

APPLICATION OF MAXIMUM LIKELIHOOD AND EVIDENTIAL REASONING CLASSIFIERS
FOR MAPPING CONIFER UNDERSTORY*

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ABSTRACT

Information about the presence and spatial distribution of white spruce conifer understory within deciduous and deciduous-dominated mixed-wood stands is required for boreal mixed-wood management in Alberta. A set of forest land cover classes was created that consisted of 30 classes described by overstory stand structure and three levels of understory amount. These polygons were overlaid onto two-date, leaf-off and leaf-on, Landsat Thematic Mapper (Landsat TM) images from which random pixel samples were extracted for classification and independent validation. An iterative supervised classification algorithm combined with class aggregation rules were used to reduce the 30 classes to 16. These 16-classes were compared to results obtained with a knowledge-based, supervised evidential reasoning classifier. Similar classification accuracy results were obtained from the two classifiers with spectral data alone but accuracy increased significantly when information about stand structure was added to the evidential reasoning classifier. Species composition, height, and crown closure describes stand structure but are often represented on a nominal or ordinal scale that is not appropriate for statistical classifiers but can be used in an evidential reasoning classifier to improve classification performance.

1.0 INTRODUCTION

Mixtures of aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss) occur frequently in the Mixedwood Section (Rowe 1972) of the western boreal forest. Within these mixtures, white spruce often occurs as understory trees in aspen and aspen-dominated mixed-wood stands, but current forest inventories often do not document their amount or distribution (Brace and Bella 1988; Lieffers et al. 1996). Information about the understory component is needed for spruce management planning (Brace and Bella 1988), and is important because of its future contribution to white spruce timber supply (Morgan 1991; Lieffers et al. 1996).

Understory information is currently obtained by interpretation of leaf-off aerial photographs and field surveys that are costly and time-consuming to undertake when large areas are involved. A method involving satellite remote sensing data may provide useful information at the planning level by providing an initial stratification of the forest landscape for understory location, distribution and amount. A prerequisite to the mapping of conifer understory is a classification system to describe the structure of

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such stands. Devising a classification system for understory stands is problematic because these stands tend to occur as a continuum rather than in clearly recognizable associations due to their fire history, species ecology and site quality (Navratil et al. 1994). The Alberta Vegetation Inventory (AVI) system (Resource Information Division 1991) can be used to classify and map understory as a two-story stand, but it is very detailed and not appropriate for satellite data. The use of AVI data in geographic information system (GIS) format, however, can be a useful tool to stratify an area into more homogeneous strata (Miguel-Ayaz and Biging 1996). A remote sensing-GIS integration approach was utilized in this study to address the classification problem by overlaying onto the digital image, spatial polygons of known identity. Forest land cover types consisting of overstory stand structure and understory distribution were mapped in this study to 30 classes. The problem was to determine the logical subset of land cover classes that could be discriminated with Landsat Thematic Mapper (Landsat TM) data.

This study utilized a two-stage classification approach, with an iterative supervised maximum likelihood classification process at the second stage, to aggregate overstory and understory classes into a meaningful subset. The class subset derived was then subjected to a supervised evidential reasoning classifier. Using this classifier, an assessment of accuracy using spectral data and forest inventory parameters such as stand height, crown closure and species composition was compared to the use of spectral data alone. The objective of this paper is to report on preliminary results achieved with this combination of classification methods.

2.0 STUDY AREA

The study area consisted of four townships (approx. 625 square km) in north-central Alberta that included Township 92, Ranges 19 and 20, and Township 93, Ranges 19 and 20, west of the 5th Meridian. The four townships are approximately bounded by 57.12° North Latitude and 117.22° West Longitude on the Northwest, to 56.94° North Latitude and 116.90° West Longitude on the Southeast. This area is part of the Mixedwood Section of the Boreal Forest Region (B.18a, Rowe 1972) characterized by mixtures of trembling aspen, balsam poplar (*Populus balsamifera* L.), white spruce and jack pine (*Pinus banksiana* Lamb.). A few isolated stands of white birch (*Betula papyrifera* Marsh.) and balsam fir (*Abies balsamea* [L.] Mill.) are found on wet and dry sites, respectively. Black spruce (*Picea mariana* [Mill.] B.S.P.) are found on poorly drained sites throughout the area. The study area has been mapped to the Alberta Vegetation Inventory (AVI) standards (Resource Information Division 1991) that describe cover types by moisture regime, crown closure, stand height, species composition, and stand origin.

