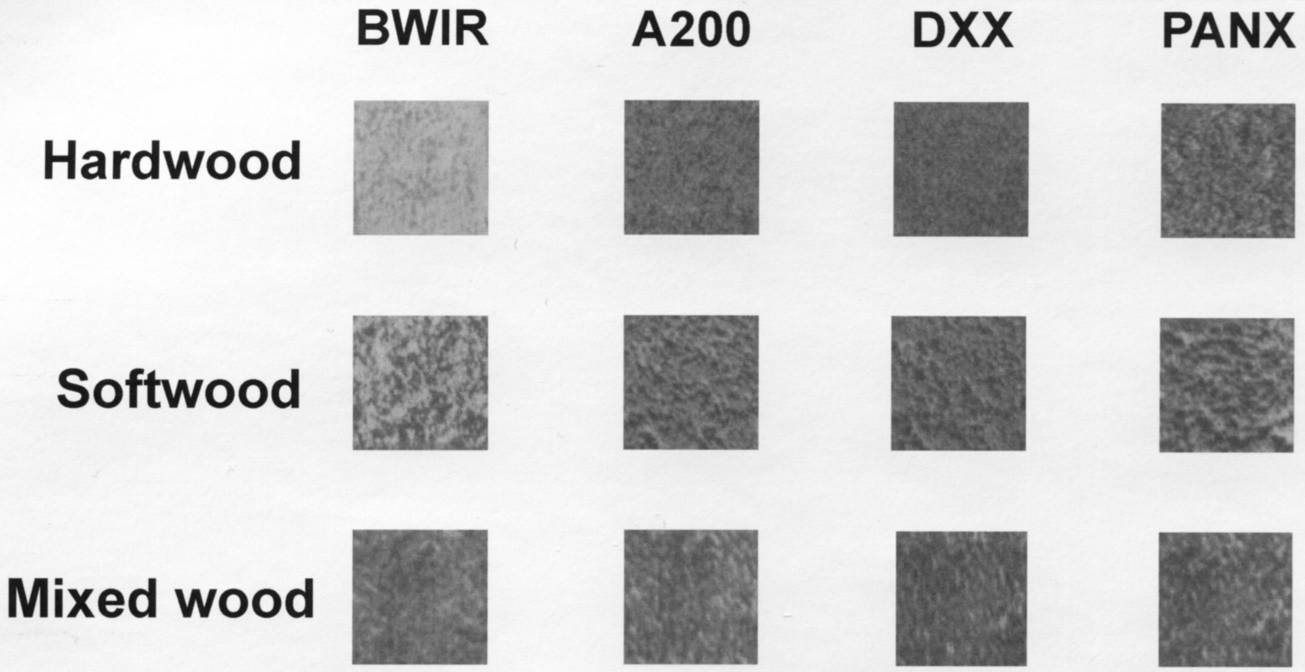

**Figure 2.**
**Air photo composite of selected hardwood, softwood and mixed wood stands for digital analysis.**

### *Digital Analysis and Image Texture*

Three stands of similar structure (i.e., height between 16 and 22 m, and crown closure between 45 and 70 %) comprising a pure hardwood aspen, pure softwood black spruce, and 50 % aspen, 50 % white spruce were scanned at 400 dots per inch (dpi) to produce digital images. These digital images and their grey values were used as an indicator of average film density and density range for these stands. For this study, density range is defined as the difference in the maximum and minimum densities within the imaged forest stands. The difference between pixels in the 5th and 95th quantiles were used as a measure of density difference for each of the three stands on the four films. The scanning resolution, using a Howtek Scanmaster[3] scanner resulted in a nominal pixel size of 1.3 m of which several pixels would represent a single tree crown. The three stands and four films resulted in 12 digital images whose sizes were each 50 pixels by 60 lines (**Figure 2**).

