SATELLITE REMOTE SENSING OF WHITE SPRUCE UNDERSTORY IN DECIDUOUS AND MIXEDWOOD STANDS

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ABSTRACT

A satellite remote sensing approach was evaluated for detecting and mapping white spruce understories in deciduous and mixedwood stands in Alberta. These stands may be considered as part of the conifer land base which is defined as stands which contain or are projected to contain a minimum conifer volume at rotation. Landsat Thematic Mapper images acquired in late April (leaf-off) and late July (leaf-on) were used to generate signatures for three levels of understory (nil, light, heavy) in five overstory classes mapped from interpretation of aerial photographs and field observations. Analysis of separability statistics suggest a reasonable degree of success may be obtained in mapping some of the understory classes with conventional classification tools. An unsupervised classification appears to confirm the separability analysis and indicates that the understory may be discriminated in two or three different overstory compositions.

INTRODUCTION

A current inventory problem in the Mixedwood Section of the Boreal Forest Region (Rowe 1972) is to determine the location and amount of conifer understory within deciduous and mixedwood forest stands (Brace and Bella 1988; Expert Panel on Forest Management in Alberta 1990; Peterson and Peterson 1992). This information is important in calculating the annual allowable cut (Morgan 1991), which is defined as the average volume of wood that may be harvested annually under sustained yield management, and also in determining the conifer land base. Forest stands comprised of fifty percent or more coniferous stems are managed as part of the conifer land base because they contain or are projected to contain a minimum conifer volume at rotation. The amount of conifer understory beneath pure deciduous and mixedwood stands governs the management approach. Current efforts to map softwood understory in the boreal mixedwood zone involve the interpretation of leaf-off aerial photographs and field surveys. This approach is time-consuming and expensive to undertake over the large areas that constitute the forest management agreements. In addition, the ultimate destination of the forest understory inventory is a digital GIS database. Digital satellite imagery offer the advantage of relatively simple digital-to-digital transfer of data if satisfactory levels of mapping accuracy can be obtained.

Few satellite remote sensing studies have attempted to map conifer understory directly (Stenback and Congalton, 1990), although the understory can contribute significantly to spectral response patterns in remote sensing studies of open canopies (Spanner et al. 1990; Fioria and Ripple 1993). In central Alberta, Kneppeck and Ahern (1990) analyzed Landsat Thematic Mapper (TM) images during leaf-off (fall) and leaf-on (summer) conditions, and suggested that leaf-off/leaf-on image dates could be used to map overstory conditions and understory vegetation in the boreal mixedwood zone. The basis of their classification was the use of the leaf-on image to separate the overstory conditions into pure deciduous and mixedwood stands. The leaf-off image was then used to indicate understory presence or absence. The influence of overstory stand structure and varying amounts of understory on Landsat TM spectral responses, however, were not addressed in their study. The purpose of this study is to further evaluate Landsat TM data for determining the detectability of conifer understory within pure deciduous and predominately deciduous stands.

STUDY AREA

The study area consists of four townships (approx. 625 square km) in north-central Alberta (Figure 1). This area is part of the Mixedwood Section of the Boreal Forest Region (B.18a, Rowe 1972) that is characterized by mixtures of trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), white spruce (*Picea glauca* [Moench] Voss) 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 dry and wet sites, respectively. Black spruce (*Picea mariana* [Mill.] B.S.P.) may also be 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 origin.

DATA ACQUISITION AND METHODS

Landsat TM images were acquired in geocoded format for April 18, 1991 (representing leaf-off) and July 23, 1991 (representing leaf-on) with solar conditions of 40.58° elevation/150.71° azimuth, and 49.52° elevation/144.77° azimuth, respectively. Atmospheric effects were corrected using the dark-object pixel subtraction technique (Chavez, 1988). A solar zenith angle correction algorithm was implemented to permit the direct comparison of reflectance between the two dates. Topographic correction was not necessary in the relatively flat terrain of the study area.