A mask was created from digital AVI data to limit the study area to be analyzed to include only deciduous and deciduous dominant mixed-wood stands. Areas not of interest to the classification such as water, conifer-dominated stands and wetlands were therefore removed at the first stage of the two-stage classification.

3.0 METHODS

3.1 LANDSAT TM DATA AND PREPROCESSING

Landsat TM images were acquired in geocoded format for April 18, 1991, representing leaf-off, and July 23, 1991, representing leaf-on stages of phenology. The timing of data acquisition for remote sensing data is important due to the changing phenology of the canopy and the understory (Blackburn and Milton 1995). The leaf-off image was used to identify the presence of an understory, and the leaf-on image was used to separate the overstory into pure deciduous and mixedwood stands. The Landsat TM

data were atmospherically corrected using the "Fast Atmospheric Algorithm" developed by the German Aerospace Research Establishment - DLR and implemented on the PCI Easi-Pace system. The algorithm transforms the original radiance image to a reflectance image by accounting for the atmospheric effect of the additive path radiance term (Richter 1990; PCI Inc. 1995). The reflectance image was represented in an 8-bit, 0-255 scale, grey-level image for each Landsat TM band.

For this initial study on the classification of deciduous-dominant mixedwoods for understory, all six reflective Landsat TM bands for each date, TM bands 1, 2, 3, 4, 5, and 7, representing the visible, near infrared and middle infrared spectral regions were selected for analysis. The Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1974) was computed for each of the leaf-off and leaf-on datasets. The influence of texture on separability was also incorporated by computing a measure of homogeneity for each image date (Mather 1987). The greatest change in Landsat TM band values was expected for the near infrared band because of the change from leaf-off to leaf-on conditions, and this change would be manifested in the texture renditions of forest stands. This combination resulted in 16 image bands that were used in image classification.

3.2 MAPPING CONIFER UNDERSTORY TO 30 CLASSES

Species composition and crown closure are among the important parameters that affect spectral responses of forest canopies (Guyot et al. 1989). These components of stand structure were incorporated into the conifer understory map. Starting with five overstory species compositions and following preliminary fieldwork, understory crown closure was interpreted to three levels (i.e., nil, light, heavy) from mostly 1:10,000 color infrared leaf-off aerial photographs (Table 1). Four classes of crown closure, as originally interpreted for the AVI, were reclassified in the GIS to two classes consisting of 7 to 50 percent crown closure to represent an open canopy, and greater than 50 percent to represent a closed canopy. The five overstory species x two overstory crown closure x 3 class understory resulted in 30 forest land cover classes (Table 1) of which 29 occurred in the study area. These 29 forest land cover classes were represented in an ESRI Arc/Info¹ GIS coverage that was imported into a PCI¹ image database. The GIS coverage was thresholded for each of the individual understory classes (Table 1) to create separate 100 percent filled bitmaps. New bitmaps were also created for each understory class (Table 1) that consisted of a 35 percent random sample. This sample intensity was selected to ensure sufficient training pixels for each of the 29 classes were available to allow reasonable estimates of the mean vector and covariance matrix to be determined for the maximum likelihood classifier.

3.3 DIGITAL CLASSIFICATION METHODS

3.3.1 Iterative Supervised Classification

The objective of the iterative supervised classification process was to identify which of the 29 classes to aggregate. A supervised maximum likelihood classification based on a random sample of pixels was undertaken after each iteration. An approximate 33% random sample of pixels not used in generation of signatures was used to assess classification performance in a contingency table between the classification and GIS map. The contingency table was used to indicate which classes were statistically and spectrally similar. The decisions as to which classes to merge entailed an analysis of the contingency table, relative frequency or size of land cover class within the study area, interpretation of similarity in

¹ The mention of trade names is for information only.

class definitions, and analysis of separability statistics between classes. For example, a 60/40 closed crown closure heavy understory would be a candidate to merge with a 70/30 class of identical attributes. No more than one to three classes were selected for merging after each iteration, which resulted in a merging of training class pixels and calculation of new class statistics.

