EVALUATING LANDSAT DIGITAL IMAGERY FOR DETECTING SOFTWOOD UNDERSTORY UNDER A HARDWOOD CANOPY

Final Report

DSS File No. XSG93-00110-(610)/A

S. E. Franklin
Department of Geography
The University of Calgary
Calgary, Alberta T2N 1N4

R. J. Hall
Natural Resources Canada
Canadian Forest Service
Northern Forestry Centre
Edmonton, Alberta T6H 3S5

June 1995

EXECUTIVE SUMMARY

The objective of this study was to determine the extent to which Landsat Thematic Mapper (TM) digital imagery could be used to detect and map softwood understory in hardwood and mixedwood forest stands in northern Alberta. This study undertook a stratification of the forest landscape for deciduous and deciduous-mixedwood stands with a softwood understory. The intended application was an image map that could be readily transferred to the GIS as a data layer and incorporated into an inventory database.

The study methodology consisted of an analysis of class structure through leaf-off and leaf-on image spectral separability, the prediction of classification accuracy through discrimination at selected field sites, the production of unsupervised and supervised classification maps, the assessment of accuracy of those maps using separability measures, and the development of a modified supervised classification method that includes an interpretation of the final map produced using the signatures generated from the intersection of unsupervised clusters and GIS polygons. The original class structure was comprised of three understory classes defined in crown closure percentage as nil (0-5%), light (6-60%) and heavy (61%+) beneath five overstory classes defined as percentage coniferous and deciduous canopy (100% deciduous, 90-10% deciduous-coniferous, 80-20% deciduous-coniferous, 70-30% deciduous-coniferous, and 60-40% deciduous-coniferous). A GIS-based polygon map showing these classes over the area was generated through a combination of aerial photointerpretation and field work in 1992. This map was imported as a vector, converted to a raster bitmap, and overlayed onto the TM imagery to generate image statistics.

Discrimination of the original class structure using 71 field-checked locations revealed 74% classification accuracy based on the leaf-off and leaf-on TM spectral data. The limited sample used to generate the spectral basis for this separability, however, would not be appropriate for large area classification because of the patchy nature of the understory, and the variability in overstory stand structure, would preclude signature extension without more field observations. An alternative, more useful class structure *for mapping purposes* was devised based on a combination of clustering, interpretation of spectral separability statistics, and supervised and unsupervised image classifications. The final class scheme consisted of six classes (up to 100% deciduous and up to 10%

coniferous overstory with heavy, light or nil understory, and up to 80% deciduous and up to 30% coniferous overstory with heavy, light or nil understory).

The supervised classification maps, based on signatures generated within the GIS polygons, did not appear to represent the understory classes with sufficient accuracy. This interpretation was based on very poor separability measured by the B-distance statistic, and the knowledge that the patchy nature of the understory was not adequately captured in the original understory mapping using the aerial photographs. The unsupervised classification confirmed the separation of heavy and nil understory beneath various canopy structures, but revealed significant error with the light understory class which appeared too broadly defined.

A *modified supervised classification approach* based on the intersection of the unsupervised classes with the original GIS polygons was used to generate new training areas. Signatures from these new training areas had 10-15% greater separability than those generated using the entire GIS polygon area for a given overstory/understory class. Greater statistical separability is a predictor of potential improvements in map accuracy. *Actual* improvements in map accuracy, and the absolute degree of accuracy achieved in the mapping portion of this study, await the collection of more detailed field observations in the summer of 1995 which will be reported in a future communication. Additional work is planned on spectral texture analysis to account for the patchy nature of the understory within stands, and on the influence of crown closure on spectral separability and class boundaries.

This report includes a discussion of the project, and a detailed summary of the three earlier formal submissions:

Ghitter, G. S., Hall, R. J., Franklin, S. E., Variability of Landsat Thematic Mapper Data in Boreal Deciduous and Mixedwood Stands With Conifer Understory, *International Journal of Remote Sensing*, accepted December 1994, in press.

Franklin, S. E., Hall, R. J., Ghitter, G. S., Satellite Remote Sensing of White Spruce Understory in Deciduous and Mixedwood Stands, *Proc. RT/Decision 2000 Symposium*, Toronto, Ontario, September 1994, pp. 239-247.

Ghitter, G. S., Hall, R. J., Franklin, S. E., 1995, Indentifying Class Structure of White Spruce Understory Beneath Deciduous or Mixedwood Stands for Improved Classification Results, *Proc. 17th Canadian Symposium on Remote Sensing*, Saskatoon, Sask., June 1995, 643-649.

Each of these submissions is also reproduced in a set of three separate Appendices. In addition, the main body of the report contains a summary of the *MSc thesis* by Mr Geoff Ghitter (A Modifed Supervised Classification Approach for Mapping Coniferous Understory in the Boreal Mixedwood Forest of Northern Alberta, Unpubl. MSc Thesis, University of Calgary, June 1995). The original contract specifications and three flow charts outlining the methodology are included as Appendices.

TABLE OF CONTENTS

Appendix 5

Satellite Remote Sensing of White Spruce Understory in Deciduous and Mixedwood Stands, *Proc. RT/Decision 2000 Symposium*, Toronto, Ontario, September 1994, pp.239-247.

Appendix 6

Indentifying Class Structure of White Spruce Understory Beneath Deciduous or Mixedwood Stands for Improved Classification Results, *Proc. 17th Canadian Symposium on Remote Sensing*, Saskatoon, Sask., June 1995, pp. 643-649.

1.0 Problem Definition

A current inventory problem in the Mixedwood Section of the Boreal Forest Region (Rowe 1972) is to determine the location and amount of white spruce (Picea glauca [Moench] Voss) that occurs as a conifer understory within deciduous, and predominantly deciduous mixedwood forest stands (Expert Panel on Forest Management in Alberta 1990; Peterson and Peterson 1992). Recent surveys in Alberta have reported that white spruce understory can occur in up to 80% of stands that have been inventoried as hardwood and hardwood-softwood, but current inventories do not document their amount, size, spatial location and distribution (Brace and Bella 1988).

Most forest management activities are based directly or indirectly on forest inventory information (Morgan 1991). For example, there are several recent management-oriented studies that have investigated harvesting methods for the overstory that also minimize damage to the understory (Brace 1992; Navratil et al. 1994). Inventory information about the understory component, and its protection during harvesting of the overstory, is considered important because the main source of spruce timber in boreal mixedwoods, 60 to 80 years hence, will be those that developed under the protection of hardwoods (Brace 1992). Knowledge of the conifer understory is also used to determine the conifer land base and to calculate the annual allowable cut (Morgan 1991). Thus, a method to identify the potential locations and amounts of understory stands becomes an important component of the processes involved in achieving mixedwood management goals (Navratil et al. 1994).

1.1 Understory Mapping and Classification

Current efforts to map softwood understory in the boreal mixedwoods 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. An additional problem in devising a classification system for mapping understory, is that understory 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). This complexity has partially explained why there is, at present, no standard provincial classification system for the mapping of conifer understory stands. Since the ultimate destination of any conifer understory inventory is a digital Geographic

Information System (GIS) database, the output of a conifer understory classification system should also be a digital map. A satellite remote sensing approach may be appropriate for this application due to its synoptic coverage of large areas, and the relative ease by which the digital-to-digital transfer of classified data to a GIS can be undertaken. Thus, one of the problems that this study undertook, was to define a conifer understory classification system that would have informational value in defining the land base, and be appropriate for use with satellite remote sensing data.

There have been relatively few remote sensing studies that have attempted to map conifer understory directly (Stenback and Congalton, 1990). The understory, however, can contribute significantly to spectral response patterns in remote sensing studies of open canopies. Spanner et al. (1990) for example, reported an increase in reflectance from open conifer stands with a well-developed deciduous understory. Fiorella and Ripple (1993) employed Landsat Thematic Mapper (Landsat TM) data to identify successional stages in regenerating conifer stands when the relationship between understory (herb and shrub cover) and reflectance was strong in young, open stands. Maps of insect defoliation in Newfoundland contained errors because of understory reflectance (Luther et al. 1991), since an increase in reflectance occurred over areas where the canopy was reduced in density following defoliation. Stenback and Congalton (1990) quantified the spectral effect of understory presence or absence in the Sierran mixed conifer zone for three canopy classes (sparse, moderate, dense).

In central Alberta, Kneppeck and Ahern (1990) analyzed Landsat TM images during leaf-off (fall) and leaf-on (summer) conditions. They suggested that leaf-off/leaf-on image dates could be used to map overstory conditions and understory vegetation in the boreal mixedwood zone, but that methods must be optimized before the technique could be considered for application on an operational basis. The foundation of their classification was the use of the leaf-on images 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 were not addressed in their study, nor was the applicability of their approach for mapping large areas evaluated. Thus, a study designed to assess the detectability of conifer understory over a range of overstory species compositions, would further evaluate the utility of Landsat TM data for this application. The goal of this study was to determine the extent to which multidate Landsat Thematic Mapper (TM) data could be used for mapping softwood understory.

This goal was met by pursuing two specific objectives under contract (Appendix 1) that included:

i) determining and evaluating classification schemes for detecting and mapping conifer understory within deciduous and mixedwood stands (Appendix 2); and

ii) devising a satellite-based methodology for mapping understory stands and illustrating the level of map classification accuracy that can be achieved using several combinations of one and two-date (leaf off, leaf on), Landsat TM data (Appendix 3).

2.0 Study Methodology

2.1 Study Area

The study area consists of four townships (about 625 square km) in north-central Alberta. This area is within 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 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), which describe cover types by moisture regime, crown closure, stand height, species composition, and origin.

2.2 Understory Classification System and Understory Map

Based on a cooperative effort between Daishowa-Marubeni, The Forestry Corp. (Formerly with W.R. Dempster & Associates), Alberta Environmental Protection, and the Canadian Forest Service, the structure of an understory classification system was created (Appendix 4: Table 1). A conifer understory map was subsequently produced and input to a Geographic Information System (GIS), to provide the basis for image training and development of class signatures, and calculation of separability measures. In creating this map, considerations for overstory stand structure were required because there are major differences between spruce-dominated and aspen-dominated stands (Peterson and Peterson 1992). The overstory information was derived from the Alberta Vegetation Inventory (AVI) map supplied by the forest company that holds the timber lease for the study area. The discrimination between light and heavy understory was based on a threshold of 60% crown closure in the understory interpreted on 1:10,000 and 1:20 000 scale color and black-and-white infrared leaf-off metric aerial photographs, respectively, taken during the early spring following snow melt to permit maximum penetration into the stand. 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.

These considerations resulted in an initial classification system (Appendix 4: Table 1) whereby conifer understory stands were mapped to three levels (heavy, light, nil) beneath five overstory stand structures that ranged from pure deciduous (100% deciduous) to a 60%-40% deciduous-conifer mixedwood composition. 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 to generate class signatures. A subset of the classes described in Appendix 4: Table 1 is presented in Appendix 3: Figure 1.

2.3 Methods to Determine Class Structure, Separability, and Potential Classification Accuracy

The first goal of this study was to develop a classification scheme that may correspond to naturally occurring class structures, and which could be tested for separability using the remote sensing data. For example, the understory classification system with 14 classes was unlikely to be suitable for large area mapping, because the 10% increments in conifer overstory did not generate a significantly different spectral response that can be discriminated using the available satellite images. Therefore, all possible combinations of merging the overstory classes with two or three understory combinations were examined together with the original class schema. These original and merged classes were tested for accuracy using a variety of bandsets, including the leaf–off/leaf–on data separately, and then combined. These tests yielded a relative indication of the mapping potential of the Landsat TM data for the conifer understory within overstory classes. Each bandset was evaluated using discriminant analysis at the 71 field sites. Associated separability measures were generated initially using the signatures generated from the GIS polygon overlay bitmaps, and then later using signatures derived from a modified supervised classification approach.

First, a pixel sampling program (Franklin et al., 1991) was employed to arrange the Landsat TM data for each of the 71 field sites that were used to field–check the aerial photointerpretation into an attribute table. This table was sorted into training and test samples for subsequent analysis and classification using discriminant functions. The discriminant procedure combines the variables into linear combinations which maximize inter–class distinctiveness. Second, Bhattacharyya distance (Haralick and Fu, 1983) was computed as a measure of statistical separability between pairs of spectral signatures. Bhattacharyya or B–distance is a measure of the probability of correct classification (Mather 1987; Leckie and Ostaff, 1988). Interpretation of the Bhattacharyya distance is straightforward: If 0 < B–distance < 1.0 then the data demonstrate very poor separability, if 1 < B–distance < 1.9 there is poor separability, and if 1.9 < B–distance < 2.0 there is good separability (PCI Inc., 1993). Separability was computed for training areas derived from the original GIS polygon overlays and the merged class bitmaps.

2.4 Unsupervised Classification and Mapping

The ISODATA unsupervised clustering algorithm was used to generate a map of the spectral classes for comparison to the GIS polygon understory map. 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. More complex tests - which isolate the effect of different band combinations and algorithm parameters - were not devised for this study, but could be examined in follow-on work to determine if there could be improvements in definition of the spectral classes.

2.5 Modified Supervised Classification (Intersection Method)

The ISODATA unsupervised classification map was combined with the GIS polygon understory map using a logical 'AND' function to create a new image map that contains the intersection of every ISODATA cluster with the corresponding understory polygons. Nine tests of this intersection approach were conducted using various unsupervised classifications and different original or merged GIS polygons. The results when using an unsupervised classification based on an initial cluster standard deviation of 12 intersected with the four–class scheme are summarized in this report.

Following the map intersections, each ISODATA cluster was ranked in descending order according to the percentage of pixels overlapping with each overlay class. ISODATA clusters accounting for a minimum of 70% of the overlap were thresholded to create bitmaps from which new signatures for a maximum likelihood classification could be created. For example, the intersection of ISODATA clusters 7, 4, 5 and 8 accounted for 71.3% of the overlap with Class 1, and was used to create a new signature. It was hypothesized that signatures created using this approach would more adequately describe their spectral variation while maintaining the basic character of the original GIS polygons.

3.0 Results

3.1 Discrimination of Field Sites

Appendix 4: Table 5 contains the classification accuracies based on the discriminant analysis in each of the original and merged classification schemes using the full TM image band set and the reduced band set (three bands suggested by Kneppeck and Ahern, 1990). The tests were based on the spectral values located at the 71 field sites used to develop the field descriptions of the understory and overstory stands.

The overstory stands were more accurately defined using the leaf–on image and the understory stands were better defined using the leaf–off image, but more accurate results were obtained from a combination of leaf–off and leaf–on data. For example, the full 14–class scheme showed 53% classification accuracy with the Landsat TM leaf–off image, and 47% classification accuracy using the Landsat TM leaf–on image. This increased to 74% classification accuracy when the image data were combined in the discriminant function. When fewer classes were considered in the merging procedure, the overstory conditions appeared to dominate and were slightly better defined using the leaf–on image data. In schema with relatively more classes, the leaf–off data produced higher accuracies since the classes were more dependent on differences in understory. Separability and discrimination results were highest when adjacent classes were combined using the full bandset (Appendix 4: Table 6).

3.2 Spectral Separability of the Original Class Schema Using the GIS Polygons to Generate Signatures

Class separabilities based on B-distance were interpreted following the generation of signatures in training areas based on the original GIS polygons. The highest class separabilities were achieved using the two–date Landsat images for the fourteen classes (Appendix 5: Table 2). Single–date imagery performed poorly relative to the combined image data. There was a decrease in separability in the leaf–on TM data set, illustrating that the leaf–off data set was sensitive to the understory because the overstory stands in the leaf–on data set partially masked the spectral responses from the understory.

Appendix 5: 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 original GIS polygons mapped using aerial photography. Overall, there was poor separability based on B–distance < 1.0 in all cases. Classes 3, 9 and 13 were the most separable and could 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 was 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) was most separable from the classes without an understory (classes 3, 6, 9 and 12). The least separable classes were 2, 4, 5, 7 and 11. Heavy understory was more separable from nil understory classes than from light understory. Light understory classes were confused primarily with heavy understory classes.

Some confusion in the overstory structures associated with mixedwood canopies could be expected, but these results indicated that the GIS polygons could not be used to generate signatures for use in a classification.

3.3 Unsupervised Classification (ISODATA Clusters)

The results when using an unsupervised classification (ISODATA algorithm) with an initial cluster standard deviation of 12 are presented in the form of a contingency table (Appendix 5: Table 3). Heavy understory in all overstory classes was mapped primarily in spectral clusters 1 and 2. The majority of light understory pixels in all overstory classes occurred in spectral clusters 2 and 3. There was some overlap between the light and the nil understory, which was mapped into clusters 3 and 4. The patterns suggested that there was confusion in spectral cluster 2 between heavy and light understory, and confusion in spectral cluster 3 between light and nil understory.

The pure deciduous overstory was separable from the 60–40% deciduous—coniferous overstory. For example, 62% of the pixels under the 60–40% deciduous—coniferous heavy understory bitmap were 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 appeared to indicate that these overstory structures were spectrally indistinguishable. Merging these overstory and understory compositions would result in higher mapping accuracy. This step is consistent with that reported by Stenback and Congalton (1990) in the Sierran mixed–conifer zone; they achieved 69% classification accuracy in the detection of three overstory canopy closure classes and understory presence or absence.