A conifer understory map was produced to provide the basis for the calculation of Bhattacharyya Distance (B-distance) as a measure of spectral separability, and to augment the interpretation of an unsupervised classification in the form of a comparison matrix (Tsakiri-Strati, 1994). Conifer understory stands were mapped to three levels (nil, light, heavy) beneath five overstory stand structures that ranged from pure deciduous (100% deciduous) to a 60%-40% deciduous-coniferous mixedwood composition (Table 1). The overstory information was derived from the AVI map. The distinction between light and heavy understory was based on a threshold of 60% crown closure in the understory interpreted on 1:20 000 scale color infrared leaf-off metric aerial photographs taken during the early spring following snow melt to permit maximum penetration into the overstory. In addition, 71 field plots and several 35mm oblique supplemental aerial photographs located throughout the study area were used to assist in the photointerpretation process. Of the fifteen possible classes, fourteen were present in the study area. The map was digitized and overlaid onto the Landsat TM image data, and polygons representing the fourteen classes were used as training areas in computing B-Distance and for comparison to the classes generated in an ISODATA unsupervised classification. The influence of single- and two-date images and a band subset (Horler and Ahern 1986) on spectral separabilities were also conducted.

RESULTS AND ANALYSIS

Spectral Separability

The highest class separabilities were achieved using the two-date Landsat images plus the NDVI statistics for the fourteen classes (Table 2). Single-date imagery performed poorly relative to the combined image data. There is a decrease in separability in the leaf-on TM data set, illustrating that the leaf-off data set is sensitive to the understory conditions because the overstory stand in the leaf-on data set partially masks the spectral response from the understory.

Figure 2 contains a graphical representation of the B-distance separability statistics generated as a trend surface for the 14-class classification scheme based on the Landsat TM leaf-off/leaf-on data in the areas mapped for each class in the color infrared photographs. Overall, there was poor separability based on B-distance < 1.0 in all cases. Classes 3, 9 and 13 are the most separable and can be considered relatively distinct. For example, class 3 - a class with no understory and a 100% deciduous overstory reached a maximum separability with classes 4, 7, 10, and 13 all of which have a heavy understory with different overstory structures. On the other hand, class 3 is most similar to classes 5, 6, 8, 9 and 12, all of which are classes with nil or light understory and different overstory structures. Class 13 (60-40% mixed overstory with a heavy understory) is most separable from the classes without an understory (classes 3, 6, 9 and 12). The least separable classes are 2,4,5,7, and 11. Heavy understory is more separable from nil understory classes than from light understory. Light understory classes are confused with primarily with the heavy understory classes. Some confusion in the overstory structures associated with mixedwood canopies can be expected.

Unsupervised Classification

The ISODATA unsupervised clustering algorithm was used to generate a map of the spectral classes for comparison to the understory map and the spectral separability measures. Four runs of the ISODATA routine were initialized with an expected number of clusters (12 to 16) and with a standard deviation of 8, 12, 16, and 20. The results when using an initial cluster standard deviation of 12 are presented in a contingency table (Table 3). Only the clusters which incorporated significant numbers of pixels in the understory map polygons are interpreted here.

Heavy understory in all overstory classes are mostly mapped in spectral clusters 1 and 2 (Table 3). The majority of light understory pixels in all overstory classes occurs in spectral clusters 2 and 3. There is some overlap between the light and the nil understory, which is mapped into clusters 3 and 4. The patterns suggest there is confusion in spectral cluster 2 for heavy and light understory, and spectral cluster 3 for light and nil understory.

The pure deciduous overstory is separable from the 60-40% deciduous-coniferous overstory. For example, 62% of the pixels under the 60-40% deciduous-coniferous heavy understory bitmap was incorporated into spectral cluster 1, but only 23% of the corresponding heavy understory pixels beneath a 100% deciduous canopy were included in this cluster. However, the very poor separation of the 70-30% mixedwood class and the 60-40% mixed class appears to indicate that these overstory structures are spectrally indistiguishable. Merging these overstory and understory compositions would result in the higher mapping accuracy, which may be consistent with that reported by Stenback and Congalton (1990) in the Sierran mixed-conifer zone (69% classification accuracy in detection of three canopy closure classes and understory presence or absence).

