1996 HALL

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A Comparison of Four Black-and-White Aerial Films and their Texture on Interpreting Images of Forest Species Composition

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Abstract - **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 that were imaged on these films were digitally scanned and quantitative estimates of image texture were obtained. Panatomic-X film produced the highest interpretation accuracy results for species interpretation. This suggests that Panatomic-X's high spatial resolving properties outweigh that of films with wider film spectral sensitivity, including that of Kodak black-and-white infrared 2424 and Agfa's Aviphot Pan 200. These results have implications for operational forest agencies who continue to use infrared-sensitive aerial films in forest inventory applications.**

I. 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 (Gillis and Leckie 1993). Among the forest attributes that are interpreted during this process include species composition, crown closure and stand height. The extent to which these attributes can be interpreted, particularly tree species, is largely determined by the films that are used (Fent et al. 1995), and the quality of the photographs acquired (Lillesand and Kiefer 1994).

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 1994; Lillesand and Kiefer 1994). The sharpness of an image is also 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). 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 (eg., film speed, resolution, spectral sensitivity, contrast characteristics) and camera technologies (eg., forward image motion compensation, improved lens resolution, integrated computer exposure controls), photo quality has become more important because of the controls now available to the photo acquisition process. Thus, efforts to refine air photo quality specifications could have a significant influence on map production, and the resultant accuracy of the information base upon which forest management decisions are made.

This study addresses the influence of aerial films on the interpreted accuracies of species composition in the boreal mixed wood forest. It is one of several studies directed at increasing the knowledge base for defining air photo specifications that are specific to forest resource inventory applications (Hall and Fent 1991; Fent et al. 1995). Forest stands of varying species composition were identified and interpreted on four black-and-white aerial films that included Kodak infrared 2424, Agfa Aviphot PE 200, Kodak Double-X 2405, and Kodak Panatomic-X 2412. Except Panatomic-X, these films are also those 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 address the following two questions:

- Which of the four black-and-white films are most accurately interpreted for species composition?
- Would a quantitative measure of image texture help to explain any differences in the interpretation results?

II. 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). A flight line 60 km in length was flown over an area that exhibited a diversity in 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.).

III. METHODS

A. *Aerial Photography*

The four black-and-white films selected are described in Table 1 (Agfa-Gevaert 1990; Eastman Kodak 1992). 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 recent availability of cameras with forward motion compensation (F.M.C.) capabilities.

The photography was experimentally planned and conducted with an F.M.C. camera on the same day near solar noon and processed with the same processor and chemicals. These considerations served to reduce the influence of image motion, variable exposure, and film processing that would otherwise mask the differences among films, and affect interpretation accuracies. All selected negatives were printed with Grade 2 photographic paper.

B. *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. Interpreters from across Canada and the United States familiar with the boreal forest participated in the study. 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 percent intervals ranging from 0 to 100 percent.

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.

C. *Statistical Analysis*

A one-way analysis of covariance (ANCOVA)[1], using the interpreter geographic origin as the covariate, was conducted to determine if statistical differences in terms of accuracy existed. If there were significant differences between films, then the Bonferroni multiple mean comparison test (Neter et al., 1990) was employed.

D. *Digital Analysis and Image Texture*

Five stands of similar structure (ie., height, density, and crown closure) ranging from 100% deciduous to 50% deciduous / 50% coniferous species composition in 10% intervals, 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. The difference between pixels in the 5th and 95th quantiles were used as a measure of density range for each of the five stands on the four films. The five stands and four films resulted in 20 digital images whose sizes were 50 pixels by 60 lines.

Texture within an image processing context is often used to

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

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 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 spatial co-occurrence matrices in a 3x3 moving window. The angular second moment is a measure of homogeneity that describes the number of transitions from one grey level to another (Mather 1987). The average grey value for texture 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.

III RESULTS AND DISCUSSION

A. *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 interpreted, and its variation was smallest among the four films (Table 2).

There was a statistically significant difference in interpretation accuracy for the four films based on the ANCOVA design (Table 3). Thus, film type affects interpretation accuracy. The covariate term was 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.