The relationship between the average grey value along a photographic grey scale and image density measured with an X-Rite 310 Densitometer was determined using a least squares regression model (Stroebel 1990). The model form was based on a comparison between the scatterplot and example plots presented in Freese (1964). The descriptive statistics and regression model performance were assessed using statistical measures such as adjusted $R^2$, root mean square error, significance of predictor variables, and standardized residuals to determine if a multiple linear model approach was sufficient to describe the relationship, or whether a non-linear model approach was warranted. The regression model relates the scanned image grey values with photographic density, and is a convenient vehicle to assess the film's densitometric difference between hardwood and softwood stands.

Texture within an image processing context is often used to improve classification accuracy by the inclusion of textural features (Mather 1987). In this study, quantitative measures of texture were only used to characterize the image by providing a measure of the spatial distribution of grey tones. By keeping stand structure relatively consistent, the influence of species composition on texture by film could be determined.

Image texture was computed using a statistical approach based on a spatial co-occurrence matrix in a 3×3 moving window that shows the relationship between a given pixel and its specified neighbour. A texture measure called homogeneity was computed to describe the number of transitions from one grey level to another (Mather 1987). The average texture value for each stand by film was interpreted as a texture homogeneity index. A high homogeneity value would imply few transitions of grey levels. It is hypothesized that stands of pure species composition would have a smoother texture and a higher homogeneity value than in more mixed stands.

## RESULTS AND DISCUSSION

### *Assessment of Interpretation Accuracy*

The first question of this study was to determine if significant differences existed among the four films for interpretation accuracy. The ANCOVA provides an experimental means to evaluate differences among the films while controlling for the possible influence of the interpreter's geographic location. The descriptive statistics suggest film PANX was most accurately

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Table 2.
Interpretation accuracy descriptive statistics for film and species.

| Item | Mean (%) | Standard deviation | Standard error | Coefficient of variation |
|---|---|---|---|---|
| Film: | | | | |
| BWIR | 66.8 | 25.2 | 1.4 | 37.7 |
| A200 | 64.8 | 22.0 | 1.2 | 34.0 |
| DXX | 68.8 | 18.7 | 1.0 | 27.2 |
| PANX | 70.7 | 12.8 | 0.7 | 18.1 |
| Species: | | | | |
| Hardwood | 56.8 | 29.2 | 1.5 | 51.4 |
| Softwood | 65.1 | 27.2 | 1.5 | 41.8 |
| Mixed wood | 69.8 | 11.9 | 0.6 | 17.0 |

Table 3.
Interpretation accuracy descriptive statistics by film and species.

| Film | Mean (%) | Standard deviation | Standard error | Coefficient of variation |
|---|---|---|---|---|
| BWIR | | | | |
| Hardwood | 56.8 | 35.2 | 4.20 | 61.9 |
| Softwood | 63.1 | 29.8 | 2.80 | 47.3 |
| Mixed wood | 70.6 | 14.2 | 2.30 | 20.0 |
| A200 | | | | |
| Hardwood | 49.9 | 32.2 | 4.00 | 64.5 |
| Softwood | 61.5 | 23.2 | 1.89 | 37.8 |
| Mixed wood | 71.3 | 12.5 | 2.03 | 17.5 |
| DXX | | | | |
| Hardwood | 59.7 | 27.7 | 2.60 | 46.4 |
| Softwood | 78.1 | 37.5 | 6.00 | 48.0 |
| Mixed wood | 67.3 | 12.7 | 1.03 | 18.8 |
| PANX | | | | |
| Hardwood | 57.9 | 23.9 | 2.26 | 41.4 |
| Softwood | 72.1 | 13.4 | 2.17 | 18.6 |
| Mixed wood | 72.2 | 8.97 | 0.84 | 12.4 |

Table 4.
Analysis of covariance table for films evaluated.

| Source | Degrees of freedom | F value | Pr > F |
|---|---|---|---|
| Films | 3 | 4.21 | 0.0057 |
| Species | 2 | 32.3 | 0.0001 |
| Film×species | 6 | 2.81 | 0.0101 |
| Covariate: region | 1 | 53.46 | 0.0001 |

interpreted, and its variation was smallest among the four films (**Table 2**). The smaller variation was consistent for all hardwood, softwood, and mixed wood stands across the four films (**Table 3**).