3.3.2 Evidential Reasoning

The classifications were performed using an evidential reasoning classifier implemented in the MERCURY[®] software system by Peddle (1993). The evidential reasoning classifier was designed to handle multisource data as individual pieces of evidence over a set of classes that are combined to produce a final decision (i.e., pixel labeling) (Peddle 1993). The MERCURY[®] software package (Peddle 1995) can process data at any scale (i.e. nominal, ordinal, interval, and ratio), and was designed to allow direct integration of GIS data types. The evidential reasoning classifier was run on the output number of aggregated classes determined from the iterative supervised classification with the same set of random pixels used in the iterative classification. For that class set, 3 band sets were tested that included the 16 image bands, 16 image bands plus 1 AVI variable (i.e., stand height), and 16 image bands plus 3 AVI variables (i.e., stand height, crown closure and species composition). This combination of variables would not have been possible with the 16 input variable restriction found in the PCI maximum likelihood classifier. All input variables were set with equal *a priori* weighting and a bin size of 1. Classification performance was tested with the same independent random pixels used in the assessment of the iterative supervised classification.

4.0 RESULTS

There were a total of 8 iterations to reduce the original 29 classes to 16. The decision as to which classes to merge required a combination of empirical data and ecological interpretation by class definition. The resulting 16 classes consisted of combinations of overstory species composition, overstory crown closure and understory amount (Table 2). The average classification accuracy was 27 percent unfiltered and 30 percent following a 3x3 median filter, with Kappa coefficients of 0.25 and 0.28, respectively (Table 3). These values, however, were likely conservative because they were based on comparisons with the photo-interpreted map. Although all 16 classes are illustrated in Figure 1, a simplified legend showing only the dominant species composition was devised due to limitations in grey scale representation. The general pattern of the photo interpreted map (Figure 1a) has been captured in the iterative classified image map (Figure 1b), although the latter appears considerably noisier due to the per pixel maximum likelihood classification algorithm. Conifer understory is patchy in distribution, however, which suggests the classified image map may more closely resemble reality than what the accuracy statistics appear to indicate.

The evidential reasoning classifier produced similar accuracies to the iterative supervised classification when spectral data were used alone (Table 3). Average accuracy values increased from 26 percent to 34 percent with the addition of AVI stand height, and to 71 percent with the addition of AVI crown closure and species composition (Table 3). Accuracy therefore increased as stand parameters were incorporated as additional variables into the classification. The higher accuracy value is indicative of the similarity of the photo interpreted map (Figure 1a) to the image map from the evidential reasoning classifier (Figure 1c). The integration of multisource data appears to have made significant improvements to the classification of mixedwood stands for understory compared to the use of spectral data alone.

5.0 DISCUSSION

The assessment of classification accuracy was affected, in part, from the difficulty in capturing spatially, the patchy spatial distribution of conifer understory within overstory polygons. Classified image maps were compared to polygons produced during photo interpretation that resulted in a map of overstory stand structure and understory distribution. During a map overlay exercise, it is assumed that every pixel within a polygon is representative of that class. Stand attribute labels attached to a polygon, however, are intended to serve as an average descriptor of the polygon. In mixed deciduous-conifer stands, there is variability within polygons since the conifer component in both the overstory and understory may not be uniformly distributed throughout the stand. Field samples collected using Global Positioning System (GPS) data would likely be needed for a more comprehensive assessment of classification performance.