3.4 Accuracy of Integration—Classification Maps

The sparseness of the field observations precluded using standard remote sensing accuracy assessment techniques based on confusion matrices and the Kappa statistic (Congalton, 1991). However, comparison of visual output products, and training area separability, can provide critical insight into resulting map accuracy and utility.

Appendix 6: Table 4 shows the B–distances associated with the class signatures generated by training the classifier using the *modified supervised* approach. Average separability for this test was 1.52, significantly higher than the test for the same classes based on the signatures generated by the GIS polygon overlays alone (Appendix 6: Table 3). Significant confusion was evident between classes 1 and 2; classes with heavy understory but with different canopy mixtures, and classes 3 and 4, classes with nil understory and different canopy mixtures. Separability was very high between all classes with heavy or nil understory, indicating that the maximum likelihood classification routine was sensitive to understory components regardless of overstory mix. The rise in sensitivity can be attributed directly to the new signatures created by the modified method.

Visual inspection of the classification output (see Appendix 3) can provide qualitative evidence of the potential for increased map accuracy when comparing the original supervised classification maps (which use the GIS polygons as training areas) with the modified supervised classification maps (which use the intersection of the GIS polygons and the unsupervised classes as training areas). Classes generated from the modified supervised method appeared to match the spatial occurrence exhibited in the original polygon overlays quite closely. In addition, those classes tended to have well–defined boundaries with decreased 'speckle' which may be associated with confusion among similar classes.

4.0 Discussion

4.1 Synthesis

The underlying themes in this study relate to the problem of identifying a useful class structure for mapping conifer understory, and the related issue of the separability of spectral classes. Which comes first? The classes, or the fact that they can be mapped using satellite remote sensing? Obviously, the *need* to map certain classes precedes the *ability* to do so using any particular technology. However, the benefits of a large-scale satellite remote sensing approach to mapping forest structure - including locating and estimating the amounts of understory conifers - must be explored (Appendix 1).

The understory classes are by nature, unevenly distributed over the landscape, because the overstory structures are complex mixtures of species and density. In mapping these phenomena using aerial photointerpretation, some degree of generalization and spatial averaging occurs, and this blurs the boundary of any class structure. Representing such heterogenous GIS polygons with high spatial resolution remote sensing signatures that are based on the mean and variance within the polygon area, will result in low spectral separability. These natural variations will be identifed by more than one spectral class within a mapped GIS understory polygon.

A supervised classification approach requires 'relatively' pure samples of training pixels in an exhaustive, mutually exclusive classification structure. An unsupervised classification approach requires that no pre-conceived notion of class structure exists. In this study those approaches represent extreme positions that were modified to ensure a successful map could be produced. Thus, a modified supervised classification approach which combined the best features of each technique was devised; the unsupervised clusters were ‘merged’ with the original GIS polygons to generate areas for training pixel extraction that were relatively pure and representative of the overlapping and broad classes in the final mapping scheme.

4.2 Considerations to Photointerpretation and Understory Mapping

There are cartographic limits that result in a concept of minimum polygon size at a given map scale that may not adequately represent the uneven spatial distribution of conifer understory over the landscape. At any map scale, the smallest stand that would usually be interpreted and mapped ranges from 0.5 to 1 cm^2, and this represents 2 to 4 hectares on a 1:20,000 scale map. This area on a geometrically-corrected, resampled Landsat TM image with an effective pixel size of 25 m, would range from 32 to 64 pixels. The results obtained with this study has shown mixed classes within the understory map polygon. This suggests that the digital Landsat image map may provide a finer level of stratification than what has been interpreted from aerial photographs. An accuracy assessment, however, has not been possible because the understory map was broader in detail than what the classified image appears to be showing. Thus, additional point sampling with differential GPS is suggested so that a contingency table could be constructed and an accuracy analysis undertaken.

5.0 Conclusions and Recommendations

5.1 Summary

The discrimination and separability results indicated that the overstory structures were not spectally distinguishable in 10% increments of conifer composition. A more reasonable spectral discrimination was made between stands containing more or less than about 20% conifer in the overstory. The leaf-off/leaf-on data set was superior to either data set alone. Reducing the number of bands arbitrarily did not generate better classification results. And, the merging of adjacent overstory classes provided maximum accuracies on the order of 80%. However, the field sample was too small and biased in certain classes to yield a confident predictor of mapping accuracy.

The supervised classification procedures revealed that areas of understory mapped from colour aerial photographs had poor overall separability because the understory is often unevenly distributed within overstory stands, and mapped polygons are often averaged during photointerpretation to a much higher degree than can be represented with high spatial resolution satellite data. Based on the unsupervised classification tests, the understory appeared distinct in at least two classes (presence or absence) within each overstory class. Additional work on separating overstory compositions might be based on crown closure (to refine class structure) and image texture processing (to account for spatial variability in reflectance).

An intersection technique based on a remote sensing - GIS integration has shown potential for mapping conifer understory in deciduous and mixedwood stands. Spectral class signatures generated by training on areas of intersection between unsupervised clusters and GIS polygon overlays had 10-15% greater average separability than the signatures generated by training on the GIS polygon overlay alone. The intersection of these unsupervised classes and the mapped polygons can overcome the natural variability within these polygons caused by the uneven distribution of understory, the complex overstory structures, and the degree of spatial averaging (or the minimum mapping unit) used in construction of the GIS map by aerial photointerpretation.

5.2 Potential Application Scenario

The premise of this study was to determine the extent to which leaf-off/leaf-on Landsat TM data could be used to identify and map the extent of understory stands, as a tool in defining conifer land base. Over the 2-year period during which this study was undertaken, a newly defined information need by Daishowa was created, and the mere identification and location of potential understory stands, in themselves, became insufficient. Thus, the original objective as defined by Daishowa-Marubeni, had been changed in response to the interests for a more ecosystem-based approach to forest management. The current information need by Daishowa-Marubeni is to produce an understory map as an independent layer in the GIS, and to place an AVI label for each understory stand. To meet this information need will entail photointerpretation of leaf-off photographs, ground verification and sampling, transfer to a map base, digitization and database creation. Though this process is expensive, the funding for this program has been proposed to FRIP. Because the remote sensing approach based on satellite data does identify potential locations of understory stands based on an overstory and understory classification, but without an AVI descriptor label, the merging of the image classification with photo interpretation as a process, merits investigation.

A brief overview of the possible procedures to implement this application includes:

1. Undertake an image classification for understory.
2. Undertake post-classification filtering.
3. Export the classification as a raster to the Arc/Info GIS such as to ArcGrid.
4. Run GRIDPOLY to convert the raster to a vector polygon coverage.
5. Produce a plot onto an acetate and overlay the acetate onto the air photo.
6. Have an AVI photo interpreter place an AVI label for each understory stand.

Subsequent stems/ha information, if needed, would be obtained from ground surveys. This process would permit the interpreter to check the image classification to address omissions and commissions, and to assign an AVI label to classified polygons. The GIS exercise simplifies to a database creation exercise by entering the AVI attributes, thus saving the cost of photointerpretation transfer to a map and manual digitization. To be cost-effective, however, the cost of image data acquisition and analysis must more than offset the cost of polygon delineation by the interpreter, its subsequent transfer to the map base and the digitization process.

5.3 Recommendations

This study has shown that digital Landsat TM leaf-off/leaf-on data can be used to map several combinations of overstory and understory conditions in boreal mixedwood and deciduous stands in Alberta. The maps produced through the modified supervised classification approach compare well to the original GIS polygon map and to the qualitative knowledge of the distribution of stand structures in the area acquired during the study. Additional efforts in quantitative accuracy assessment, identification of class structures, and satellite image processing are needed to develop the operational aspects of the understory mapping evaluation which was initiated in this report.

Future work should include plans to acquire the additional field data to conduct independent accuracy assessments of the classified understory map. Additional work on refining the class structures (crown closure, more understory classes, etc.) will depend on careful design of the data acquisition and stand selections for field sampling and the direction of future image processing work. The application scenario described in section 5.2 should be pursued in order to assess the operational utility. Image texture analysis has been shown to provide a powerful method to account for spatially varying phenomena in forested environments (Franklin and McDermid, 1993; Peddle and Franklin, 1991). In this study, texture could account for complexity in overstory structures and the uneven distribution of understory within the GIS polygons.

A large-scale texture analysis may lead ultimately to a small-scale understanding of the distribution of reflecting surfaces. A subpixel analysis of fractional reflectance patterns based on mixture models driven by surface observations of endmember spectra (crown, background, understory, shadow, etc.) could potentially be used to predict understory abundance. The problem of mapping conifer understory in leaf-off imagery may be more suited to a mixture-modelling solution where the emphasis is not on the detection of the understory, but in an estimation of the understory proportion within image pixels.

6.0 Summary of Major Presentations and Reports

March 1994 (submitted), December 1994 (accepted), March 1995 (revised): Variability of Landsat Thematic Mapper Data in Boreal Deciduous and Mixedwood Stands With Conifer Understory, International Journal of Remote Sensing.

September 1994: Satellite Remote Sensing of White Spruce Understory in Deciduous and Mixedwood Stands, RT/Decision Support 2001, Toronto, pp. 239-247.

December 1994: Evaluation of Classification Approaches to Conifer Understory Mapping, Progress Report, Edmonton.

June 1995: Identifying Class Structure of White Spruce Understory Beneath Deciduous or Mixedwood Stands for Improved Classification Results, 17th Canadian Symposium on Remote Sensing, Saskatoon, pp. 643-649.

June 1995: A Modified Supervised Classification Approach for Mapping Coniferous Understory in the Boreal Mixedwood Forest of Northern Alberta, MSc Thesis, Department of Geography, The University of Calgary.

7.0 References

Brace, L.G. 1992. Protecting white spruce understories when harvesting aspen. Can. For. Serv., North. For. Cent. Edmonton, Alberta. Unpublished Progress Report.

Brace, L.G., and Bella, I.E. 1988. Understanding the understory: dilemma and opportunity. pp. 69-86, in J.K. Samoil (ed.)., Management and utilization of northern hardwoods, Can. For. Serv., North. For. Cen., Info. Rep. NOR-X-296. Edmonton, AB.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing Environ. 37: 35-46.

Expert Panel on Forest Management in Alberta. 1990. Forest Management in Alberta: report of the expert review panel. Alberta Energy, Forests, Lands and Wildlife, Edmonton, Alberta.

Fiorella, M., and Ripple, W. J. 1993. Analysis of conifer forest regeneration using Landsat Thematic Mapper data. Photogrammetric Engineering and Remote Sensing, 59, 1383-1388.

Franklin, S. E., and McDermid, G. J. 1993. Empirical relations between digital SPOT HRV and CASI spectral response and lodgepole pine (Pinus contorta) forest stand parameters. Int. J. Remote Sensing, 14, 2331-2348.

Franklin, S. E., Peddle, D. R., Wilson, B. A., and Blodgett, C. F. 1991. Pixel sampling of remotely-sensed digital image data. Computers & Geosciences, 17, 759-775.

Haralick, R. N., and Fu, K. S. 1983. Pattern recognition and classification, in Manual of Remote Sensing, Robert N. Colwell (ed.), (Falls Church, VA.: American Society for Photogrammetry and Remote Sensing), pp. 793-804.

Kneppeck, I., and Ahern, F.J. 1990. Summary Report on the Alberta Conifer Landbase. Canada Centre for Remote Sensing, Ottawa Ont., unpublished.

Leckie, D.G., and Ostaff, D.P. 1988. Classification of airborne multispectral scanner data for mapping current defoliation caused by the spruce budworm. For Sci. 34(2): 259-275.

Luther, J. E., Franklin, S. E., and Hudak, J. 1991. Satellite remote sensing of current year defoliation by forest pests in western Newfoundland. Proc., 14th Canadian Symposium on Remote Sensing, (Calgary, Alberta: Canadian Remote Sensing Society), pp. 192-198.

Mather, P. 1987. Computer processing of remotely sensed images, (London: Wiley).

Morgan, D.J. 1991. Aspen inventory: problems and challenges. pp. 33-38, in S. Navatril and P. B. Chapman (eds.), Proceedings, Aspen management in the 21st century, North. For. Cen. and Poplar Council of Canada, Edmonton, AB.

Navratil, S., Brace, L.G., Sauder, E.A., and Lux, S. 1994. Silvicultural and harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwoods. Nat. Res. Can., Can. For. Serv., Northwest Region, Edmonton, Alta. Inf. Rep. NOR-X-337.

PCI Inc. 1993. EASI/PACE Image Analysis System Manuals, Vers. 5.3, Richmond Hill, Ontario, variously paged.

Peddle, D.R., and Franklin, S.E. 1991. Image texture processing and ancillary data integration for surface pattern discrimination. Photogrammetric Engineering and Remote Sensing, vol. 57, pp. 413-420.

Peterson, E.B., and Peterson, N.M. 1992. Ecology, management, and use of aspen and balsam poplar in the prairie provinces. Can. For. Serv., North. For. Cen., Northwest Region Special Report 1, Edmonton, AB.

Resource Information Division. 1991. Alberta Vegetation Inventory Standards Manual. Version 2.1, Alberta Forestry, Lands and Wildlife, Resource Information Division, Edmonton, AB.

Rowe, J. S., 1972. Forest Regions of Canada. Environ. Can., Can. For. Serv., Ottawa, ON. Publication No. 1300.

Spanner, M. A., Pierce, L.L., Peterson, D. L., and Running, S. W. 1990. Remote sensing of temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation, and background reflectance. International Journal of Remote Sensing, 11, 95-111.

Stenback, J.M., and Congalton, R.G. 1990. Using Thematic Mapper imagery to examine forest understory. Photogrammetric Engineering and Remote Sensing, vol. 56, pp. 1285-1290.

APPENDIX 1

ORIGINAL CONTRACT SPECIFICATIONS

Supply and Services Canada / Approvisionnements et Services Canada

ALBERTA/NORTHWEST TERRITORIES REGION
10704 - 102 AVENUE
EDMONTON, ALBERTA
T5J 4H9

FAX NUMBER (403) 495-2601

CONTRACT - CONTRAT

SSC file No. - N° de référence d'ASC: XSG93-00110-(610)

Date of Contract - Date du contrat: 18 Aug 1993

Contract No. - N° du contrat: 4Y080-3-0503/01-XSG

Requisition No. - N° de la demande:

Order office / Bureau demandeur	Yr / An	Serial No. / N° de série
4Y080	3	0503

Financial Code(s) - Code(s) financier(s): 8163-220-3233-8048-1907

Duty - Droits: See herein

F.O.B. - F.A.B.: Destination

Goods and Services Tax - Taxe sur les produits et services: See Herein

Destination:
FORESTRY CANADA
NORTH.FOR.RES.CTR.
5320 - 122ND.STREET
EDMONTON ALTA. T6H 3S5

Invoices - original and two copies are to be made out and sent to:
Factures - remplir et envoyer l'original et deux copies à:
FORESTRY CANADA
ADMIN.NORTH.FOR.RES.CTR.
5320 - 122ND.STREET
EDMONTON ALTA. T6H 3S5

Your proposal is accepted to sell to Her Majesty the Queen in right of Canada, in accordance with the terms and conditions set out herein, referred to herein or attached hereto, the services listed herein and on any attached sheets at the price or prices set out therefor.

Nous acceptons votre proposition de vendre à Sa Majesté la Reine du chef du Canada, aux conditions énoncées ou incluses par référence dans les présentes, et aux annexes ci-jointes, les services énumérés dans les présentes, et sur toute feuille ci-annexée, au(x) prix indiqué(s).

S.E. Franklin Consulting Inc. @1B88T
43 Sandalwood Heights, NW
Calgary, Alberta,
T3K 4B6

Address enquiries to: - Adresser toute demande de renseignements à: Elaine Barton

Area code / code régional	Telephone No. / N° de téléphone	Extension / Poste	Telex No. / N° de télex
403	495-2134		

Total est. cost - Coût total est.: $48,150.00

For the Minister / Pour le Ministre: [signature] E. Barton

Canada

DSS-MAS 9400-9 (10/90)

CONTINUATION - SUITE

Contract No. - N° du contrat: 4Y080-3-0503/01-XSG

SSC file No. - N° de référence d'ASC: XSG93-00110-(610)

TITLE: EVALUATING LANDSAT AND SPOT DIGITAL IMAGERY FOR DETECTING SOFTWOOD UNDERSTORY UNDER A HARDWOOD CANOPY

STANDARD INSTRUCTIONS AND CONDITIONS

The Standard Instructions and Conditions DSS-MAS 9403-5 (12/92) set out in the Standard Acquisition Clauses and Conditions (SACC) Manual, issued on 1 June 1991, Section 1, are hereby incorporated by reference and form part of this Contract. Submission of a bid constitutes acknowledgement that the Contractor has read and agrees to be bound by such instructions.

GENERAL CONDITIONS

The general conditions set out in DSS-MAS 9224 (12/92), as well as those conditions and clauses otherwise identified herein by number, date and title, all of which are set out in the SACC Manual, are hereby incorporated by reference, pursuant to the Department of Supply and Services Act and to the Ministerial Order dated 22 May 1991 published in the Canada Gazette.

These general conditions and clauses form part of this Contract as though expressly set out herein, and are subject to any other express terms and conditions contained herein.