There was a statistically significant difference in interpretation accuracy for the four films based on the ANCOVA design (**Table 4**). Thus, film type affects interpretation accuracy. Although film PANX rated the highest for interpretation accuracy, it was not statistically different from films DXX and BWIR (**Table 5**). All three of these films, however, were different from film A200. Films A200 and BWIR were also determined to be similar. The determination of film PANX as the highest performing film for interpreting species composition may have important implications for forestry because the other three films are more frequently used in operational forest inventories. To date, film PANX has not been used at medium scales for resource inventory applications. Both films BWIR and A200 have spectral sensitivities that extend into the near infrared portion of the spectrum. These film properties contribute to haze penetration, and help to accentuate the tonal differences between hardwoods and softwoods based on their differences in near infrared reflectance, and the large amount of shadows that often occur on conifer crowns (Murtha 1972; Lillesand and Kiefer 1994). Interpretation accuracies, however, were not as high as those obtained for film PANX.

There was a statistically significant difference in the interpretation of hardwood, softwood and mixed wood stands (**Table 4**). Based on the Bonferroni multiple mean comparison test, hardwood, softwood and mixed wood stands were not interpreted equally (**Table 6**). Mixed wood stands were more accurately interpreted than softwood stands, and softwood stands were more accurately interpreted than hardwood stands (**Table 3**). The film by species interaction and covariate terms were also statistically significant, and this suggested the ANCOVA design was appropriate for this application because it accounted for a significant portion of the sample variation. A significant interaction between film and species confirms that film type influences how stands are imaged.

### *Relationship Between Image Grey Value and Photographic Density*

Image grey value and photographic density were highly correlated (Pearson's $r = 0.99516$, $P = 0.0001$). Based on a review of the scatterplot (**Figure 3**) and several model forms (Freese 1964), a multiple regression model based on grey value and inverse grey value was fitted (**Table 7**). The fitted regression model had an extremely high adjusted $R^2 = 0.997$ and root mean square error that was within the tolerance of the densitometer employed (**Table 7**). The plotted regression line also closely followed the points presented on the scatterplot (**Figure 3**). The strong relationship with this model form suggested investigation of alternate linear and nonlinear model forms was not necessary.

The relationship between digital image grey values and their corresponding density values offer users of aerial photography potential benefits from the digital domain. The Alberta