Classification results with spectral data from the iterative supervised and evidential reasoning classifiers were similar. The ability of the evidential reasoning classifier to include the AVI forest inventory parameters resulted in significant improvements in classification accuracy. Conifer understory follows a successional trend whereby pure stands of aspen tend to be younger, on average, than more mixed stands, and the proportion of stands with understory appears to increase as the stands become more mixed (Hall et al. in prep.). Stand height may be used as a surrogate measure of age that will explain, in part, this behavior of understory distribution. Understory distribution in mixed stands, however, was only evident in closed crown closure stands (Hall et al. in prep.). This suggests species composition and overstory crown closure are important determinants of understory distribution, and explains, in part, why classification performance was improved with the addition of stand structure variables. The statistical distributions of forest inventory parameters from the AVI were not appropriate for statistical classifiers but were well suited for use in the evidential reasoning classifier. As with any supervised classification algorithm, the evidential reasoning classifier requires a predefined set of classes. In this study, the iterative supervised classification was used to define this class structure.

6.0 CONCLUSIONS

A two-stage classification approach was implemented in this study by using GIS data as a mask to confine image classification to an area of interest that only contained deciduous and deciduous-dominated mixed-wood stands. The incorporation of forest inventory parameters from the AVI into an evidential reasoning classifier resulted in a higher classification accuracy compared to the use of spectral data alone. The patchy distribution of understory within deciduous-dominated mixed-wood stands was not fully represented in the aerial photo interpretation products used for assessing classification accuracy. Pixels which are correct in the field may therefore be labeled as incorrect owing to the lack of agreement with the more generalised air photo map. A more intensive field survey of point data would likely be required to provide a more appropriate basis for classification accuracy assessment, from which we would expect our current products to yield even higher levels of absolute accuracy.

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Table 1. 30-Class Conifer Understory Classification System.

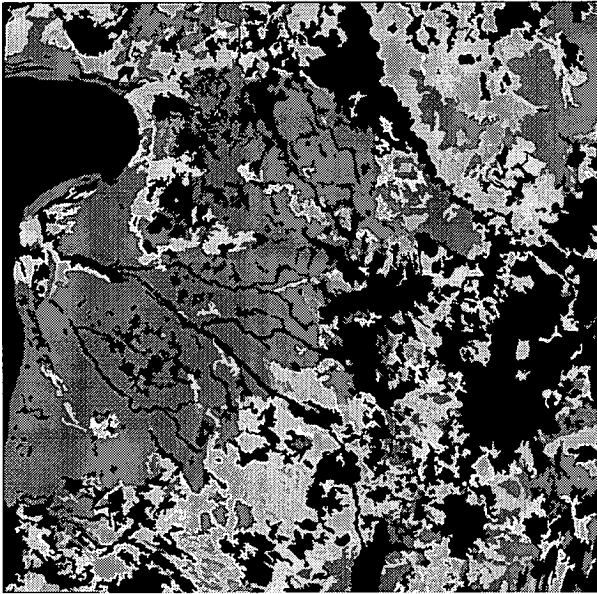
Class attribute	Attribute level and value
Overstory species composition	1. 100: 100% deciduous 2. 90/10: 90% deciduous/10% coniferous 3. 80/20: 80% deciduous/20% coniferous 4. 70/30: 70% deciduous/30% coniferous 5. 60/40: 60% deciduous/40% coniferous
Overstory crown closure (%)	1. Open: 7 – 50% 2. Closed: > 50%
Understory crown closure (%)	1. Nil: 0 – 6% 2. Light: 7 – 60% 3. Heavy: > 60%

Table 2. Description of the 16 Aggregated Forest Land Cover Classes.