CONCLUSIONS

Digital Landsat TM leaf-off/leaf-on data may be used to map several combinations of overstory and understory conditions in boreal mixedwood and deciduous stands in Alberta. Areas of understory mapped from color infrared aerial photographs had, on average, poor overall spectral separability because understory is often unevenly distributed within overstory stands, and mapped polygons are often averaged during photointerpretation. Based on the unsupervised classification tests, the understory appears distinct in at least two classes (presence or absence) within each overstory class, and additional work on discriminating the five different overstory compositions is recommended. One approach is to map the overstory at a finer level than the simple separation of pure deciduous and mixedwood stands employed in this study. Crown closure for example, has long been known to be an important contributor to stand reflectance (Beaubien 1979). Because the reflectance spectra of stands are a combination of the reflectance spectra of trees and ground vegetation (Guyot et al. 1989), incorporating crown closure may increase the separation of the overstory classes and improve the detection and mapping of conifer understory. Image texture processing (Peddle and Franklin 1991) may also be used to account for the natural variability in understory patterns in the leaf-off image, and to characterize more precisely, the overstory structures in the leaf-on image to improve conifer understory classification and mapping accuracy.

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Table 1. Original class schema of overstory stand and understory composition (14 classes).

Overstory - understory	Class Number	Class label
100% deciduous		
heavy	1	H100
light	2	L100
nil	3	N100
90% deciduous - 10% coniferous		
heavy	4	H90
light	5	L90
nil	6	N90
80% deciduous - 20% coniferous		
heavy	7	H80
light	8	L80
nil	9	N80
70% deciduous - 30% coniferous		
heavy	10	H70
light	11	L70
nil	12	N70
60% deciduous - 40% coniferous		
heavy	13	H60
light	14	L60

Table 2. Average class separability statistics (B-distance) for several band combinations based on spectral data in areas interpreted using aerial photographs as different overstory and understory conditions (see Table 1).

Band combination	B-distance
TM bands 1,2,3,4,5,7 plus NDVI from each date	0.82
TM bands 1,2,3,4,5,7 from April 18, 1991	0.63
TM bands 1,2,3,4,5,7 from July 23, 1991	0.48
TM bands 3,4,5 plus NDVI from each date	0.77
TM bands 3,4,5 from April 18, 1991	0.59
TM bands 3,4,5 from July 23, 1991	0.43

Table 3. Percent pixels from the understory classification map which overlap with spectral clusters generated by the ISODATA algorithm (Note: Table values in bold correspond to spectral clusters whose pixels are 15 percent or more of its corresponding understory class label).

Class Label[a]	# Pixels	Percent of pixels in each spectral cluster corresponding to each Class Label[b]					
		1	2	3	4	5	6
H100	34368	**23**	**38**	14	5	7	1
H90	16098	**33**	**35**	9	1	13	1
H80	23625	**48**	**26**	6	1	12	1
H70	10119	**52**	**22**	5	1	14	1
H60	14814	**62**	**17**	4	1	12	0
L100	47396	3	**15**	**39**	**20**	4	3
L90	22757	5	**21**	**43**	12	5	4
L80	17693	6	**21**	**38**	12	6	3
L70	5730	13	**32**	**21**	7	11	1
L60	3284	8	**24**	**26**	**15**	6	2
N100	190034	0	0	**22**	**57**	1	5
N90	16770	2	7	**30**	**34**	4	6
N80	8273	2	7	**29**	**35**	2	12
N70	1581	2	5	**26**	**17**	4	**18**

[a] Understory class label described in Table 1.

[b] Percent figures have been rounded to the closest integer.