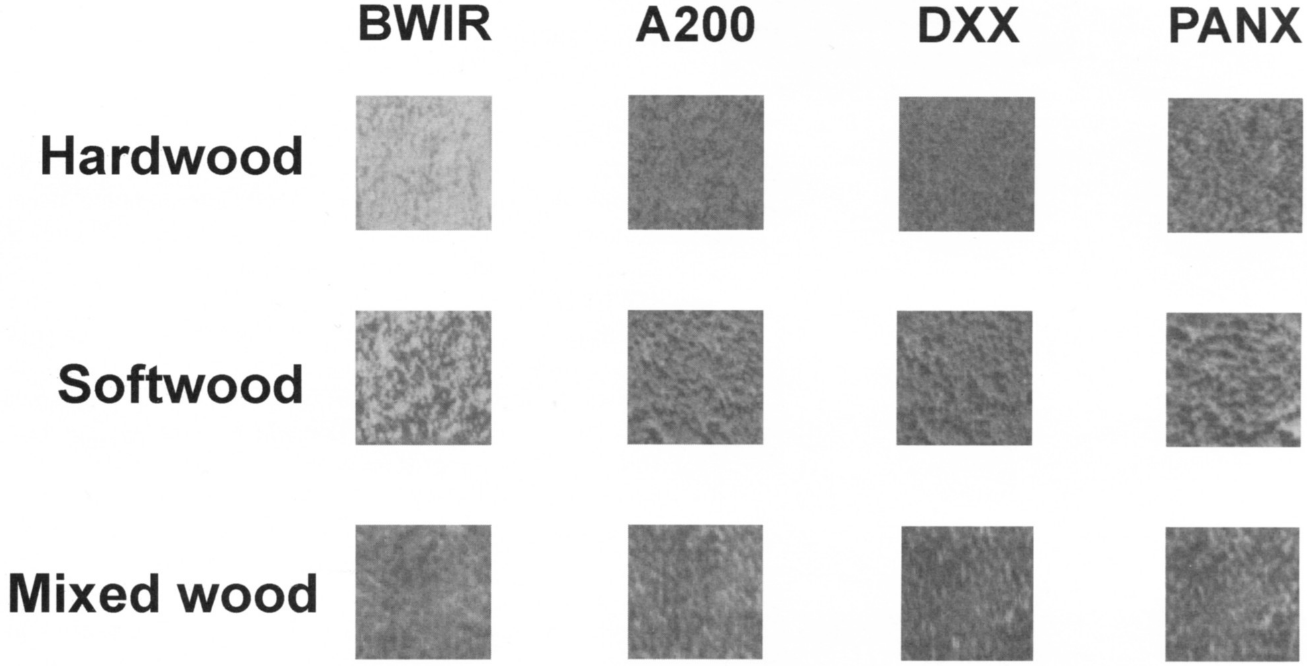

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Table 5.
Bonferroni T-tests for mean film comparisons.

| Film comparison | Lower confidence limit | Difference between means | Upper confidence limit |
|---|---|---|---|
| BWIR - PANX | -9.38 | -3.76 | 0.27 |
| BWIR - DXX | -8.93 | -3.47 | 1.96 |
| BWIR - A200 | -3.26 | 2.41 | 6.06 |
| A200 - PANX | -11.59 | -6.17 | -1.76** |
| A200 - DXX | -11.13 | -5.89 | -0.07** |
| A200 - BWIR | -8.08 | -2.41 | 2 |
| DXX - PANX | -5.48 | -0.29 | 2.15 |
| DXX - BWIR | -1.98 | 3.47 | 5.91 |
| DXX - A200 | 0.65 | 5.89 | 7.93** |
| PANX - DXX | -4.9 | 0.29 | 5.95 |
| PANX - BWIR | -1.87 | 3.76 | 8.02 |
| PANX - A200 | 0.76 | 6.17 | 10.04** |

** Significant at the 0.05 level, Critical value of T = 2.64

Table 6.
Bonferroni T-tests for mean species comparisons.

| Species comparison | Lower confidence limit | Difference between means | Upper confidence limit |
|---|---|---|---|
| Hardwood - Softwood | -12.49 | -8.27 | -4.04** |
| Hardwood - Mixed wood | -17.16 | -12.94 | -8.71** |
| Softwood - Hardwood | 4.04 | 8.27 | 12.49** |
| Softwood - Mixed wood | -8.96 | -4.67 | -0.38** |
| Mixed wood - Hardwood | 8.71 | 12.94 | 17.16** |
| Mixed wood - Softwood | 0.38 | 4.67 | 8.96** |

** Significant at the 0.05 level, Critical value of T = 2.40

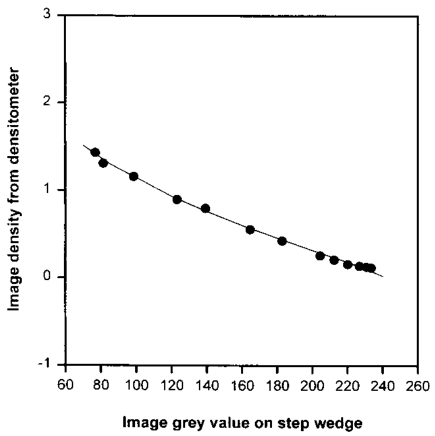

**Figure 3.**
**Relationship between image grey value and photograpic image density.**

Department of Environmental Protection contract specifications for forestry aerial photography requires a densitometric difference of 0.3 between hardwood and softwood stands. Many agencies have greater access to a digital scanner on a personal computer than a densitometer, consequently, this procedure has operational implications for in-house monitoring of photographic quality. This procedure requires the calibration between image grey level and photographic density by using a grey scale, and determining its statistical relationship. Selected stands can then be digitally scanned, and selected hardwood and softwood areas sampled to obtain representative grey values. Photographic densities can then be calculated from the regression model and assessed against contract specifications.