The SACC Manual may be obtained from the Canada Communication Group - Publishing, telephone (819) 956-4802. Clauses and conditions referenced may also be viewed on the Open Bidding Service (OBS) electronic bulletin board.

EFFECTIVE CONTRACT COMMENCEMENT DATE

Contract to commence on September 1, 1993.

CONTRACT COMPLETION DATE

All work required under this contract is to be completed on or before March 31, 1995.

PRIORITY OF DOCUMENTS

The documents listed below form part of and are incorporated into this contract. If there is a discrepancy between the wording of one document from the wording of any other document which appears on the list, the wording of the document which first appears on the list shall prevail over the wording of any document which subsequently appears on the list:

1. these articles of agreement
2. General Conditions DSS 9224 Research

and Development
3. Statement of Work, Annex "A"
4. Schedule of Payments, Annex "B"
4. Disclosure Certification, Annex "C"
5. The Technical portion of the Contractor's proposal dated August 5, 1993.

SCIENTIFIC AUTHORITY

Ron Hall
Northern Forestry Centre
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

TELEPHONE: (403) 435-7210
FACSIMILE: (403) 435-7359

The Scientific Authority is responsible for all matters concerning the scientific and technological content of the Work under this Contract. Any proposed changes to the Scope of the Work are to be discussed with the Scientific Authority, but any resultant changes may be authorized only by a contract amendment issued by the Science Contracting Officer.

SCIENCE CONTRACTING OFFICER

Elaine Barton
Science and Professional Services
Alberta/NWT Region
Supply and Services Canada
10704 - 102 Avenue,
Edmonton, Alberta T5J 4H9

TELEPHONE: (403) 495-3704
FACSIMILE: (403) 495-3399

The Science Contracting Officer named above is responsible for the management of this Contract and any changes to the Contract must be authorized by a formal contract amendment issued by that Officer. The Contractor is not to perform work in excess of or outside the scope of this Contract based on verbal or written requests or instructions from any government personnel other than the aforementioned Officer.

STATEMENT OF WORK

The Contractor shall perform the Work as outlined in the Statement of Work attached hereto as Annex "A" and in accordance with the technical portion of the Contractor's proposal dated August 5, 1993 and forming part of this Contract.

DELIVERABLES

The Contractor shall deliver the items as listed in the Statement of Work, to the Scientific Authority, in accordance with the schedule in the Contractor's proposal.

The Contractor shall notify the Science Contracting Officer, in writing, once these items have been delivered.

DISCLOSURES CERTIFICATION

On completion of the Work under this Contract, the Contractor shall submit a certification to the Scientific Authority and to the Science Contracting Officer stating that all applicable disclosures were submitted or that there were no disclosures to submit under section 14 of General Conditions - Research and Development, DSS-MAS 9224.

A copy of a Disclosures Certification is attached as Annex "C".

INSPECTION/ACCEPTANCE

All the work performed under this contract shall be subject to inspection by the Scientific Authority, designated herein, prior to acceptance. Should the work or any portion thereof not be in accordance with the requirements of the contract, the Scientific Authority shall have the right to reject it or require its correction.

BASIS OF PAYMENT - FIRM PRICE

In consideration of the Contractor satisfactorily completing all of its obligations under this Contract, the Contractor shall be paid a firm price of $45,000.00, GST extra. Payment will be made in accordance with the Schedule of Payments, attached as Annex "B". Payments will be subject to a 10% holdback. No increase in the total liability of Canada or in the price of the Work or Services resulting from any design changes, modifications or interpretations of the specifications, will be authorized or paid to the Contractor unless such design changes, modifications or interpretations shall have been approved by the Minister prior to their incorporation in the Work or Services.

GOODS AND SERVICES TAX

The goods and services tax (GST) is not included in the amounts shown in the Basis of Payment clause and the Schedule of Payment. The GST which is estimated at $3,150.00, is included in the Total Estimated Cost shown on page 1 of this Contract. The GST, to the extent applicable, is to be shown separately on all invoices and claims for progress payments and will be paid by Canada. The Contractor agrees to remit to Revenue Canada - Customs and Excise any GST that the Contractor receives from Canada pursuant to this Contract.

METHOD OF PAYMENT

1. Payments will be made in accordance with the Schedule of Payments attached as Annex "B", provided that:

(a) the Contractor submits an original and two (2) copies of its invoice to the Scientific Authority;

(b) such invoices will show the amount currently claimed, the holdback of 10 percent, the total amount of the previous invoices and cumulative total to date;

(c) such invoices will show the Contract Number and Financial Codes as given on Page 1 of the Contract;

CONTINUATION - SUITE

Contract No. - N° du contrat: 4Y080-3-0503/01-XSG

SSC file No. - N° de référence d'ASC: XSG93-00110-(610)

(d) all reports/deliverables required for the milestone claimed have been received and accepted by the Scientific Authority;

(e) the invoice is approved.

2. The balance owing will be paid to the Contractor, subject to:

(a) completion and acceptance of the Work;

(b) the submission of all deliverable items to the Scientific Authority;

(c) the approval of the final invoice by the Scientific Authority.

3. Payment by Canada to the Contractor for the Work shall be made:

(a) in the case of a milestone payment other than the final payment, within thirty (30) days following the date of receipt of a duly completed Contractor's invoice; or

(b) in the case of a final payment, within thirty (30) days following the date of receipt of a duly completed Contractor's invoice or within thirty (30) days following the date on which the work is completed, whichever date is the later;

(c) if Canada has any objection to the form of the invoice, within fifteen (15) days of its receipt, Canada shall notify the Contractor of the nature of the objection. "Form of the invoice" means a invoice which contains or is accompanied by such substantiating documentation as Canada requires. Failure by Canada to act within fifteen (15) days will only result in the date specified in subparagraphs 3 (a) and (b) of this clause applying for the sole purpose of calculating interest on overdue accounts.

H3008C 01/06/91
CONDITIONS PRECEDENT TO PAYMENT

H0001D 01/12/92
INTEREST ON OVERDUE ACCOUNTS

A9018C 01/06/91
STATUS OF CONTRACTOR

K0017C 01/06/91
GENERAL CONDITIONS, DSS-MAS 9224

K2200D 01/04/92
CONFLICT OF INTEREST

K2100D 11/12/91
SOUTH AFRICAN/HAITIAN CONDITIONS

C0101D 01/06/91
DISCRETIONARY AUDIT

TITLE: Evaluating Landsat and SPOT Digital Imagery for Detecting Softwood Understorey under a Hardwood Canopy

1.0 Background

A current problem in mixedwood management is to ascertain the spatial distribution and presence of conifer understory to assist management of the land base. Previous studies have suggested as much as 80% of stands previously inventoried as hardwood or mixedwood contain significant amounts of softwood, and particularly, white spruce understory. Two major studies; the expert review panel on "Forest management in Alberta" (1990), and "Ecology, management and use of aspen and balsam poplar in the prairie provinces" (1992) have recommended efforts to enhance current inventory programs to locate and estimate the amounts of understory conifers. Current efforts to meet this need involves interpretation of leaf-off aerial photographs and field surveys. This approach can be expensive and time-consuming to undertake.

The proposed approach is a stratification of the forest landscape for candidate deciduous stands with a softwood understory. By producing a product from an image classification, an image map could be readily transferred to a GIS as a data layer and incorporated into an inventory database. If the product was produced from manually interpreting an image enhancement (much like air photo interpretation), then the map would need to be digitized into the GIS. Since the magnitude of the problem in Alberta is over large areas, Landsat TM or SPOT data may be suitable for this application. The intended product from this study is a methodology suitable for enhancing/updating current inventories, on the location and amount of immature softwood understories in deciduous and mixedwood stands for management planning purposes.

To attain the highest possible classification accuracy will require a combination of spectral decision rules augmented with textural variables and modelling results that are part of the low resolution approach to satellite imagery. In low resolution data, the objects are smaller than the pixel size, and the pixels are composed of collections of discrete, spectrally dissimilar objects. In the understorey project, every pixel to be classified will be subjected to both large window variability and within-pixel analysis. Using spectral signatures, the pixels can be modelled as mixtures of objects. Any unknown pixel can be placed into one or more classes based on additive combinations of object spectral signatures. Such data are also suitable for window-based spatial processing and image semivariance analysis. Classification accuracies without such processing may not exceed 75% correct but previous research suggests improvements to at least 85% correct are possible through the combination of spectral, spatial and mixture modelling classification rules.

2.0 Project Objectives

The overall objective is to evaluate the use of multidate Landsat Thematic Mapper (TM) and SPOT data for mapping softwood understory. In addition to evaluating alternative image analysis approaches, the method developed by the Canada Centre for Remote Sensing will be evaluated, and both an accuracy assessment and identification of possible sources of error will be undertaken.

1. Determine the highest accuracy possible using a combination of spectral, spatial and modelling techniques on the TM and SPOT imagery. For example, customized pixel windows for texture analysis, based on the image semivariogram, are needed to determine the optimal spatial variables for discrimination of stands composed on non-uniformly distributed objects that are smaller than the pixel size. Similarly, the actual derivatives must be tested for optimal discrimination. Depending on the date of SPOT data acquisition, the anisotrophic effects on reflectance may also need to be evaluated.

2. Develop and apply spectral mixture models to the TM and SPOT imagery to decompose the signals to constituent objects (e.g. bare soil, conifer, deciduous shrub, shadows, etc.). This will involve a field-based signature generation technique that will enable additive mixture models to be constructed and used to predict image variance.

3. Estimate the costs, time, and discuss implications of the methods and data employed on an operational basis.

3.0 Study Design and Methods

A current inventory map to Alberta Vegetation Inventory (AVI) specifications with enhancement for softwood understory has been completed as part of an inventory for Daishowa by W.R. Dempster & Associates. This data will be used as ground truth and for comparing interpretations from analyses of two-date, leaf-off, leaf-on Landsat TM and SPOT imagery with stands mapped down to 5-10 ha in size. This study will include a literature review of image processing and accuracy evaluation methods, subarea selection to test processing options, and statistical comparisons of image enhancement and classification methods. Image data acquisition will require careful consideration to timing of bud flush for leaf-off imagery. To meet the project objectives, the following questions will be addressed:

1. Can Landsat TM or SPOT data be used to identify softwood understory stands under a hardwood canopy? If so, could the satellite data also be used to indicate relative priorities for acquiring medium and large-scale, leaf-off photography? (i.e., for use on an operational basis) The answer for this question will be pursued in the first year while answers to subsequent questions are being answered. The difference between SPOT and TM classification accuracies will depend on view angle, anisotropic effects and pixel size differences. A method of normalizing SPOT data for off-nadir viewing should be developed, and tested for accuracy compared to nadir-view TM imagery. The angular signature generated through bidirectional reflectance distribution functions can be used to discriminate among spectrally similar pixels and may help to separate different density classes of understory vegetation.

2. What is the variation in softwood understory class accuracy between:

   a) interpretations made on single and two-date enhancements?

   b) parallelepiped (CCRS method) and supervised maximum likelihood (based on original bands + vegetation index) classifications?

   c) classifications that make use of spectral and spatial (textural) information derived over variable window sizes estimated with the aid of image semivariograms?

3. What is the difference in softwood understory class accuracy between Landsat TM and SPOT data? The performance of the SPOT bandset compared to the TM bandset will be determined through a sensitivity analysis which employs the NDVI statistic; and pixel size differences should be studied using semivariograms and mixture models.

4. Is there a proposed solution and what are the costs and implications associated with its implementation?

3.1 General Procedures

3.1.1 Review forestry and remote sensing literature relevant to forest understorey mapping, change detection, and forest image classification. This should also include defining/specifying likely methods of accuracy evaluation.

3.1.2 Acquire ancillary information (inventory maps (paper, digital), air photos)
Acquire satellite data from scientific authority

3.1.3 Preprocessing
- Using georeferenced data, select image subset, perform image-image registration for leaf-off / leaf-on satellite data, provide residual analysis report, conduct nearest neighbour pixel resampling.
- Perform atmospheric correction to radiometrically calibrate the data to reflectance units.
- Extract subareas for image processing and analysis corresponding to "ground-truth" areas.

3.1.4 Preliminary analysis

- Investigate enhancement approaches and analyze individual band frequency histograms that may be useful in identifying potential understorey stands. For example, the following multidate color composite may be a useful first step to identifying areas having understorey:

Leaf on - TM band 4 as RED image plane	may result in
Leaf off - TM band 4 as GREEN image plane	understorey as
Leaf on/off - TM band 3 as BLUE image plane	yellow - orange

The analysis should attempt discrimination among 3 classes of understorey:

Sparse (light)	< 250 stems/ha
Moderate	250 - 500 stems/ha
Dense	> 500 stems/ha

for 2 major stand types:

Pure overstorey			Mixed stand overstorey		
sparse	moderate	dense	sparse	moderate	dense

Approximately 30 stands of each will be identified and mapped of which 15 of each can be used for training and generating spectral statistics. The remaining 15 stands of each can be reserved for independent testing of classification results.

3.1.5 Import vectors of selected understorey stands from GIS into PCI. Create bitmaps and spectral signatures. Compile spectral separability statistics using Bhattacharrya Distance measure. Of major importance is to ascertain the separability among the 3 understorey classes (ie., are they spectrally separable?), or whether some aggregation of these classes would result in higher classification accuracies.

3.1.6 Produce a scatterplot (in hardcopy and digital graphic form ie., PCX or BMP or CGM) to support descriptive analysis of the image data set where Y-axis is average band reflectance, X-axis is image channel value from channel 1 to 7, and 3 line charts representing each of the understorey classes (sparse, moderate, dense).

3.1.7 Feature Selection Requirements

A 2-date Landsat TM dataset with an NDVI channel for each date results in 14 image channels being available for analysis. High correlation among some spectral bands results in redundant information and conditioning of the covariance matrix in PCI. A more optimal band subset should be determined for the image classifications.

3.1.8 Evaluate image classification approaches; conduct a) 2-date parallelepiped (CCRS method), b) supervised maximum likelihood classifications, and c) classifications using spectral decision rules and textural variables to address study questions. Apply post-classification filtering as needed and compute/assess classification accuracies.

3.1.9 Assess the overall importance of bidirectional reflectance patterns, view angle effects, pixel size and mixture modelling in obtaining the maximum classification accuracy for the classes of interest. This step will include the analysis of image semivariance, and the integration of ground-based field spectroradiometer signatures (to characterize mixtures).

4.0 Deliverables:

1. For Item 3.1.1: literature review report, progress report
1. For Items 3.1.3, 3.1.4: Progress report describing results of preliminary analysis written as a conference paper and supported by references, copy of PCI image database file with enhancement channels, several hardcopy images for review by ForCan, Daishowa, WR Dempster, and Alta. Environmental Protection. Sample images should include an enhancement, and an enhancement with the vectors encoded on the image with labels.
2. For Items 3.1.5, 3.1.6: Draft journal paper supported with appropriate references describing spectral separability statistics and analysis of scatterplot. The scatterplot should be in both hardcopy and digital graphic format (eg., CGM and PCX or BMP). Digital graphic slides (eg., CDR, CGM, PCX) describing the first year study that may be used for oral presentations.

3. For Items 3.1.7, 3.1.8 a,b: Completion of field spectroradiometer study for 3.1.9, draft conference or journal paper describing results of conventional image classification approaches, hardcopy and digital images showing classification results.
4. For Item 3.1.8c: Progress report, hardcopy and digital images showing results of classification approach using spectral decision rules and textural variables.
5. For Item 3.1.9: Draft final journal paper and if time permits, a paper presenting an overview of the entire project, return of image data and materials, copy of PCI digital image database complete with documentation, presentation of results to assembled forestry audience.

SCHEDULE OF PAYMENTS

Payment will be made to you in accordance with the following Payment Schedule subsequent to acceptance by the Scientific Authority of the relevant Progress Report.

Payments are to correspond to the level of effort described in the Contractor's proposal dated August 5, 1993.

PAYMENT	DETAILS	AMOUNT CLAIMED	HOLDBACK	AMOUNT DUE
1.	Following the delivery of Items 3.1.1, 3.1.3, and 3.1.4 (December 31, 1993)	$14,000.00	$1,400.00	$12,600.00
2.	Following the delivery of Items 3.1.5 & 3.1.6 (March 31, 1994)	$ 6,000.00	$ 600.00	$ 5,400.00
3.	Following the delivery of Item 3.1.7 (August 31, 1994)	$13,000.00	$1,300.00	$11,700.00
4.	Following the delivery of Item 3.1.8 (December 31, 1994)	$ 7,000.00	$ 700.00	$ 6,300.00
5.	Following the delivery of Item 3.1.9 (March 31, 1995)	$ 5,000.00	$ 500.00	$ 4,500.00
6.	Release of holdback following acceptance by the Scientific Authority of all reports/ contract deliverables (March 31, 1995)	$ -------	($4,500.00)	$ 4,500.00
	TOTAL FIRM PRICE excluding GST	**$45,000.00**	**$ --------**	**$45,000.00**

FOB Edmonton, Alberta

This document is to be completed by the Contractor and submitted to the Regional Science Contracting Officer designated in the contract document upon completion of the contract.

[ ] "We hereby certify that all applicable disclosures were submitted in compliance with General Conditions DSS 9224 (Research and Development) and in accordance with the Contract and the Regional Science Contracting Officer's instructions."