The Bonferroni multiple mean comparison test provided an indication of how the films compared statistically. Although film PANX rated the highest in terms of interpretation accuracy, it was not statistically different from films DXX and BWIR (Table 4). All three of these films, however, were different from film A200. Films A200 and BWIR were also determined to be similar.

Table 2
INTERPRETATION ACCURACY DESCRIPTIVE STATISTICS

Film	Mean	Standard deviation	Standard error	Coefficient variation
A200	64.8	22.0	1.2	34.0
BWIR	66.8	25.2	1.4	37.7
PANX	70.7	12.8	0.7	18.1
DXX	68.8	18.7	1.0	27.2

Table 3
ANALYSIS OF COVARIANCE TABLE FOR FILMS EVALUATED.

Source	Degrees of freedom	F value	Pr > F
Films	3	5.11	0.0016
Covariate: Region	1	56.62	0.0001

Table 4
BONFERRONI T-TESTS FOR MEAN COMPARISONS

Film comparison	Lower confidence limit	Difference between means	Upper confidence limit
A200 - PANX	-10.04	-5.90	-1.76**
A200-XX	- 7.93	-4.00	-0.07**
A200 - BWIR	- 6.06	-2.03	2.00
BWIR - PANX	-8.02	-3.87	0.27
BWIR - XX	-5.91	-1.97	1.96
BWIR - A200	-2.00	2.03	6.06
XX - PANX	-5.95	-1.90	2.15
XX - BWIR	-1.96	1.97	5.91
XX - A200	0.07	4.00	7.93**
PANX - XX	-2.15	1.90	5.95
PANX - BWIR	-0.27	3.87	8.02
PANX - A200	1.76	5.90	10.04**

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

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.

B. *Assessment of Image Texture*

The second question of the study was to determine if image texture based on a homogeneity measure could help explain differences observed for stands of varying species composition over the four films. The image grey values provide a measure of average film density, and since each stand has inherent variation with respect to shadows and highlights, the difference in 95 and 5 percent quantiles were considered more representative of density range (ie., range in tones) than their absolute values. Five stands were selected for image scanning, and these were composed of 100 % aspen (Aw10), 80% aspen and 20% white spruce (Aw8Sw2), 70% aspen and 30% white spruce

(Aw7Sw3), 60% aspen and 40% white spruce (Aw6Sw4), and 50% aspen and 50% white spruce (Aw5Sw5).

Density range generally increased for all films as species composition ranged from pure aspen (Aw10) to mixed aspen and spruce (Fig. 1). Changes in density range were most pronounced for film BWIR as it increased from a value of 33 for Aw10, to a value of 75 for the mixed aspen-spruce stand (Aw5Sw5) (Fig. 1). Film PANX density range changed a smaller amount between the pure and mixed stand types, but its overall density range was generally higher for the more pure stands. The higher density range for film PANX implies there is more contrast in the pure stands relative to that obtained by the other films. The smallest change in density range between stands was recorded for film A200, and this suggests the contrast changes little with species composition for this film.

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 stands have a coarser texture and are more heterogeneous. For the relatively pure stands (ie., Aw10 and Aw8Sw2), both films BWIR and DXX had high textural homogeneity indices compared with films A200 and PANX (Fig. 2). Relatively low textural homogeneity was recorded for the mixed stand Aw5Sw5 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 and resolution.

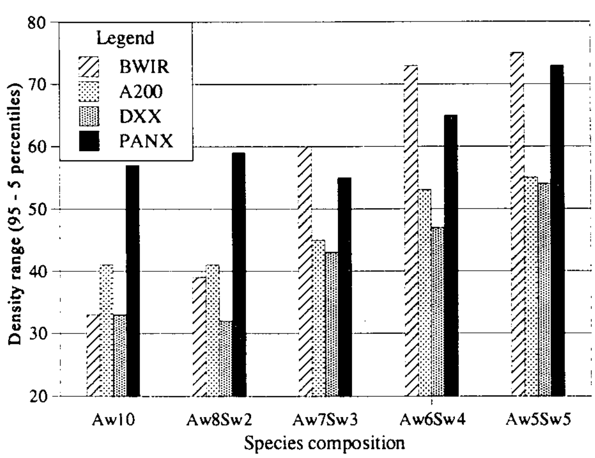

Fig. 1. Density range for five stands of varying species composition.