An example application of the regression model was carried out for the scanned hardwood and softwood stand over the four films. Based on the scanned hardwood and softwood stands, the only density range that was sufficient to meet the Alberta densitometric standard was BWIR film (0.91 - 0.48 = 0.43). The other films had density differences that ranged from 0.02 to 0.08 (**Table 8**). The small density ranges for A200, DXX and PANX films may result in insufficient tonal differences between hardwood and softwood stands, resulting in a greater reliance on texture to differentiate between species. It is precisely this occurrence that the digital environment provides the advantage of contrast stretching the grey level range. The density difference could be increased to give the interpreter greater contrast for interpreting hardwoods from softwoods. DXX film, for example, has an average density value of 1.05 in the hardwood stand and 1.11 in the softwood stand for a difference of 0.06 (**Table 8**). The associated grey level values are 108 and 102, respectively. Stretching these levels to 122 for the hardwood stand and 93 for the softwood stand would achieve the Alberta densitometric standard of 0.30 density range. An alternative approach to changing contrast is to increase either the hardwood or the softwood grey level to achieve the desired range. Holding the softwood value constant at 102 requires the hardwood grey level to be set at 134, holding the hardwood value constant at 108 requires the softwood grey level value to be set at 81. The regression relationship (**Table 7**) can therefore be beneficial in digitally enhancing substandard original aerial photographic products. Photographic contrast manipulation is a time and material consuming process because different paper grades must be employed on a trial-and-error process to change inherent contrast. Image processing, however, gives the user control to create tonal enhancements by expansion or compression of grey levels. Enhancements may then be interpreted digitally on-screen, or written to film. The regression relationship

Table 7.
Regression statistics for relationship between image grey value and photographic density.

Model: Density = 1.1943 - 0.0056 (Grey value) + 49.785 / (Grey value)

Parameter estimates

| Variable | Degrees freedom | Parameter value | Standard error | T for H0: Parameter = 0 | Prob. > \|T\| |
|---|---|---|---|---|---|
| Intercept | 1 | 1.1943 | 0.1319 | 9.058 | 0.0001 |
| Grey value | 1 | -0.0056 | 0.0004 | -12.692 | 0.0001 |
| 1 / Grey value | 1 | 49.785 | 8.4153 | 5.916 | 0.0001 |

Analysis of variance

| Source | Degrees freedom | Sum of squares | Mean square | F - value | Prob. > \|T\| |
|---|---|---|---|---|---|
| Model | 2 | 2.7825 | 1.3913 | 2327.068 | 0.0001 |
| Error | 10 | 0.006 | 0.0006 | | |
| Total | 12 | 2.7885 | | | |

Root mean square error = 0.024 Adjusted R-square = 0.9974

Table 8.
Calculation of film density and density difference for hardwood and softwood stands from image grey value.

| Film | Average grey value: hardwood stand | Average density: hardwood stand | Average grey value: softwood stand | Average density: softwood stand | Grey value difference | Density difference |
|---|---|---|---|---|---|---|
| BWIR | 177 | 0.48 | 122 | 0.91 | 55 | 0.43 |
| A200 | 119 | 0.94 | 121 | 0.92 | 2 | 0.02 |
| DXX | 108 | 1.05 | 102 | 1.11 | 6 | 0.06 |
| PANX | 113 | 1.00 | 105 | 1.08 | 8 | 0.08 |

may provide the enhancement necessary to ensure tonal discrimination of the vegetative features of interest because tonal enhancements often rely on the subjective preference of the analyst.

### *Assessment of Density Range*

Density range is an indicator of image contrast with larger density differences suggesting greater contrast. A plot of the descriptive statistics using the average grey value and its standard deviation provides an indication of density range and how hardwood, softwood and mixed wood stands compare over the four films (**Figure 4**). The average grey values were highest with BWIR film and lowest for DXX film for all stands. The grey values were also higher for the films with infrared sensitivity (i.e., BWIR, A200) relative to the panchromatic films DXX and PANX for all species types.