[ ] "We hereby certify that there are no disclosures to submit under the above referenced Contract, referred to in the General Conditions DSS 9224 (Research and Development)."

____
Signature

____
Print Name

____
Title

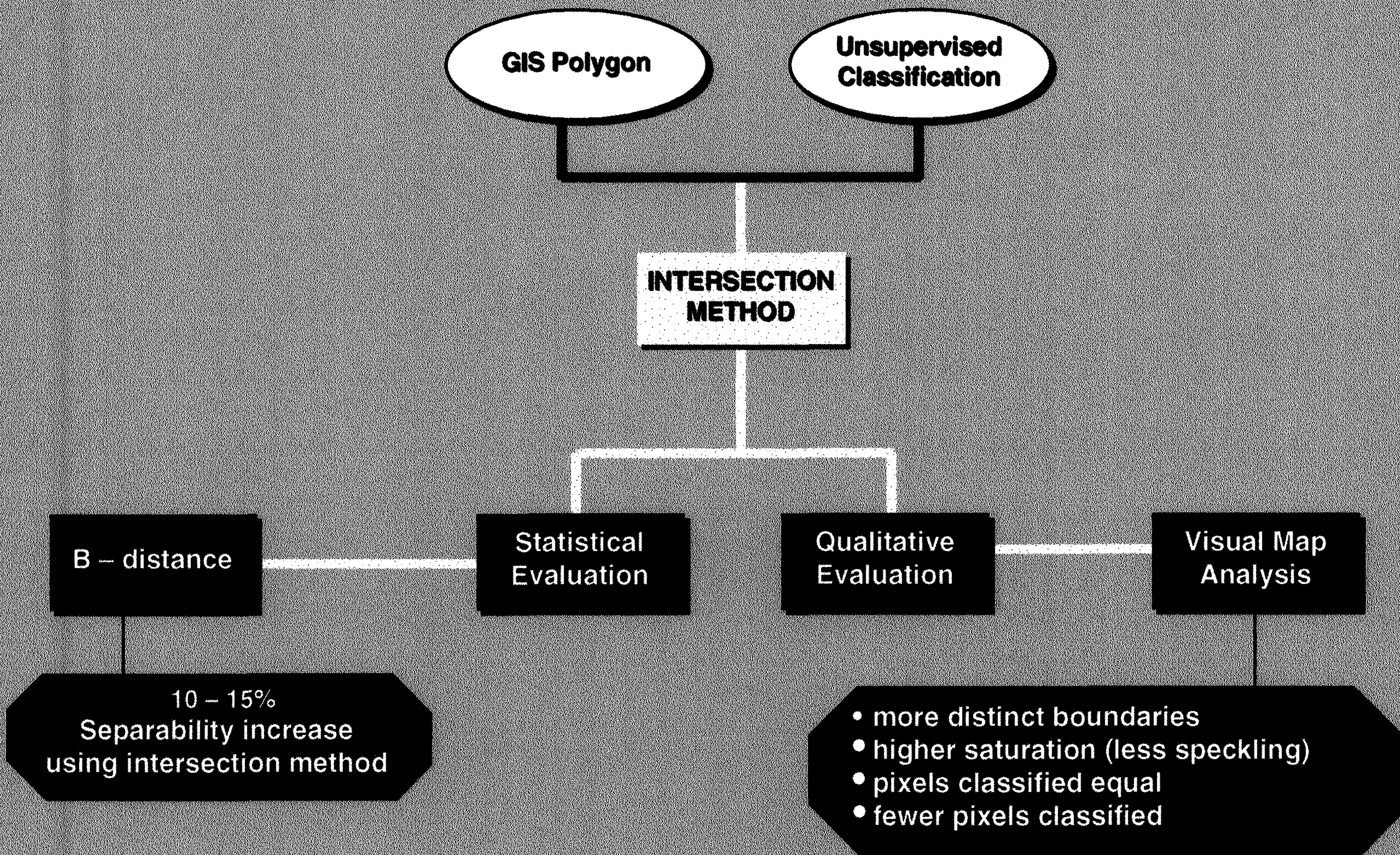
____
Company Name

____
Date

APPENDIX 2

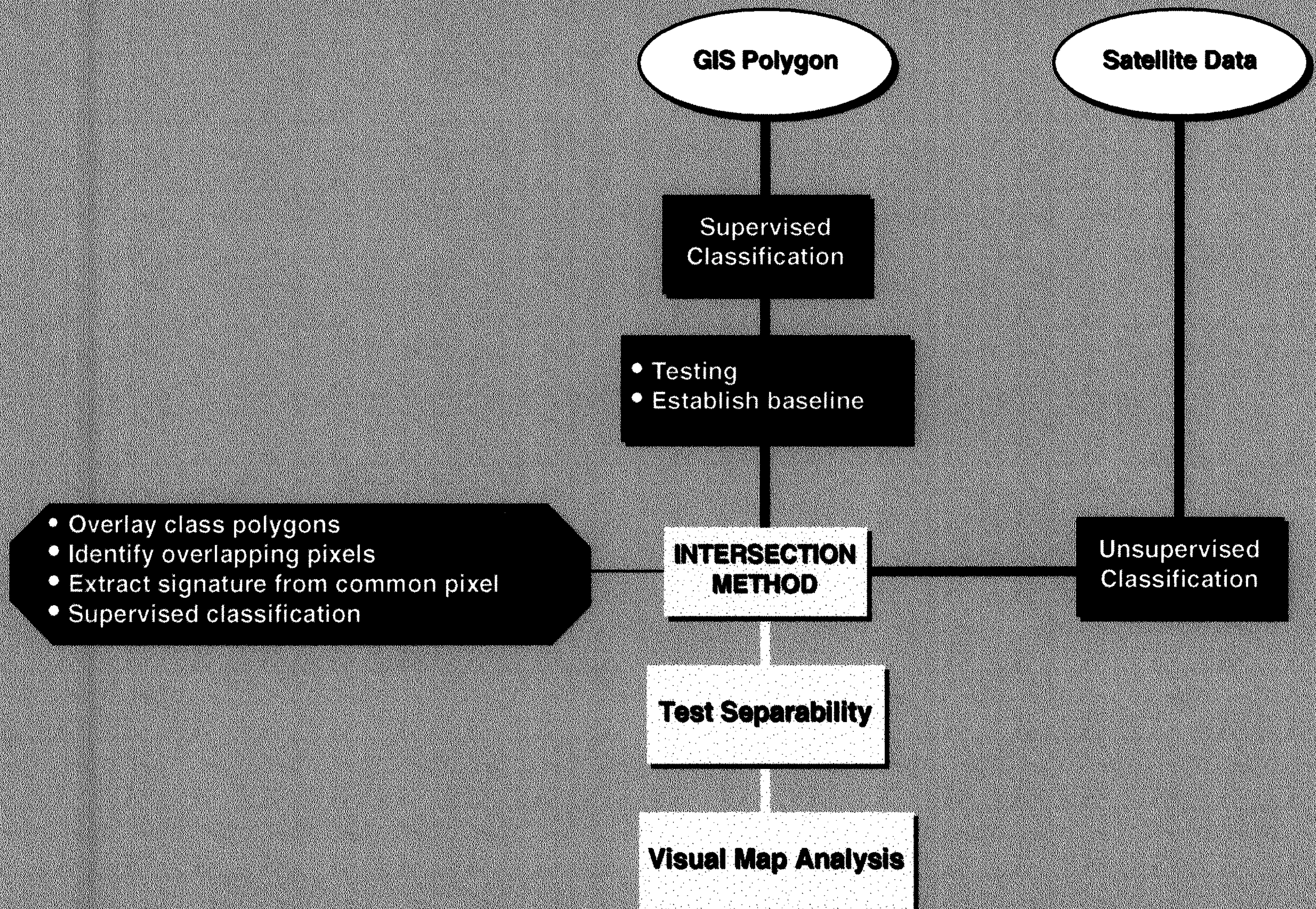
FLOW CHARTS

EVALUATION AND TESTING

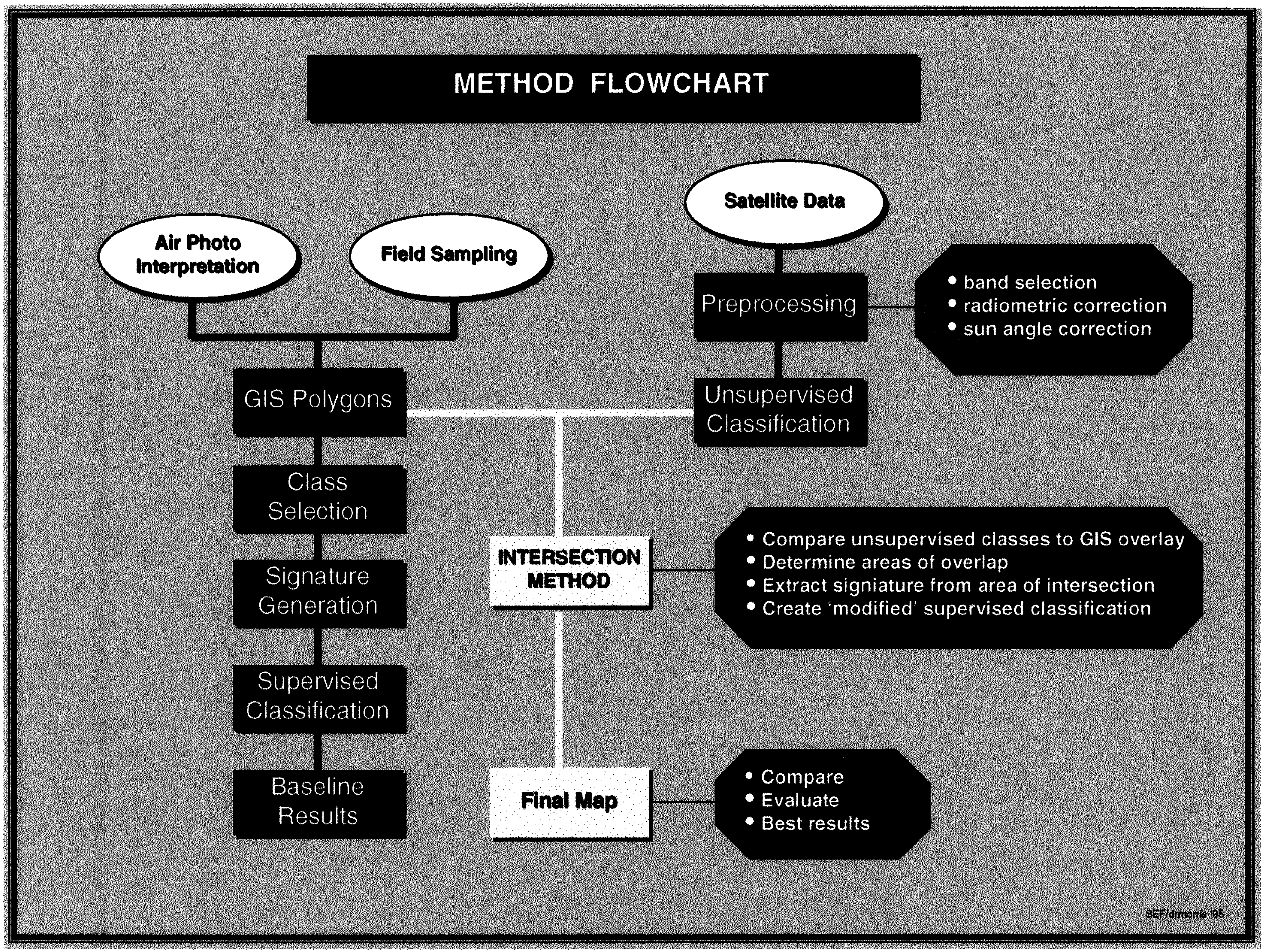


SEF/drmorris '95

MODIFIED INTERSECTION METHOD



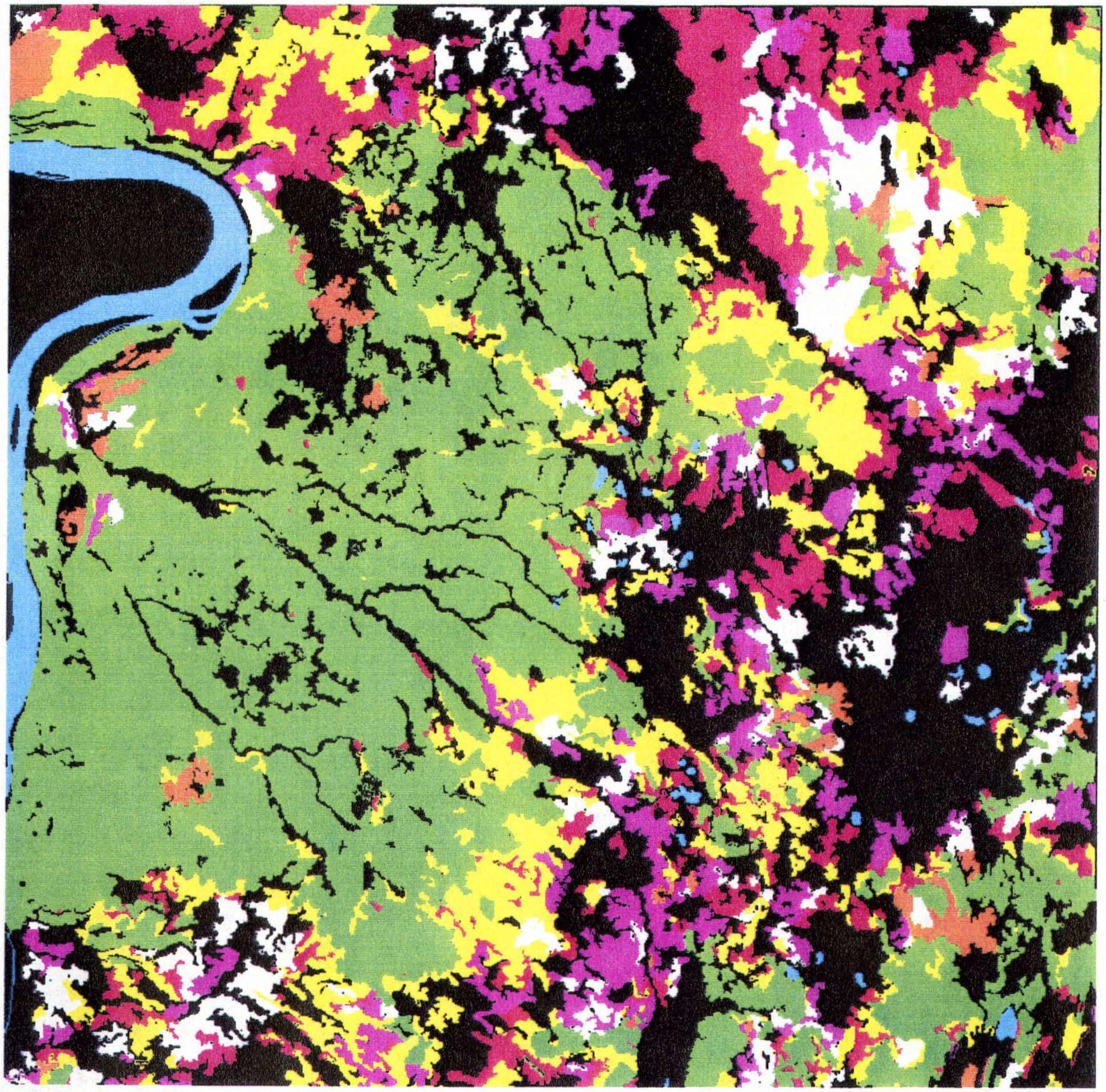
SEF/dmorris '95


METHOD FLOWCHART
Air Photo Interpretation
Field Sampling
Satellite Data
Preprocessing
• band selection
• radiometric correction
• sun angle correction
GIS Polygons
Unsupervised Classification
Class Selection
Signature Generation
INTERSECTION METHOD
• Compare unsupervised classes to GIS overlay
• Determine areas of overlap
• Extract signiature from area of intersection
• Create 'modified' supervised classification
Supervised Classification
Baseline Results
Final Map
• Compare
• Evaluate
• Best results
SEF/drmorris '95