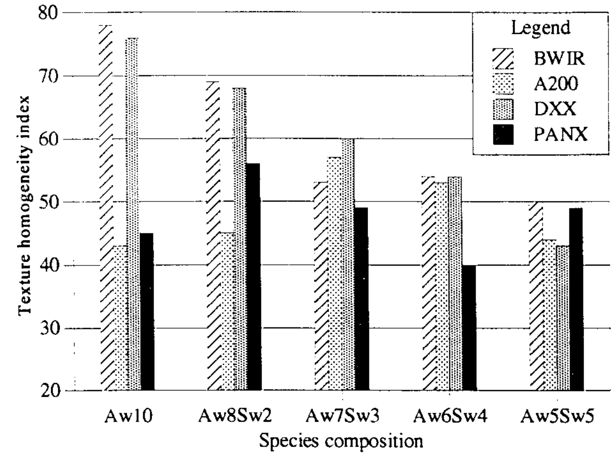

Fig. 2. Texture homogeneity indices for five stands of varying species composition.

Film PANX has low textural homogeneity for all stands relative to other films (Fig. 2). 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, however, may be related to its superior resolution characteristics (Table 1). As a high resolving film, texture renditions may be enhanced resulting in greater texture heterogeneity. This observation is consistent with photographic science concepts that state as film granularity decreases and resultant resolution increases, so does the film's inherent contrast (Neblette 1964). PANX's high density range values coupled with its low texture homogeneity index contributed to its performance as the most accurately interpreted film.

IV CONCLUSIONS AND RECOMMENDATIONS

This study shows that for interpreting forest species in the boreal forest, film PANX produced the highest accuracy values. The implications for using a film considered a newcomer in forest inventory aerial photography should be considered. PANX is a slow speed film that requires state-of-the-art camera technology for successful mission acquisition at medium scales. Its slow film speed reduces the effective photo-daylight required for proper exposure. The film's higher contrast and narrow exposure latitude also increase the likelihood of improperly exposed photographs.

Considering PANX's operational drawbacks, it is a film that, once properly exposed and processed, would appear to enhance interpretation effectiveness greatly. This study suggests that the film's texture and tonal renditions are, for most stand types, superior to the other films that are currently being used operationally.

Kodak, furthermore, continues to improve the film's contrast range qualities. The new version of film PANX will enable users to expose and process to average gradients as low as 1.2. This technical improvement greatly enhances the versatility of the film.

The forest community should investigate the film's operational utility in forest management. The film will then be embraced as either a tool that will improve the quality of forest inventories, or it will be dismissed, as has often been done in the past, as a 'special purpose' type film.

ACKNOWLEDGMENTS

Interpreters were provided by several agencies including: Aerial Image Technology, Alberta Environmental Protection, B.C. Ministry of Forests, Indian and Northern Affairs Canada, Manitoba Natural Resources, Minnesota Dept. of Natural Resources, Newfoundland Department of Natural Resources, Ontario Ministry of Natural Resources, Saskatchewan Environment and Resource Management, and United States Dept. of Agriculture, Forest Service. The cooperation of Canadian Forest Inventory Committee was greatly appreciated. Partial funding for this project was provided by the Canada-Alberta Partnership Agreement in Forestry.

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Proceedings

for

The 26th International Symposium on Remote Sensing of Environment

The 18th Symposium of the Canadian Remote Sensing Society

Information Tools for Sustainable Development

March 25 - 29, 1996

Vancouver, B.C., Canada

Organized by

International Symposia on Remote Sensing of Environment (ISRSE),

and the

Symposia of the Canadian Remote Sensing Society (CRSS)

ISBN 0-920203 - 12 - 4