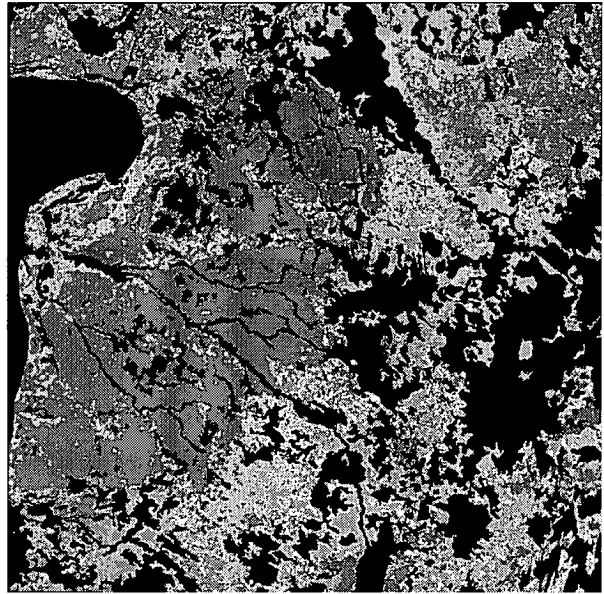
Class number	Overstory species composition	Overstory crown closure	Understory crown closure
1	100	Closed	Nil + Light
2	100 + 90/10	Open	Heavy
3	100 + 90/10	Closed	Heavy
4	100 + 90/10	Open	Nil + Light
5	90/10	Closed	Light
6	90/10 + 80/20	Closed	Nil
7	80/20	Open	Light
8	80/20	Closed	Light
9	80/20	Open	Nil
10	80/20 + 70/30 + 60/40	Open	Heavy
11	80/20 + 70/30 + 60/40	Closed	Heavy
12	70/30	Closed	Light
13	70/30	Open	Nil
14	70/30 + 60/40	Open	Light
15	70/30 + 60/40	Closed	Nil
16	60/40	Closed	Light

Table 3. Summary of Classification Results.

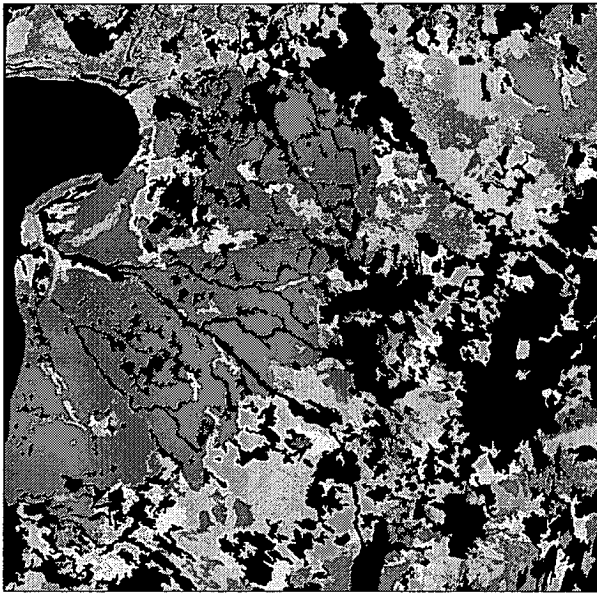
Description	Average accuracy (%)	Kappa coefficient
1. 16 Image bands, iterative classification		
- unfiltered	27.0	0.25
- 3x3 median filter	30.1	0.28
2. Evidential reasoning classifier		
- 16 image bands	25.5	0.20
- 16 image bands + AVI stand height	33.8	0.29
- 16 image bands + 3 AVI: stand height, crown closure, % deciduous	70.9	0.69



a) Air photo interpretation



b) Iterative supervised classification



c) Evidential reasoning classification

Legend









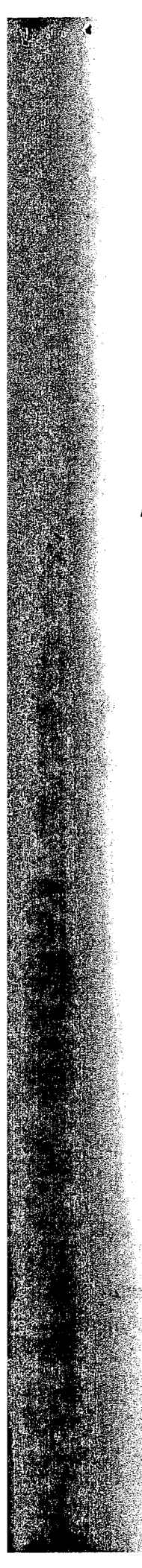
-  100
-  100 + 90/10
-  90/10
-  80/20
-  70/30
-  70/30 + 60/40
-  60/40
-  Unclassified

Figure 1. Air Photo Interpretation and Classified Image Maps with Simplified Legend.



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