APPENDIX 3

FINAL MAP PRODUCTS

3-Class Conifer Understory Map From Air Photo Interpretation



H100 + H90

H80 + H70

L100 + L90

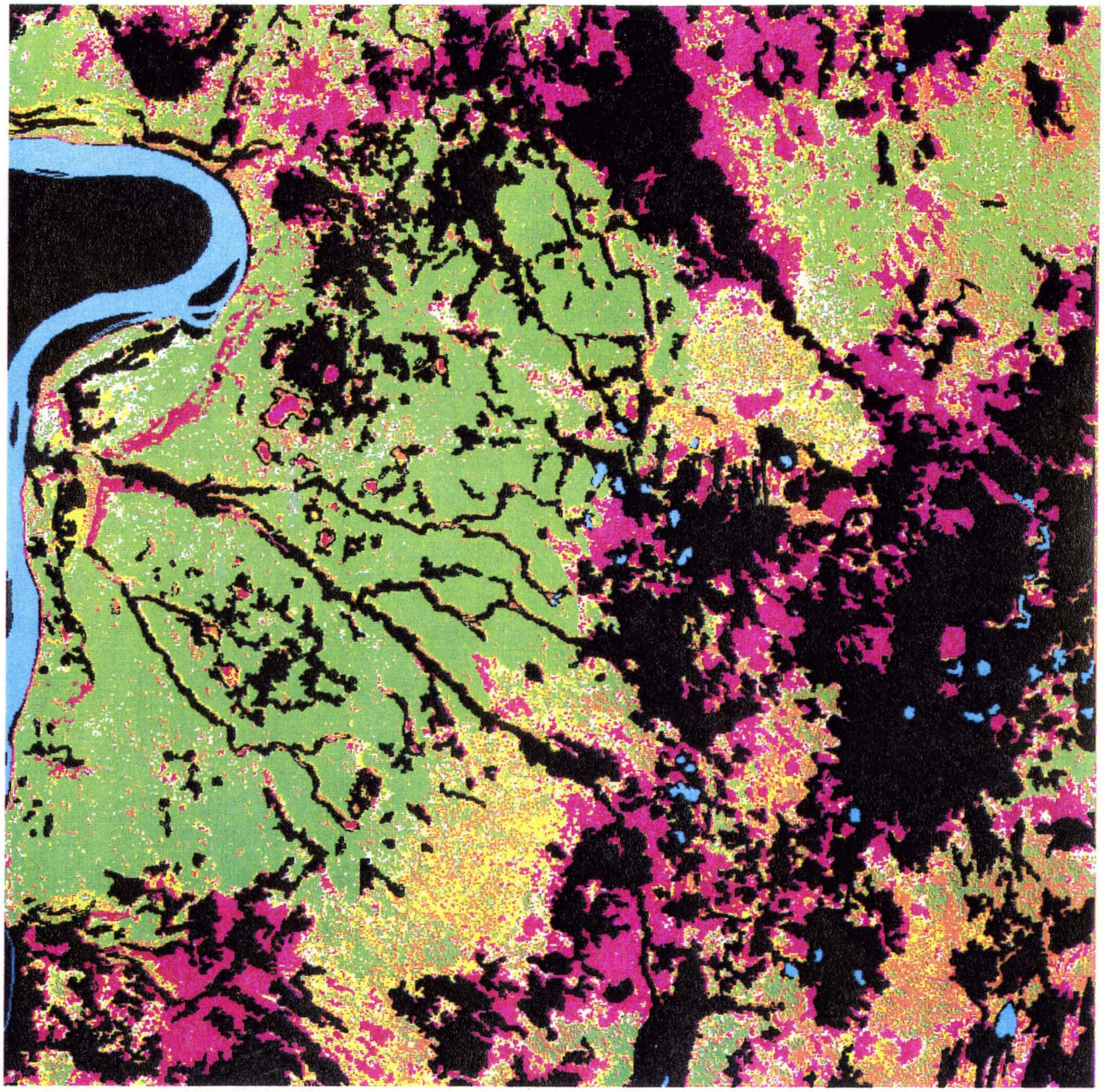
L80 + L70

Water

N100 + N90

N80 + N70

3-Class Conifer Understory Map
Supervised Classification with GIS Polygons



H100 + H90

H80 + H70

L100 + L90

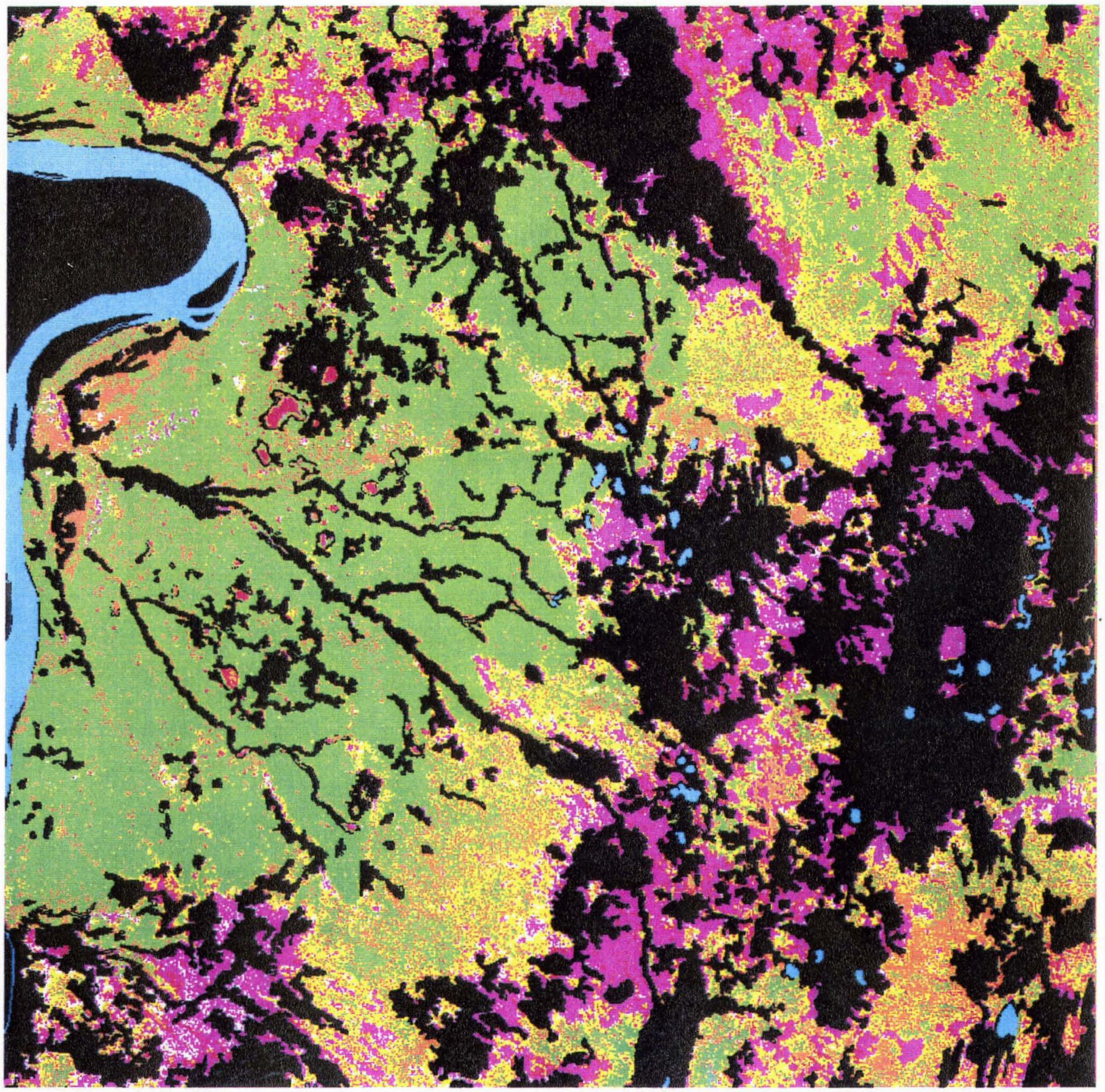
L80 + L70

Water

N100 + N90

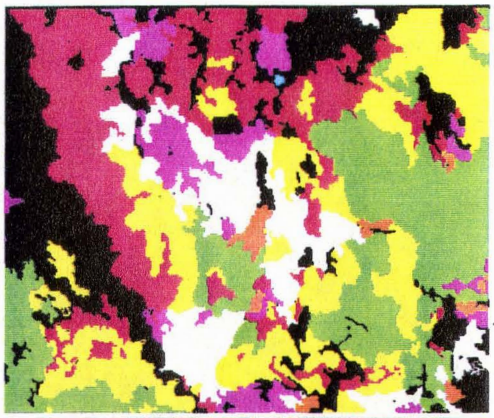
N80 + N70

3-Class Conifer Understory Map From Intersect Method

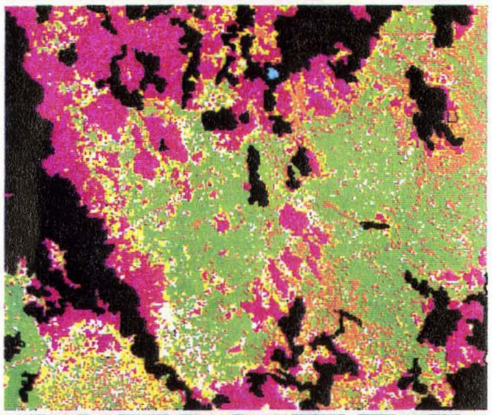


H100 + H90	H80 + H70	
L100 + L90	L80 + L70	Water
N100 + N90	N80 + N70	

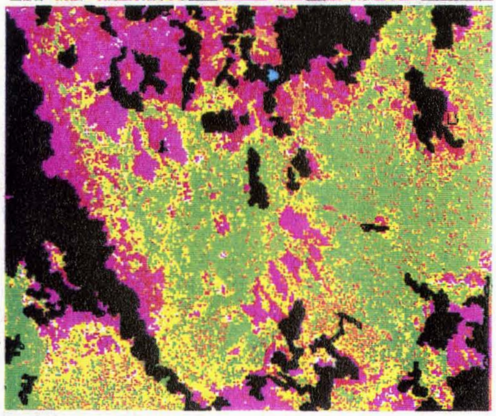
Conifer Understory Maps: Comparisons



GIS Map from air photo interpretation



Supervised Classn. with understory polygons as TA's



Supervised Classn. using Intersect of GIS & Unsupervised Classn. as TA's.

H100 + H90

H80 + H70

L100 + L90

L80 + L70

Water

N100 + N90

N80 + N70

APPENDIX 4

Variability of Landsat Thematic Mapper Data in Boreal Deciduous and Mixedwood Stands With Conifer Understory

Variability of Landsat Thematic Mapper data in boreal deciduous and mixedwood stands with conifer understory

G.S. Ghitter[1], R. J. Hall[2], S.E. Franklin[1*]

[1]Department of Geography, The University of Calgary, Calgary, Alberta , Canada
Tel: (403) 220-5584 Fax: (403) 282-6561
e-mail: gsghitte@acs.ucalgary.ca, franklin@acs.ucalgary.ca

[2]Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Canada
Tel: (403) 435-7277 Fax: (403) 435-7359 e-mail: rhall@nofc.forestry.ca

Abstract. In this study, we examine Landsat TM satellite multispectral imagery and several image processing strategies to determine the most accurate method to detect and map white spruce understories in deciduous and mixedwood stands in Alberta. These stands may be considered as part of the conifer land base that is defined as stands which contain or are projected to contain a minimum conifer volume at rotation. Images acquired in late April (leaf-off) and late July (leaf-on) were used to generate signatures for three levels of understory (heavy, light, nil) in five overstory classes. Separability statistics indicate that a reasonable degree of success can be obtained in mapping some of the understory classes with conventional classification tools. Linear discriminant functions using different classification schema and discriminating variables are presented to indicate the level of accuracy that may be obtained in a supervised classification mapping exercise.

1. 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 (Expert Panel on Forest Management in Alberta 1990), and 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 remote sensing studies have attempted to map conifer understory directly (Stenback and Congalton, 1990), although the understory is important in describing stand structure and in site classification (Corns 1992). The understory can contribute significantly to spectral response patterns in remote sensing studies of open canopies. Spanner et al. (1990) for example, reported an increase in reflectance from open conifer stands with a well-developed deciduous understory. Landsat Thematic Mapper (Landsat TM) data could also be used to identify successional stages in regenerating conifer stands (Fioria and Ripple 1993), when the relationship between understory (herb and shrub cover) and reflectance was strong in young, open stands. Maps of insect defoliation in

Newfoundland contained errors because of understory reflectance (Luther et al. 1991), since an increase in reflectance occurred over areas where the canopy was reduced in density following defoliation. In another study, Stenback and Congalton (1990) quantified the spectral effect of the understory in the Sierran mixed conifer zone in three canopy classes (sparse, moderate, dense). They tested numerous TM band combinations and concluded that TM band 5 was required to achieve the highest accuracies. The highest classification accuracy obtained in the detection of understory vegetation was 69%.

In central Alberta, Kneppeck and Ahern (1990) analyzed Landsat TM images during leaf-off (fall) and leaf-on (summer) conditions. They suggested that leaf-off/leaf-on image dates could be used to map overstory conditions and understory vegetation in the boreal mixedwood zone, but that methods must be optimized before the technique could be considered for application on an operational basis. The foundation of their classification was the use of the leaf-on images 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 were not addressed in their study, nor was the applicability of their approach for mapping large areas evaluated. Thus, a study designed to assess the detectability of conifer understory over a range of overstory species compositions, would further evaluate the utility of Landsat TM data for this application.

A two-date, Landsat TM image data base was assembled to determine the classification accuracies that may be obtained in the mapping of conifer understory, as compared to a map produced from interpreting leaf-off aerial photographs. This paper presents a proposed classification scheme for conifer understory that was arrived at after testing cluster analysis results and interpretation of separability statistics. Since the classification accuracies that may be achieved with Landsat TM data may be influenced by the image bands employed, results from the full set of Landsat TM bands are compared with those using a band subset (Horler and Ahern, 1986). This resulted in creating two objectives for this study that included: 1) determining and evaluating classification schemes for detecting and mapping conifer understory within deciduous and mixedwood stands; and 2) illustrating the level of classification accuracy that can be achieved using several combinations of one and two-date (leaf off, leaf on), Landsat TM data.

2. Study area

The study area consists of four townships (approx. 625 square km) in north-central Alberta north east of the town of Peace River (Figure 1). This area is within the Mixedwood Section of the Boreal Forest Region (B.18a, Rowe 1972) 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.

3. Data acquisition and methods

3.1 Image acquisition and preprocessing

Landsat TM images were acquired in geocoded format for April 18, 1991 (leaf-off) and July 23, 1991 (leaf-on) with solar conditions of 40.58° elevation/150.71° azimuth, and 49.52° elevation/144.77° azimuth, respectively. Atmospheric effects, judged minor after examination of image displays were corrected using the dark-object pixel subtraction technique (Chavez, 1988; Campbell and Ran, 1993). The solar zenith angle correction algorithm presented by Franklin and Giles (1994) 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

3.2 Creation of a conifer understory map classification system

A conifer understory map was produced and input to a Geographic Information System (GIS), to provide the basis for image training and development of class signatures, and calculation of separability measures. In creating this map, considerations of overstory stand structure were required since there are major differences between spruce-dominated and aspen-dominated stands (Peterson and Peterson 1992). The overstory information was derived from the AVI map supplied by the forest company that holds the timber lease for the study area. The discrimination 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 stand. 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. These 71 plots were used in the discrimination techniques described in the following sections.

These considerations resulted in an initial classification system (Table 1) whereby conifer understory stands were mapped to three levels (heavy, light, nil) beneath five overstory stand structures that ranged from pure deciduous (100% deciduous) to a 60%-

40% deciduous-conifer mixedwood composition 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 to generate class signatures.

3.3 Methods to determine class structure

Since a spectral basis for this class structure may not exist, the mean spectral measures in each of the classes for the fourteen class scheme were processed by a hierarchical clustering technique based on the squared Euclidean distance (Chuvieco and Congalton 1988; Kerber and Schutt 1986; Mausel et al. 1990; SPSSx 1986). The objective was to produce groups that may correspond to naturally occurring class structures which could be tested for separability using the remote sensing data. These classes were then tested for accuracy from a variety of bandsets as suggested by Horler and Ahern (1986) and Ahern and Sirois (1989) using the leaf-off/leaf-on data separately and then as one bandset. Each bandset was evaluated using discriminant analysis and Bhattacharyya distance separability measures (B-distance).

Finally, a method of combining the spectral class signatures of adjacent overstory classes in all possible combinations with one of two understory combinations was attempted (Table 3). This method was designed to arrive at a class structure where disparate classes (for example, classes with heavy and light understory) would not be combined although they may look spectrally similar.

3.4 Separability and discrimination of classes

Bhattacharyya distance (Haralick and Fu, 1983) was computed as a measure of statistical separability between pairs of signatures that were previously generated from training areas of the understory polygons. B-distance is actually a measure of the probability of correct classification (Mather 1987) that has been used as a measure of discrimination between a set of classes based on a set of spectral bands (Leckie and

Ostaff, 1988). Interpretation of the Bhattacharyya distance is straightforward: If 0 < B-distance < 1.0 then the data demonstrate very poor separability, if 1 < B-distance < 1.9 there was poor separability, and if 1.9 < B-distance < 2.0 there was good separability (PCI Inc., 1993).

A pixel sampling program (Franklin et al. 1991) was employed to arrange the Landsat TM data for each of the 71 field sites that were used to field-check the aerial photointerpretation into an attribute table. This sample was sorted into training and test samples for subsequent analysis and classification using discriminant functions. The procedure combines the variables into linear combinations which maximize inter-class distinctiveness (Klecka 1980, Tom and Miller, 1984, Kershaw 1987, Franklin and McDermid 1993). The discriminant results based on these 71 field sites are expressed as the per cent classification accuracy, and together with the Bhattacharyya statistics, yield a relative indication of the mapping potential of the Landsat TM data for the conifer understory within overstory classes.