Density range increased for all films from hardwood to softwood to mixed wood (**Figure 5**). The BWIR and DXX films display the lowest values for the hardwood stand type. BWIR film's low value can be attributed to the overexposure of the deciduous tree crowns by high levels of infrared reflection and the subsequent halation effect in the emulsion that obscures the shadow areas. This condition is common with the BWIR film due to the film's narrow exposure latitude and lower maximum density values relative to other black-and-white emulsions. These effects lead to a smaller grey level range (**Figure 5**) and a higher average grey level compared with the other films (**Figure 4**). DXX film displays a similar low density range as the BWIR film, but for different reasons. The average grey level for DXX is lower than BWIR (**Figure 4**) due to its lower infrared sensitivity (**Table 1**). The lower average grey value allows it to approach the shadow grey level values and this reduces the density range. The A200 film density range values are higher than either BWIR or DXX (**Figure 5**). The higher infrared sensitivity of A200 to DXX (**Table 1**) will increase reflectivity from the deciduous crowns that will result in higher average density values for A200 film (**Figure 4**). A200 film's lower infrared sensitivity to BWIR (**Table 1**) and wider exposure latitude will not allow the exposure saturation and halation effects noted with the BWIR film. This would help to maintain adequate distinction between crowns and shadow areas and

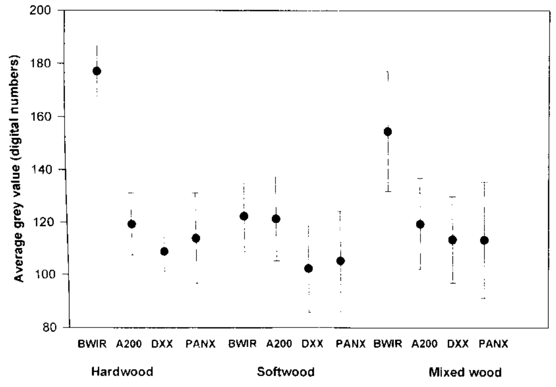

**Figure 4.**
**Average grey values for hardwood, softwood and mixed wood stands imaged on four aerial films. The error bars are ± 1 standard deviation.**

increase the density range. The PANX film's inherently higher contrast, which is typical of films with high spatial resolution and extremely fine granular structures (Sturge *et al.* 1989), allows the density range to exceed the other films by a large margin.

The softwood stand shows that PANX maintains its high density range value, but the other three films increase substantially from the hardwood stand (**Figure 5**). Lower infrared reflection from the needle-leafed crowns produces a lowering of the average grey level for BWIR (**Figure 4**). A conifer stand is not subject to the high infrared crown reflection saturation and the halation effects as noted with the hardwood stand. The result is greater visibility of the shadow areas, and they are also rendered more visible with both the DXX and A200 thus increasing the grey level range. The effect is numerically noted by an increase in the variability of the grey levels of BWIR, DXX and A200 (**Figure 4**).