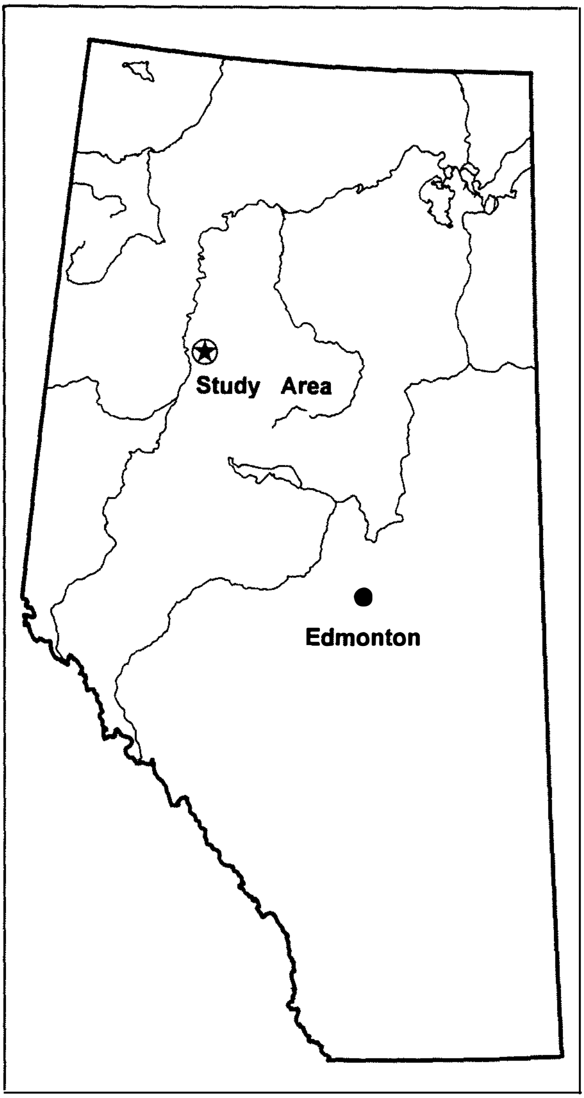

Figure 1. Location of the study area in north-central Alberta.

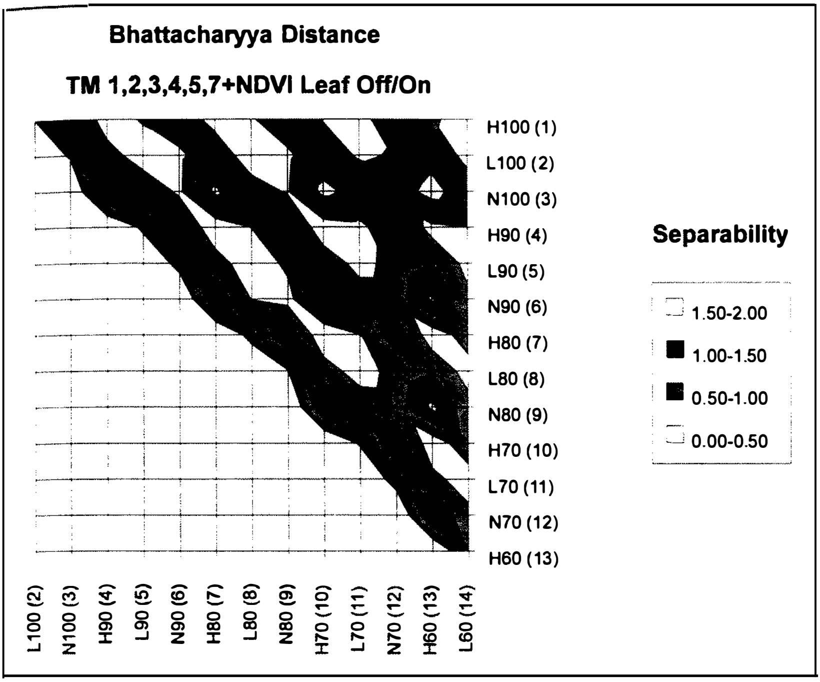

Figure 2. Bhattacharyya distance separability measures in the 14 class scheme (see Table 1) displayed as a probability surface for classification accuracy.

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