4. Results and discussion

4.1 Cluster analysis

The cluster analysis for the four stage and eight stage aggregations are shown in Table 2. The four stage clustering generated ten classes which do not appear logical and which may not conform to the requirements for mapping understory and overstory conditions. For example, in the first stage, the 90% deciduous - 10% coniferous overstory with light understory is merged with the 80% deciduous - 20% coniferous overstory with light understory. At the second stage, the 80% deciduous - 20% coniferous overstory with heavy understory is merged with the 70% deciduous-30% coniferous overstory with heavy understory. At the third stage, the first cluster (80-90% deciduous - 10-20% coniferous overstory with light understory) includes the 60% deciduous - 40% coniferous light understory. The last stage clusters the 90% deciduous - 10% coniferous with nil understory and the 80% deciduous-20% coniferous overstory with nil understory to create a single cluster with a range of 80-90% deciduous and up to 20% conifer in the overstory, but with a nil conifer understory.

In the six class scheme there was some confusion between heavy and light understory (Table 2). The 100% deciduous overstory with heavy understory is merged with the 70% deciduous - 30% coniferous overstory having only light understory. This clustering points to a significant source of confusion that can be expected in the pixel discriminations and in the larger mapping exercise: mixedwood stands with a significant component of the overstory comprised of conifers can resemble (spectrally) stands without conifers in the overstory if the understory is dense. However, the following stages illustrate reasonable mapping logic as the 80% deciduous -20% coniferous overstory with heavy understory and 70% deciduous - 30% coniferous overstory with heavy understory are grouped with the 60% deciduous - 40% coniferous overstory with heavy understory. The final two stages show that the 100% deciduous overstory with light understory is merged with 90% deciduous overstory with light understory, the 80% deciduous overstory with light understory, and then the 60% deciduous overstory with light understory. The 90% deciduous overstory with nil understory and the 80% deciduous overstory with nil understory are merged with the 70% deciduous overstory with nil understory. These results indicated that a mapping structure that may provide maximum statistical separability and maximum class accuracy was possible.

4.2 Other grouping schemes

It was apparent that a mapping structure amenable to an operational system was not forthcoming from the clustering of class means. Although the class groupings were statistically based, they must also be executable in the field and provide for a classification system which yields information that may be used for forest management. These results did, however, suggest that the clustering of the classes present could yield a class scheme that optimizes class separability based on both discriminant analysis and the B-distance measure.

A second method was designed to maximize the likelihood of arriving at a logical class structure and at optimizing the separability of the classes (Table 3). In this scheme, all adjacent overstory classes were grouped together in all possible combinations. That is, each class was merged with adjacent classes to provide a natural and intuitive class grouping to test which yielded the highest separabilities. For example, Group 1, the 100% deciduous overstory class was combined with group 2, the 90% deciduous - 10% coniferous overstory class. Additionally, each arrangement was tested with one of two understory combinations, the first consisting of heavy, light and nil, the second with the heavy and light classes combined which would indicate either the presence or absence of an understory.

4.3 Separability of training areas

General trends of average class separability are evident in Table 4 for each of the original classification schemes in the study (the original 14 classes, ten and six class systems derived through cluster analysis). Figure 2 contains a graphical representation of the Bhattacharyya separability statistics generated as a trend surface for the 14-class classification scheme based on the Landsat TM data in the areas mapped for each class in the color infrared photographs.

Overall, there is very poor separability, that is B-distance < 1.0 in all cases (Figure 2). In the original 14 class scheme, classes 3, 9 and 13 are the most separable paired with different understory characteristics. 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 were 2,4,5,7, and 11.

In general, there is relatively poor separability in all classes, but heavy understory is more separable from nil understory classes than from light understory. Light understory classes are confused with both heavy and nil understory classes, and some confusion in the overstory structures associated with mixedwood canopies can be expected. Similar trends are apparent in using all bands from two dates, or individual TM image data sets, but the maximum separability is apparent when using either all bands from both dates or the 3,4,5 combination from two dates (Table 4). There is a decrease in separability in the leaf-on TM data set, illustrating that the leaf-off data set was sensitive to the understory conditions because the overstory stand in the leaf-on data set partially masked the spectral response from the understory.

4.4 Discrimination of field sites

Table 5 contains the classification accuracies based on the discriminant analysis in each of the classification schemes using the full TM image band set and the reduced band set. The tests were based on the 71 field sites used to develop the field descriptions of the understory and overstory stands.

One pattern that emerges through examination of this table is that the overstory stands are more accurately defined using the leaf-on image and the understory stands are better defined using the leaf-off image, but more accurate results were obtained from a combination of leaf-off and leaf-on data. For example, the full 14 class scheme shows 53% classification accuracy with the Landsat TM leaf-off image, and 47% classification accuracy using the Landsat TM leaf-on image. This increases to 74% classification accuracy when the image data are combined in the discriminant function.

When fewer classes are considered, the overstory conditions appear to dominate and are slightly better defined using the leaf-on image data. In most cases, however, the leaf-off imagery performed significantly better relative to the leaf-on imagery. In schema with relatively more classes, the leaf-off data produce higher accuracies since the classes are more dependent on differences in understory.

While these results may be high enough to justify a mapping project, the division of the mixedwood stands into three or five classes may not provide sufficient information for management purposes. The original 14 class scheme shows relatively good discrimination (74% correct) compared to those schema; this test may justify an attempt to map the stands using this large number of divisions.

The 10 class scheme based on the cluster analysis appeared to provide reasonable separability relative to the other mapping combinations (Table 4), but poor discrimination (Table 5). While perhaps retaining maximum usefulness in the class structure, (for example light, heavy and nil understory beneath pure deciduous overstory, two mixedwood overstory combinations without an understory, and six mixedwood combinations with a coniferous understory), the mapping accuracy is insufficient to support larger area analysis.

The six class scheme based on the cluster analysis may represent a good compromise for extension to larger mapping areas. Discrimination revealed 71% accuracy in those classes which represent heavy or light understory in four mixedwood classes, a mixedwood class without a coniferous understory, and a pure deciduous overstory without a coniferous understory in another class.

Separability and discrimination results were highest when adjacent classes were combined using the full bandset (Table 6). The groupings break down into sets consisting of two, three or four overstory elements, each with two or three understory elements. Relative separability was given by the B-distance measure and classification accuracy was a measure of the discriminant analysis function. The trend from this analysis indicates that sets which included the combination of the 100% deciduous and 90% deciduous classes for each element grouping were consistently higher for both the Bhattacharyya distance measure and the discriminant analysis. In addition, when the 80% deciduous class was added to the 100% deciduous and 90% deciduous classes, the highest separabilities and accuracies were achieved. These results were consistently higher than previous models. For example, the combination of groups 1 and 2 (100% deciduous, 90% deciduous) that generated 11 classes (heavy, light and nil understory) and 8 classes (heavy+light, nil understory), had accuracies of 76% and 73% respectively, compared to the 10 class system generated from the cluster analysis which had 54% accuracy. The highest accuracies were obtained by combining groups 1, 2 and 3 (100%, 90%, and 80% deciduous classes) which generated eight or six classes (three overstory elements) at 80% and 81% accuracy respectively or four classes (two overstory elements) at 80% accuracy.

The Bhattacharyya distance measure was interpreted to give the relative separability between pairs of classes. Bitmaps used to generate the signatures which were tested for separability and derived from aerial photographs did not contain exclusively pure stands of the class in question.

5. Conclusions

Digital Landsat TM data may be used to discriminate among several combinations of coniferous understory within overstory stands that are either pure or predominantly deciduous. Training areas of understory polygons imported from the GIS had, on average, poor overall separability because understory is often unevenly distributed within overstory stands, and mapped polygons are often an average descriptor of a forest stand. Subsequent discriminant tests based predominantly on field plots appear to indicate greater potential for mapping. For example, a maximum classification accuracy of 81% was obtained in a six class scheme which represented three mixedwood classes and the presence or absence of understory. The original 14 class scheme based on 10% increments in conifer overstory composition and heavy, light and nil understory classes was discriminated with 74% accuracy based on 71 field test sites. This level of accuracy is 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).

The best results, however, were achieved by merging adjacent overstory classes to arrive at a reduced number of class schema with two, three, or four overstory classes. The maximum accuracies were achieved by:

(i) merging 100% deciduous with 90% and 80% deciduous overstory classes; combined with two understory classes - absence or presence - (6 classes), 81% accuracy;

(ii) merging 100% deciduous with 90% and 80% deciduous overstory classes; combined with three understory class - heavy, light nil - (9classes), 80% accuracy; and

(iii) merging 100% deciduous with 90% and 80% deciduous overstory, also 70% deciduous with 60% deciduous overstory; combined with two understory classes - absence or presence - (4 classes), 80% accuracy.

Based on the data acquired for this study these combinations provided the maximum classification accuracies and spectral separability while maintaining a workable scheme that can be applied in the field.

The work described in this paper represents an exploratory study of the two-date, leaf-off, leaf-on Landsat TM data and the detection of conifer understory in Alberta using conventional image processing methods. Some improvements in the use of Landsat TM data may be derived from image texture analysis (Peddle and Franklin, 1991) because of the patchy nature of the regeneration and variable species mixture in the overstory. The problem of conifer understory in the leaf-off imagery may also be more suited to a mixture-modeling solution whereby the emphasis is not on the detection of understory, but in an estimation of the understory proportion within Landsat TM pixels.

6.0 Acknowledgments

This project was funded, in part, by the Canada-Alberta Partnership Agreement in Forestry. Additional support provided by Daishowa-Marubeni International Ltd., Alberta Environmental Protection and the Forestry Corp is greatly appreciated.

7.0 References

Ahern F.J. and Sirois, J., 1989, Reflectance enhancements for the thematic mapper: an efficient way to produce images of consistently high quality, *Photogrammetric Engineering and Remote Sensing*, **55** (1), 61-67.

Brace, L. G., and Bella, I. E., 1988, Understanding the understory: dilemma and opportunity, In J. K. Samoil (ed.)., *Management and utilization of Northern Hardwoods,* Canadian Forest Service Northern Forestry Centre Information Report NOR-X-296, (Edmonton, Alberta: Forestry Canada), pp. 69-86.

Campbell, J. B., and Ran, L., 1993, CHROM: A C program to evaluate the application of the dark object subtraction technique to digital remote sensing data. *Computers & Geosciences*, **19**, 1475-1499.

Chavez, P. S., 1988, An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment*, **24**, 459-479.

Chuvieco, E., and Congalton, R. G., 1988, Using cluster analysis to improve the selection of training statistics in classifying remotely sensed data, *Photogrammetric Engineering and Remote Sensing,* **54**, 1275-1281.

Corns, I. G. W., 1992, Forest site classification in Alberta: its evolution and present status. *The Forestry Chronicle*, **68**, 85-93.

Expert Panel on Forest Management in Alberta, 1990, *Forest Management in Alberta: report of the expert review panel.* (Edmonton, Alberta: Alberta Energy, Forests, Lands and Wildlife).

Fiorella, M., and Ripple, W. J., 1993, Analysis of conifer forest regeneration using Landsat Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing*, **59**, 1383-1388.

Franklin, S. E., and Giles, P.T., 1994, Radiometric processing of aerial and satellite remote sensing imagery. *Computers & Geosciences*, **20**, page numbers forthcoming.

Franklin, S. E., and McDermid, G. J., 1993, Empirical relations between digital SPOT HRV and CASI spectral response and lodgepole pine (*Pinus contorta*) forest stand parameters. *International Journal of Remote Sensing*, **14**, 2331-2348.

Franklin, S. E., Peddle, D. R., Wilson, B. A., and Blodgett, C. F., 1991, Pixel sampling of remotely-sensed digital image data. *Computers & Geosciences,* **17**, 759-775.

Haralick, R. N., and Fu, K. S., 1983, Pattern recognition and classification, in Manual of Remote Sensing, Robert N. Colwell (ed.), (Falls Church, VA.: American Society for Photogrammetry and Remote Sensing), pp. 793-804.

Kerber, A. G., and Schutt, J. B., 1986, Utility of AVHRR channels 3 and 4 for land-cover mapping. *Photogrammetric Engineering and Remote Sensing,* **52**, 1877-1883.

Kershaw, C. D., 1987, Discrimination problems for satellite images. *International Journal of Remote Sensing*, **8**, 1377-1383.

Klecka, W. R., 1980, *Discriminant analysis.* Sage University Publication Series (London: Sage Publications).

Kneppeck, I., and Ahern, F. J., 1990, Summary Report on the Alberta Conifer Landbase, Canada Centre for Remote Sensing, Ottawa Ont., unpublished.

Leckie, D.G., and Ostaff, D.P., 1988. Classification of airborne multispectral scanner data for mapping current defoliation caused by the spruce budworm. *For Sci.* **34**(2): 259-275.

Luther, J. E., Franklin, S. E., and Hudak, J., 1991, Satellite remote sensing of current year defoliation by forest pests in western Newfoundland. *Proc., 14th Canadian Symposium on Remote Sensing*, (Calgary, Alberta: Canadian Remote Sensing Society), pp. 192-198.

Mather, P., 1987, *Computer processing of remotely sensed images,* (London: Wiley).

Mausel, P. W., Kramber, W. J., and Lee, J. K., 1990, Optimum band selection for supervised classification of multispectral data. *Photogrammetric Engineering and Remote Sensing,* **56**, 55-60.

Morgan, D. J., 1991, Aspen inventory: problems and challenges, In S. Navatril and P. B. Chapman (eds.), *Proceedings, Aspen Management in the 21st Century*, Northern Forestry Centre and Poplar Council of Canada (Edmonton, Alberta: Forestry Canada), pp. 33-38.

PCI Inc., 1993, EASI/PACE Image Analysis System Manuals, Vers. 5.3, Richmond Hill, Ontario, variously paged.

Peddle, D.R., and Franklin S.E., 1991. Image texture processing and ancillary data integration for surface pattern discrimination. Photogrammetric Engineering and Remote Sensing, 57, 413-420.

Peterson, E. B., and Peterson, N.M., 1992, *Ecology, management, and use of aspen and balsam poplar in the prairie provinces*, Northwest Region Special Report 1, Northern Forestry Centre, (Edmonton, Alberta: Forestry Canada).

Resource Information Division, 1991, *Alberta Vegetation Inventory Standards Manual,* Version 2.1, (Edmonton, Alberta: Resource Information Division, Alberta Forests, Lands and Wildlife).

Rowe, J. S., 1972, *Forest regions of Canada*. Environment Canada, Canadian Forest Service Publication No. 1300, (Ottawa, Ontario: Environment Canada).

Spanner, M. A., Pierce, L.L., Peterson, D. L., and Running, S. W., 1990, Remote sensing of temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation, and background reflectance. *International Journal of Remote Sensing*, **11**, 95-111.

SPSSx Inc., 1986, SPSSx User's Guide, 2nd edition (Chicago, Il.: SPSSx Inc.).

Stenback, J.M., and Congalton, R.G., Using Thematic Mapper Imagery to Examine Forest Understory. *Photogrammetric Engineering and Remote Sensing*, **56** (9): pp 1285-1290.

Tom, C. H., and Miller, L. D., 1984, An automated land-use mapping comparison of the Bayesian maximum likelihood and linear discriminant analysis algorithms. *Photogrammetric Engineering and Remote Sensing*, **50**, 193-207.

Table 1 Class Schema (14 Classes)

Overstory/Understory	Class #	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 Hierarchical cluster aggregation base on class means

	10-class scheme (4 cluster stages)	Classes Combined 6-class scheme (8 cluster stages)	
	1 H100	1 N100	
	2 L100	2 H90	
	3 N100	3 H100+L70	Fifth stage
	4 H90	4 H80+H70+H60	Sixth stage
First stage	5 L90+L80	5 L100+L90+L80+L60	Seventh stage
Second stage	6 H80+H70	6 N90+N80+N70	Eighth stage
Third stage	7 L90+L80+L60		
Fourth stage	8 N90+N80		
	9 L70		
	10 H60		

Table 3 All possible classes achieved by merging adjacent overstory classes.

Five Elements
1,2,3,4,5
Four Elements
(1+2),3,4,5
1,(2+3),4,5
1,2,(3+4),5
1,2,3,(4+5)
3 Elements
(1+2+3),4,5
1,(2+3+4),5
1,2,(3+4+5)
1,(2+3),(4+5)
(1+2),3,(4+5)
(1+2),(3+4),5
2 Elements
(1+2+3),(4+5)
(1+2),(3+4+5)

1 = 100% Deciduous, 0% Coniferous
2 = 90% Deciduous, 10% Coniferous
3 = 80% Deciduous, 20% Coniferous
4 = 70% Deciduous, 30% Coniferous
5 = 60% Deciduous, 40% Coniferous

Table 4 Average class separability statistics (Bhattacharyya distance) for several band combinations and different class schema based on spectral data in areas interpreted using aerial photographs as different overstory and understory conditions

Band Combinations*	Class Schema**		
	1	2	3
TMall	0.82	0.82	0.85
TMoff	0.63	0.64	0.71
TMon	0.48	0.49	0.45
345all	0.77	0.77	0.81
345off	0.59	0.53	0.61
345on	0.43	0.34	0.32

***Band Combinations:**

TMall = TM bands 1,2,3,4,5,7 plus NDVI from each date;
TMoff = TM bands 1,2,3,4,5,7 from 18 April 1991;
TMon = TM bands 1,2,3,4,5,7 from 23 July 1991;
345all = TM bands 3,4,5 plus NDVI from each date;
345off = TM bands 3,4,5 from 18 April 1991;
345on = TM bands 3,4,5 from 23 July 1991.