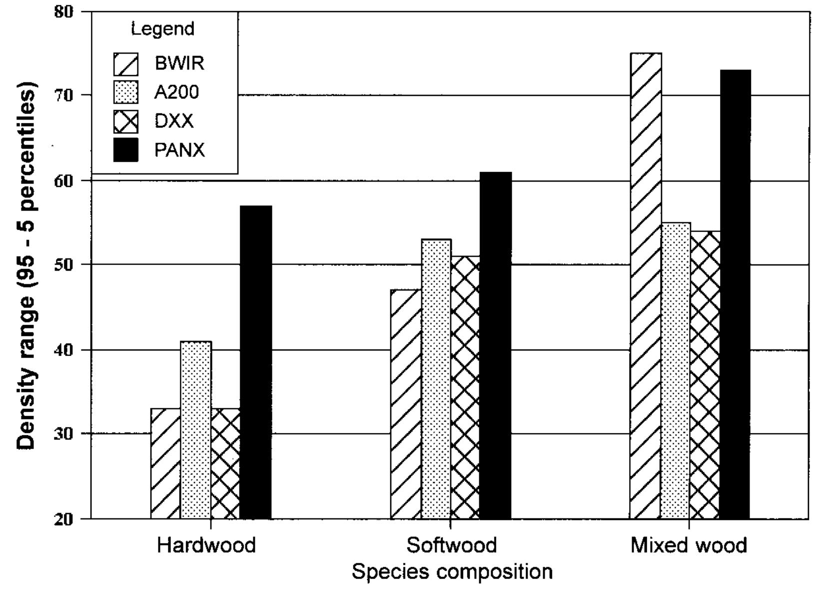

**Figure 5.**
**Density range for hardwood, softwood and mixed wood stands imaged on four aerial films.**

The density range for BWIR film in the mixed wood stand is the highest for all films and stand types, and PANX is a close second (**Figure 5**). BWIR optimally renders the deciduous trees due to their high reflective characteristics, but the coniferous trees and shadow detail are not obscured as with the hardwood stand because of small overexposure and halation effects. The lower average grey level and higher variability of the grey values of the mixed wood stand compared to the hardwood stand support this observation (**Figure 4**). The DXX and A200 density ranges remain relatively unchanged between the mixed wood and softwood stands (**Figure 5**). It seems that the infrared spectral attributes of these two films are not sufficient to differentiate between the two species within the mixed wood stand. Although PANX film's density range is almost as high as the BWIR, the spectral sensitivity of PANX compared with BWIR is relatively low (**Table 1**). The density range of PANX film is more likely a result of density ranges between bright crowns and dark shadow areas, than to highly infrared reflective deciduous crowns and dark softwoods and shadow areas.

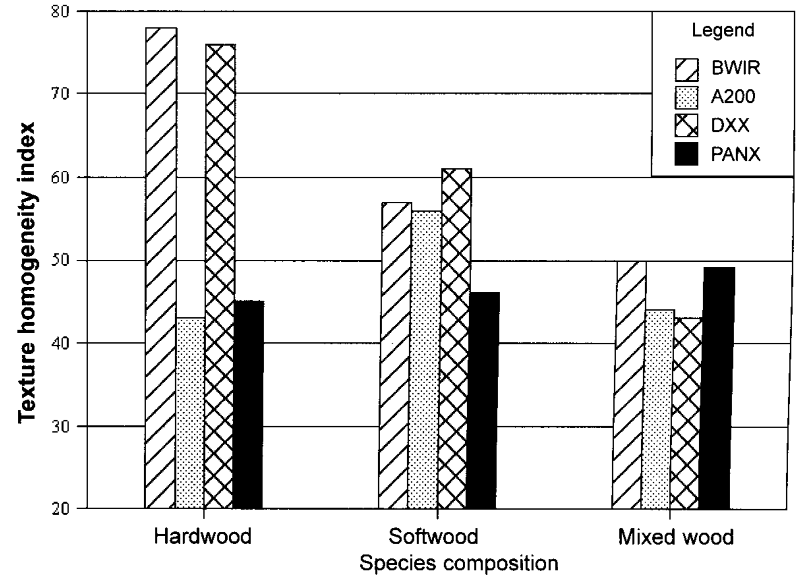

**Figure 6.**
**Texture homogeneity indices for hardwood, softwood and mixed wood stands imaged on four aerial films.**

### *Assessment of Image Texture*

When interpreting a texture homogeneity index for each forest stand, pure stands were hypothesized to have larger values than more mixed stands. Thus, smaller texture indices would suggest the stand has a coarser texture and is more heterogeneous. For the hardwood and softwood stands, both films BWIR and DXX had higher texture homogeneity indices compared to films A200 and PANX (**Figure 6**). Low textural homogeneity was recorded for the mixed wood stands for all films. Although the hypothesis that pure stands would have a larger texture homogeneity index than more mixed stands is generally true, it was only obvious for films BWIR and DXX. The differences in film response to texture renditions as a function of species composition is attributed to the film's characteristics with respect to spectral sensitivity, contrast and resolution.