****Class Schema (see Table 1):**
1 = fourteen classes;
2 = ten classes (based on 4-stage clustering);
3 = six classes (based on 8-stage clustering).

Table 5: Discriminant analysis classification accuracies for several band combinations and different classification schema based on 71 field sites.

Function*	**Class Schema****		
	1	**2**	**3**
TMall	74	54	71
TMoff	53	46	52
TMon	47	50	61
345all	44	47	59
345off	43	43	58
345on	33	37	53

***Functions:**

TMall = TM bands 1,2,3,4,5,7 plus NDVI from each date;
TMoff = TM bands 1,2,3,4,5,7 from 18 April 1991;
TMon = TM bands 1,2,3,4,5,7 from 23 July 1991;
345all = TM bands 3,4,5 plus NDVI from each date;
345off = TM bands 3,4,5 from 18 April 1991;
345on = TM bands 3,4,5 from 23 July 1991.

****Class Schema (see Table 1):**
1 = fourteen classes;
2 = ten classes (based on 4-stage clustering);
3 = six classes (based on 8-stage clustering).

Table 6: Class separability statistics and discriminant analysis classification for different variable combinations for all possible adjacent class combinations

	a,b,c (15 classes)		(a+b),c (10 classes)	
Five Elements [a]	**BD** [b]	**DA (%)** [c]	**BD** [b]	**DA (%)** [c]
1,2,3,4,5	0.82	71	0.79	70
Four Elements	a,b,c (12 classes)		(a+b),c (8 classes)	
(1+2),3,4,5	0.83	76	0.85	73
1,(2+3),4,5	0.83	71	0.82	66
1,2,(3+4),5	0.80	67	0.77	64
1,2,3,(4+5)	0.80	74	0.80	73
3 Elements	a,b,c (9 classes)		(a+b),c (6 classes)	
(1+2+3),4,5	0.86	80	**0.90**	81
1,(2+3+4),5	0.82	70	0.79	64
1,2,(3+4+5)	0.76	77	0.73	68
1,(2+3),(4+5)	0.83	67	0.82	64
(1+2),3,(4+5)	0.82	76	0.86	73
(1+2),(3+4),5	0.82	70	0.83	64
2 Elements	a,b,c (6 classes)		(a+b),c (4 classes)	
(1+2+3),(4+5)	**0.88**	76	**0.95**	80
(1+2),(3+4+5)	0.78	71	0.73	70

[a] **1 = 100% Deciduous, 0% Coniferous**
2 = 90% Deciduous, 10% Coniferous
3 = 80% Deciduous, 20% Coniferous
4 = 70% Deciduous, 30% Coniferous
5 = 60% Deciduous, 40% Coniferous

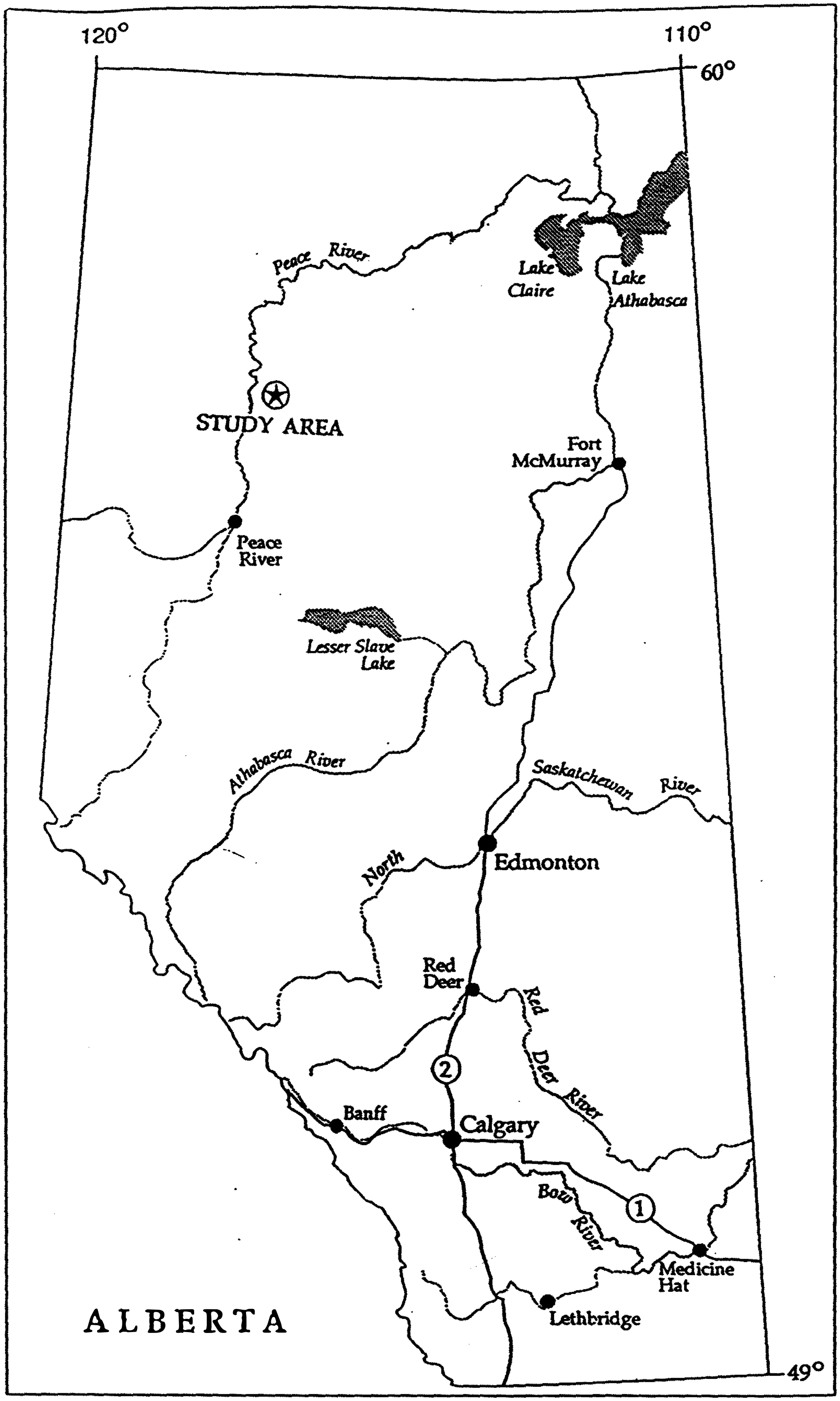
a = heavy understory
b = light understory
c = nil understory

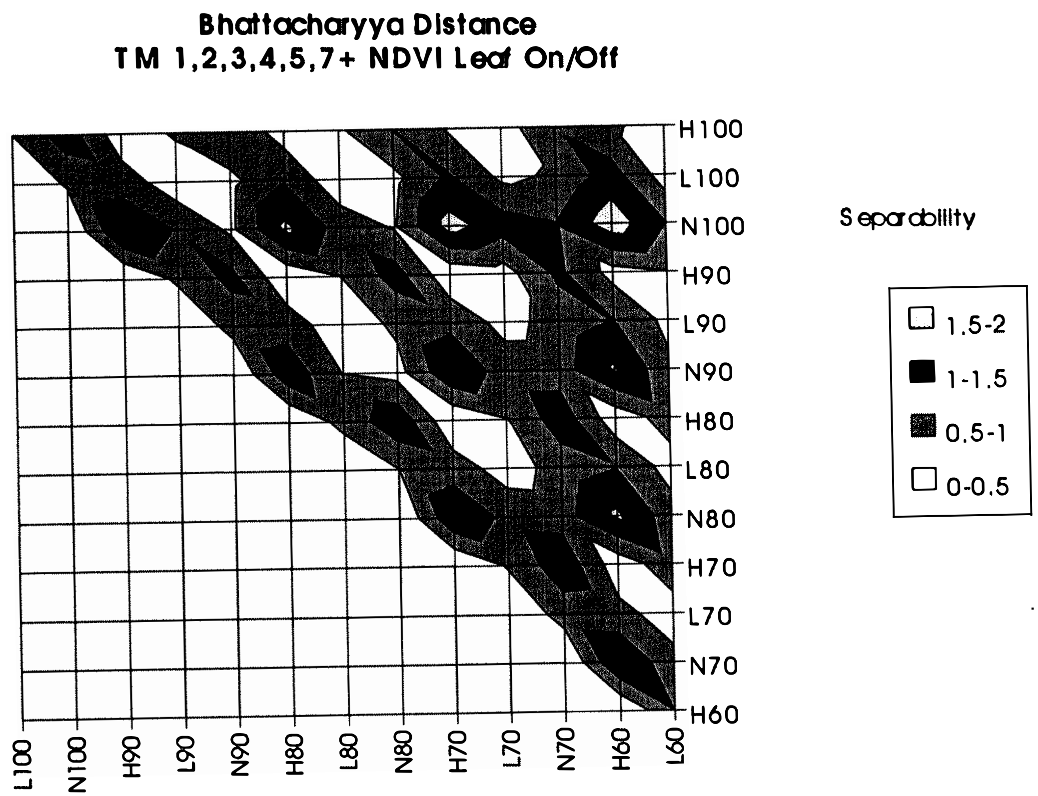
[b] BD = Bhattacharyya distance separability statistics

[c] DA = Discriminant analysis classification accuracy

Figure 1: Location of the study area in north-central Alberta, Canada

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


120°
110°
60°
Peace River
Lake Claire
Lake Athabasca
STUDY AREA
Fort McMurray
Peace River
Lesser Slave Lake
Athabasca River
Saskatchewan River
North
Edmonton
Red Deer
Red Deer River
2
Banff
Calgary
Bow River
1
Medicine Hat
Lethbridge
ALBERTA
49°



Bhattacharyya Distance
TM 1,2,3,4,5,7+ NDVI Leaf On/Off
H100
L100
N100
H90
L90
N90
H80
L80
N80
H70
L70
N70
H60
L100
N100
H90
L90
N90
H80
L80
N80
H70
L70
N70
H60
L60
Separability
1.5-2
1-1.5
0.5-1
0-0.5

APPENDIX 5

Satellite Remote Sensing of White Spruce Understory in Deciduous and Mixedwood Stands

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

S.E. Franklin[1], R. J. Hall[2], G.S. Ghitter[3]
[1]Department of Geography, The University of Calgary,
Calgary, Alberta , Canada T2N 1N4
Tel: 403 220 5584 Fax: 403 282 6561 e-mail:
franklin@acs.ucalgary.ca
[2]Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre,
Edmonton, Alberta, Canada T6H 3S5
Tel: 403 435 7209 Fax: 403 435 7359 e-mail:
rhall@nofc.forestry.ca
[3]Department of Geography, The University of Calgary,
Calgary, Alberta , Canada T2N 1N4
Tel: 403 220 5584 Fax: 403 282 6561 e-mail:
gsghitte@acs.ucalgary.ca

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 images 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 purpose of this study is to determine the detectability of conifer understory within pure deciduous and predominately deciduous stands with two-date, leaf-off and leaf-on Landsat TM satellite data.

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-conifer 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 structure. 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 contingency table (Table 3). Only the clusters which incorporated significant numbers of pixels in the understory map polygons are interpreted here.

Heavy understory in the first two overstory classes - 100% deciduous and 90-10% deciduous-coniferous - is mapped across clusters 1 and 2, with a small additional amount in clusters 3 and 5. The majority of light understory pixels in these two overstory classes appears to be organized into 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 that the heavy and light understory categories are separate within each overstory class, but that the light and nil understory categories should be merged.

The pure deciduous overstory is separable from the 60-40% deciduous-coniferous overstory. For example, 61% of the pixels under the 60-40% deciduous-coniferous heavy understory bitmap were incorporated into 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 highest 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 two 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 also to characterize more precisely, the overstory structures in the leaf-on image to improve conifer understory classification and mapping accuracy.

ACKNOWLEDGEMENTS

This project was funded, in part, by the Canada-Alberta Partnership Agreement in Forestry. Additional support was provided by Daishowa-Marubeni International Ltd., Alberta Environmental Protection and the Forestry Corp.

REFERENCES

Beaubien, J. 1979. Forest type mapping from LANDSAT digital data. Photogrammetric Engineering and Remote Sensing, vol. 45, pp. 1135-1144.

Brace, L.G., and Bella, I.E., 1988. Understanding the understory: dilemma and opportunity. pp. 69-86, in J.K. Samoil (ed.)., Management and utilization of northern hardwoods, Can. For. Serv., North. For. Cen., Info. Rep. NOR-X-296. Edmonton, AB.

Chavez, P.S., 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sensing of Environment, vol. 24, pp. 459-479.

Expert Panel on Forest Management in Alberta, 1990. Forest Management in Alberta: report of the expert review panel. Alberta Energy, Forests, Lands and Wildlife, Edmonton, Alberta.

Fiorella, M., and Ripple, W.J., 1993. Analysis of conifer forest regeneration using Landsat Thematic Mapper data. Photogrammetric Engineering and Remote Sensing, vol. 59, pp. 1383-1388.

Peddle, D.R., and Franklin, S.E., 1991. Image texture processing and ancillary data integration for surface pattern discrimination. Photogrammetric Engineering and Remote Sensing, vol. 57, pp. 413-420.

Guyot, G., Guyon, D., and Riom, J. 1989. Factors affecting the spectral response of forest canopies: a review. Geocarto International, vol. 4, pp. 3-18.

Horler, D.N.H., and Ahern, F.J. 1986. Forestry information content of Thematic Mapper data. International Journal of Remote Sensing, vol. 7, pp. 405-428.

Kneppeck, I., and Ahern, F.J., 1990. Summary Report on the Alberta Conifer Landbase. Canada Centre for Remote Sensing, Ottawa Ont., unpublished.

Morgan, D.J., 1991. Aspen inventory: problems and challenges. pp. 33-38, in S. Navatril and P. B. Chapman (eds.), Proceedings, Aspen management in the 21st century, North. For. Cen. and Poplar Council of Canada, Edmonton, AB.

Peterson, E.B., and Peterson, N.M., 1992. Ecology, management, and use of aspen and balsam poplar in the prairie provinces. Can. For. Serv., North. For. Cen., Northwest Region Special Report 1, Edmonton, AB.

Resource Information Division, 1991. Alberta Vegetation Inventory Standards Manual. Version 2.1, Alberta Forestry, Lands and Wildlife, Resource Information Division, Edmonton, AB.

Rowe, J.S., 1972. Forest Regions of Canada. Environ. Can., Can. For. Serv., Ottawa, ON. Publication No. 1300.

Spanner, M.A., Pierce, L.L., Peterson, D.L., and Running, S.W., 1990. Remote sensing of temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation, and background reflectance. International Journal of Remote Sensing, vol. 11, pp. 95-111.

Stenback, J.M., and Congalton, R.G., 1990. Using Thematic Mapper imagery to examine forest understory. Photogrammetric Engineering and Remote Sensing, vol. 56, pp. 1285-1290.

Tsakiri-Strati, M., 1994. Evaluating unsupervised classifiers with similarity and comparison matrices, International Journal of Remote Sensing, vol. 15, pp. 1941-1948.

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 (Bhattacharyya 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 classes whose pixels are 15 percent or more of its corresponding understory class label).

Class Label[a]	# Pixels	Percent of pixels in each spectral class 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 closest integer.

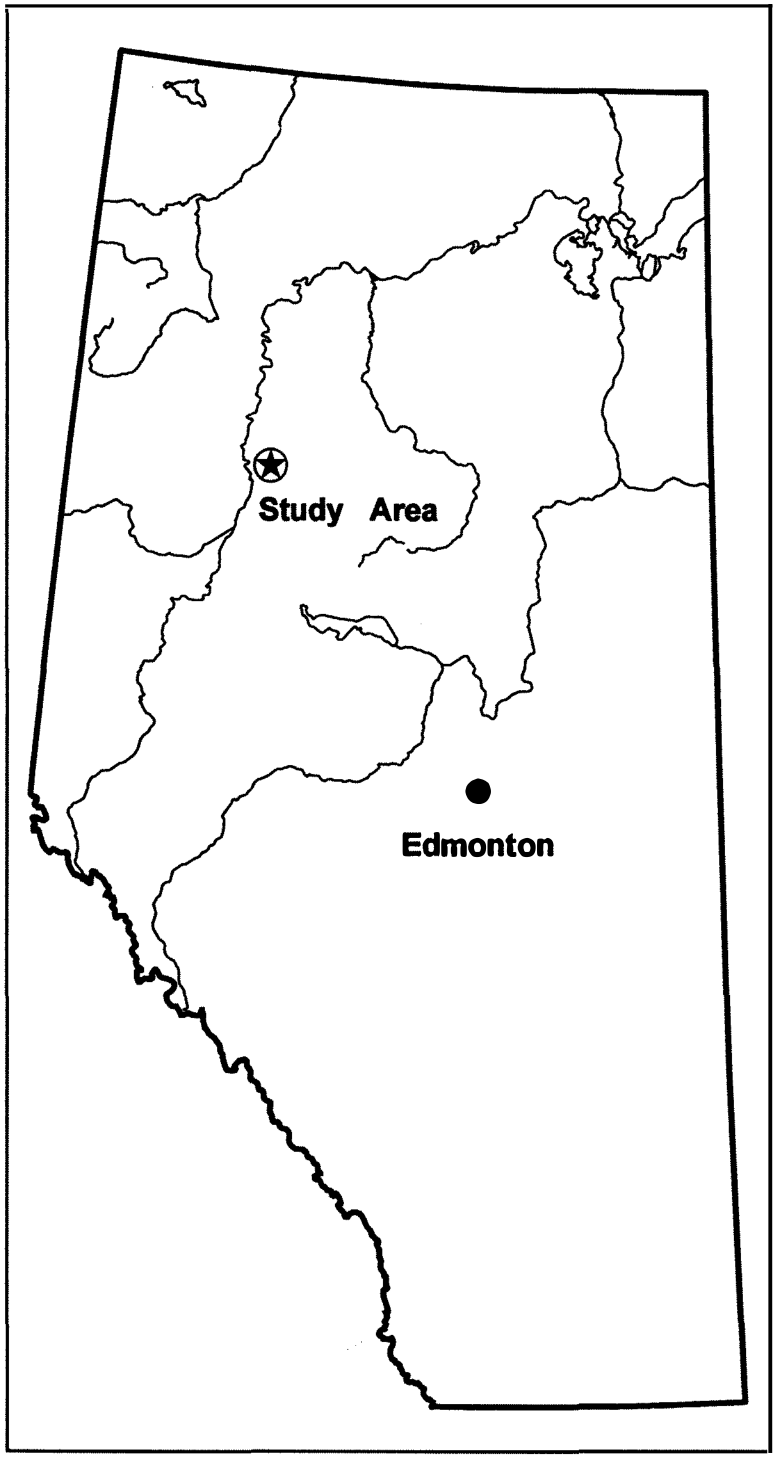


Figure 1. Location of the study area in north-central Alberta.