Film BWIR shows a decreasing trend from high textural homogeneity for the pure hardwood stand, and decreasing values as the stand becomes more mixed. This trend is attributed to the film's spectral sensitivity that extends into the near infrared (**Table 1**), and the overexposure and halation that may occur with BWIR films. The high spectral sensitivity to the near infrared causes portions of the deciduous tree crowns to be overexposed on the film. The overexposure obliterates fine tonal variations and compromises textural heterogeneity. As the stand becomes more mixed, the lower infrared reflectance from the coniferous species provides a greater amount of tonal variation that consequently increases the textural rendition of the stand. Texture becomes more heterogeneous for BWIR film as one progressed from hardwood to softwood, and from softwood to mixed wood stands.

A200 film's spectral response to infrared reflectance, although lower than BWIR, is sufficient to produce a higher density range (**Figure 5**) and average grey value response from the hardwood canopy than DXX (**Figure 4**). The higher mean density value and the absence of halation effects will produce a greater range of grey values and more contrast between the crowns and the shadow areas resulting in a more defined textural pattern.

DXX film exhibited a high texture homogeneity index for the hardwood stand followed by decreasing values for the softwood and mixed wood stands (**Figure 6**). Film DXX has the lowest spectral sensitivity (**Table 1**), and this suggests the film would be less sensitive to the high reflectance from the pure hardwood stand. DXX's low infrared sensitivity will portray the hardwood stand darker than BWIR and reduce the overexposure and halation effects due to the infrared reflectance, but the grey level range between crowns and shadows will also be reduced. The overall grey level reductions result in lower contrast and higher texture homogeneity values. As the density range of the softwood and mixed wood stands increase (**Figure 5**), the contrast increases and decreases in texture homogeneity are observed.

Film PANX has low relative textural homogeneity for all stands (**Figure 6**). The film's spectral sensitivity is identical to film DXX, and this suggests its texture pattern for stands of varying species composition should be similar. The differences in the rendition of texture homogeneity may be related to its high contrast and spatial resolution characteristics (**Table 1**). PANX film is an extremely fine- grained film and it is typical for films with such granular structures to be of relatively high contrast (Sturge *et al.* 1989). This characteristic is noted with the film's relatively wide grey level variance (**Figure 4**) and high density range (**Figure 5**) among all stands. The higher contrast of this film is the main determinant in the lower texture homogeneity index observed among all stands.

## CONCLUSIONS AND RECOMMENDATIONS

The results associated with the first study question suggest that PANX is the most accurately interpreted film for species discrimination. The implications for using a film considered a newcomer in forest inventory aerial photography should be considered. PANX is a slow speed, high resolution film that requires state-of-the-art camera technology for precise exposure at medium scales because of its slow film speed, and narrow exposure latitude relative to other black-and-white films.

Density range was noted to be higher in most cases with PANX than with other films, and textural homogeneity was generally lower with PANX than with the other films (questions 4 and 5). These measures of image quality, along with the high spatial resolving attributes of this film, set it apart from the other films investigated. Contrast as indicated by density range, spatial resolution, and its influence on rendering textural patterns are interrelated, and no one factor can be assessed in isolation. The results of this investigation do indicate, however, that analyzing patterns in density range and texture does aid in explaining interpretation results. The process of quantifying these attributes specific to PANX'S interpretation results, should translate to specifications designed to replicate photo quality on a more consistent basis.

The tonal and texture renditions on film PANX for most stand types appear to be superior to the other black-and-white films that are currently being used operationally. There was also a statistically significant difference in how species are being interpreted, with mixed wood species more accurately interpreted than hardwoods and softwoods (question 2). This is likely attributed to the greater ease that interpreters have in distinguishing between hardwoods and softwoods within a stand as opposed to distinguishing among the hardwood or the softwood species.

This study proposes that a statistical digital grey value - densitometric relationship can be determined (question 3), and used operationally for quality control and evaluation of contract photography, or to enhance the tonal rendition of scanned aerial photographs. This 'bridge' between the analogue and digital environments is needed to produce digital products that conform to set specifications and to provide for a smooth transition to the inevitable digital imaging environment.

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