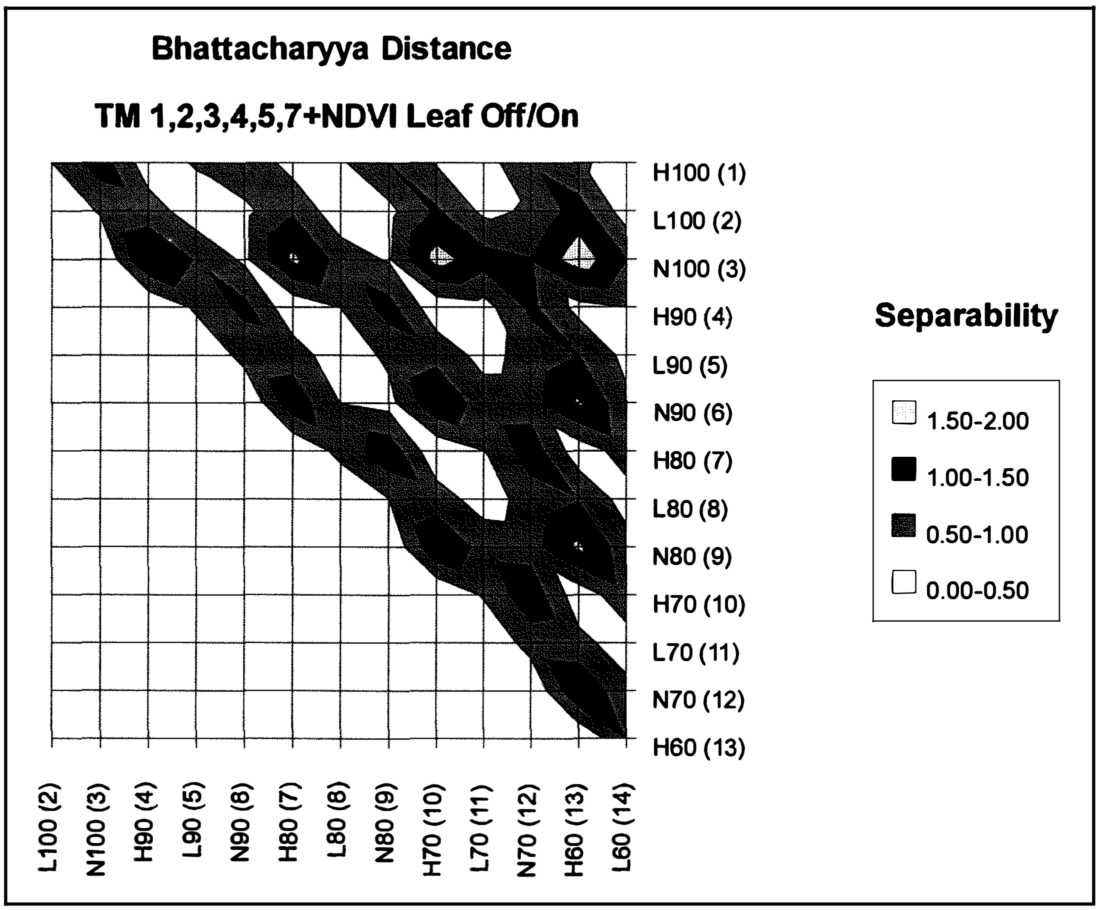


Figure 2. Bhattacharyya distance separability measures in the 14 class scheme (see Table 1) displayed as a probability surface for classification accuracy.

APPENDIX 6

Identifying Class Structure of White Spruce Understory Beneath Deciduous or Mixedwood Stands for Improved Classification Results

IDENTIFYING CLASS STRUCTURE OF WHITE SPRUCE UNDERSTORY BENEATH DECIDUOUS OR MIXEDWOOD STANDS FOR IMPROVED CLASSIFICATION RESULTS

G.S. Ghitter[1], R. J. Hall[2], S.E. Franklin[1]

[1] Department of Geography,
The University of Calgary, 2500 University Dr. N.W. Calgary, Alberta, Canada T2N 1N4 Tel: (403)220-5584 Fax:(403)282-6561 e-mail: gsghitte@acs.ucalgary.ca; franklin@acs.ucalgary.ca

[2] Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre,
5320 122 St. Edmonton, Alberta, Canada T6H 3S5
Tel: (403) 435-7277 Fax: (403) 435-7359 e-mail: rhall@nofc.forestry.ca

ABSTRACT

A satellite remote sensing approach was used to determine class structure of white spruce understory occurring within deciduous and mixedwood stands in northern Alberta. The determination of a class structure that is amenable to an operational implementation is needed to identify and stratify large areas that may comprise conifer understory. Landsat TM imagery acquired in late April (leaf-off) and late July (leaf-on) were used to generate an Isodata unsupervised classification to aid in identification of a class structure. These classes were cross-mapped to a GIS overlay containing three levels of understory (heavy, light, nil) in five overstory classes acquired from leaf-off aerial photographs and field observations. Class signatures generated from the intersection of the GIS understory polygons and the Isodata clusters were used for a supervised classification. Analysis of separability statistics suggests understory can be discriminated for understory absence or presence under two overstory strata.

INTRODUCTION

A current inventory problem in the Mixedwood Section of the Boreal Forest Region B.19a (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). Current efforts to map softwood understory in the boreal mixedwood zone involve the interpretation of leaf-off aerial photographs and field surveys that are costly to undertake over large areas. A satellite remote sensing method for the detection of understory could significantly aid in the time and cost in such surveys by providing an initial stratification of large areas to identify likely locations of softwood understory.

Previous studies (Franklin *et al.*, 1986; Spanner *et al.*, 1984; Peterson *et al.*, 1986) have acknowledged the contribution of understory to stand spectral response. Stenback and Congalton (1990) have also attempted to classify vegetated understory in the Sierran mixed conifer zone with mixed results. Ghitter *et al.*, (1995) conducted supervised classifications with class signatures based on a digital GIS overlay of 15 classes mapped to three understory (heavy, light, nil) and five overstory categories (based on 10% increments in conifer overstory composition).

Discriminant analysis testing indicated that the greatest success for mapping understory could be expected by collapsing overstory classes but this increases the variability of the class and the distinctiveness of its spectral signature. Because the mapped polygons from the GIS overlay are often averaged during photo interpretation, and that understory is often unevenly distributed within overstory stands, signatures generated using these polygons as training areas may contain too much variation in their spectral signatures to accurately discriminate these classes during production of an image map.

The purpose of this paper is to investigate a 'modified supervised' classification technique similar to Chuvieco and Congalton (1988), and to identify polygons that can be used as training areas for creating class signatures. Using a two-date (leaf off/leaf on) Landsat TM data set, this technique is based on the intersection of classes produced by an Isodata unsupervised classification and the GIS polygon overlays.

STUDY AREA

The study area consists of four townships (about 625 square km) in north-central Alberta (Figure 1). This area is within 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), which 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.

Conifer understory stands were mapped to three levels (heavy, light, nil) beneath five overstory stand structures that ranged from pure deciduous (100% deciduous) to a 60% deciduous - 40% coniferous mixedwood composition (Table 1). The ISODATA unsupervised clustering algorithm was used to generate a map of the spectral classes for comparison to the GIS polygons. Three runs of the ISODATA routine were initialized with an expected number of clusters (12 to 20) and with a standard deviation of 8, 12, and 16. Three class variations of eight classes, six classes and four classes derived from the original 15 class scheme (Table 1) were chosen for testing based on the relatively high average spectral separability of the classes (Table 2). Each ISODATA unsupervised classification result was combined with the understory map using a logical 'AND' function to create an image map that illustrates the intersection of every ISODATA cluster with its corresponding understory polygon. In all, nine tests were conducted. The results when using an initial cluster standard deviation of 12, cross-mapped to the four class scheme are presented in Table 3. Each ISODATA cluster is ranked in descending order according to the percentage of pixels overlapping with each overlay class. Only the largest 7 of 19 ISODATA clusters are presented with their percent intersections ranging from 86.4 to 94.7.

ISODATA clusters accounting for a minimum of 70% of the overlap were thresholded to create bitmaps from which new signatures for a maximum likelihood classification could be created. For example, the intersection of ISODATA clusters 7, 4, 5 and 8 accounted for 71.3% of the overlap with Class 1 and was used to create a new signature. It was hypothesized that signatures created using this approach would more adequately describe their spectral variation while maintaining the basic character of the original GIS polygons.

RESULTS AND DISCUSSION

The nature of this investigation precludes using accuracy assessment techniques based on confusion matrices and the Kappa statistic (Congalton 1991) without further field measurements. Bhattacharyya distance (B-distance) has been used, however, as a measure of separability between pairs of classes based on a set of spectral bands (Jorial *et al.*, 1991; Ghitter *et al.*, 1995), and its interpretation is considered a measure of the likelihood of correct classification (Mathur 1987). B-distance is asymptotic to 2.0, and its interpretation is straight forward: If 0 < B-distance < 1.0 then the data demonstrate very poor separability, if 1.0 < B-distance < 1.9 there is poor separability and if 1.9 < B-distance < 2.0 there is good separability (Richards 1993). Table 4 gives B-distances associated with the class signatures generated by the *modified supervised* classification. Average separability for this test was 1.52, significantly higher than the test for the same classes based on the signatures generated by the GIS polygon overlays alone (Table 3).

Significant confusion is evident between classes 1 and 2; classes with heavy understory but with different canopy mixtures, and classes 3 and 4, classes with nil understory and different canopy mixtures. Separability is very high between all classes with heavy or nil understory, indicating that the maximum likelihood classification routine is sensitive to understory components regardless of overstory mix. The rise in sensitivity can be attributed directly to the new signatures created by this modified method.

Visual inspection of the classification output also gave qualitative evidence of the potential for increasing map accuracy. Classes generated from the modified supervised method appeared to match the spatial occurrence exhibited in the polygon overlays quite closely. In addition, when compared to classification maps trained on the GIS polygons alone, the classes tended to have well defined boundaries with a decrease in speckling, which may be associated with confusion among similar classes.

CONCLUSIONS

An intersection technique based on a remote sensing-GIS integration for the detection of forest class structure has shown potential for mapping understory in deciduous and mixedwood stands in northern Alberta. Spectral class signatures generated by training on areas of intersection between an unsupervised classification and a GIS polygon overlay had 10-15% greater average separability than the GIS overlay alone. The intersection of spectral classes from an unsupervised classification and physical classes from the GIS overlay may provide more realistic training areas for supervised classification routines by increasing class separability and potential map accuracy.

Future work with this method may lead to a procedure for extracting class signatures based on GIS-remote sensing integration. Broad classes can be input into a GIS and intersected with an unsupervised classification to produce class signatures with reduced spectral variation because training areas are more homogenous. A secondary benefit may be in the reduced time that is spent on ground truthing land cover classes that fall in the study area, but are not of interest. Spectral classes are usually created so that they are exhaustive and mutually exclusive. By using a modifed supervised classification approach, spectral classes based on GIS polygons tend to be more separable because they are based on their statistical properties as defined by parameter values used in the unsupervised classification algorithm. Future work includes plans to acquire the additional field data to conduct independent accuracy assessments of the classified understory map.

ACKNOWLEDGMENTS

This project was funded, in part, by the Canada-Alberta Partnership Agreement in Forestry. Additional support provided by Daishowa-Marubeni International Ltd., Alberta Environmental Protection, and the Forestry Corp. is greatly appreciated.

REFERENCES

Brace, L.G., and Bella, I.E., 1988. *Understanding the understory: dilemma and opportunity.* Pages 69-86 in J.K. Samoil (ed.)., Management and utilization of northern hardwoods, Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-296.

Chavez, P.S. 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing Environ.* vol. 24, pp. 459-479.

Chuvieco, E., and R.G. Congalton. 1988. Using cluster analysis to improve the selection of training statistics in classifying remotely sensed data. *Photogramm. Eng. Remote Sens.* 54 (9): 1275-1281.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing Environ.* 37: 35-46.

Franklin, J., 1986. Thematic mapper analysis of coniferous structure and composition *Int. J. Remote Sens.* vol. 7, No. 10 pp. 1287-1301.

Franklin S.E., Hall, R.J., Ghitter, G.S. 1995. Satellite remote sensing of white spruce understory in deciduous and mixedwood stands. -- *Resource Technology '94 Symposium, Decision Support 2001*, Toronto, September 12-16, 1994 *in press.*

Ghitter, G.S., Hall, R.J. and Franklin, S.E., 1995. Variability of Landsat Thematic Mapper data in boreal deciduous and mixedwood stands with conifer understory. composition. *Int. J. Remote Sens.* accepted December 1994.

Expert Panel on Forest Management in Alberta, 1990. *Forest Management in Alberta: report of the expert review panel.* Alberta Energy, Forests, Lands and Wildlife, Edmonton, Alberta.

Joria, P.E., Ahearn, S.C., and Connor, M. 1991. A comparison of the SPOT and Landsat Thematic Mapper satellite systems for detecting gypsy moth defoliation in Michigan. *Photogramm. Eng. Remote Sens.* 57(12): 1605-1612.

Mather, P.M. 1987. *Computer processing of remotely-sensed images.* John Wiley & Sons, New York, N.Y.

Morgan, D.J., 1991. *Aspen inventory: problems and challenges.* pp. 33-38, in S. Navatril and P. B. Chapman (eds.), Proceedings, Aspen management in the 21st century, North. For. Cen. and Poplar Council of Canada, Edmonton, Alberta.

Peterson, E.B., and Peterson, N.M., 1992. *Ecology, management, and use of aspen and balsam poplar in the prairie provinces.* Can. For. Serv., North. For. Cent., Edmonton, Alberta. Northwest Region Spec. Rep. 1.

Richards, J.A. 1993. *Remote sensing digital image analysis.* 2nd ed., Springer-Verlag. New York, N.Y.

Resource Information Division, 1991. *Alberta Vegetation Inventory Standards Manual.* Version 2.1, Alberta Forestry, Lands and Wildlife, Resource Information Division, Edmonton, AB.

Rowe, J.S., 1972. *Forest Regions of Canada.* Environ. Can., Can. For. Serv., Ottawa, Ontario. Publication No. 1300.

Spanner, M.A., Pierce, L.L., Peterson, D.L., and Running, S.W., 1990. Remote sensing of temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation, and background reflectance. *Int. J. Remote Sens.* vol. 11, pp. 95-111.

Stenback, J.M., and Congalton, R.G., 1990. Using Thematic Mapper imagery to examine forest understory. *Photogramm. Eng. Remote Sens.* vol. 56, pp. 1285-1290.

Table 1. Original class schema of overstory stand and understory composition (15 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
nil	15	N60

Table 2. Test classes and average spectral separability values.

	8 Classes	6 Classes	4 Classes
Class 1	H100	H100+H90+H80	H100+H90
Class 2	H90	L100+L90+L80	H80+H70
Class 3	H80	N100+N90+N80	N100+N90
Class 4	H70	H70+H60	N80+N70
Class 5	N100	L70+L60	
Class 6	N90	N70[a]	
Class 7	N80		
Class 8	N70		
Average Separability [b]	1.21	1.07	1.31

[a] The nil 60% class (N60) does not appear in the study area.
[b] Bhattacharyya distance measure

Table 3. ISODATA cluster overlap with GIS polygon overlay.

Class 1		**Class 2**		**Class 3**		**Class 4**	
Isodata Cluster	Percent Overlap	Isodata Cluster	Percent Overlap	Isodata Cluster	Percent Overlap	Isodata Cluster	Percent Overlap
7	28.5	4	38.9	8	58.6	4	34.7
4	28.4	7	12.8	10	15.7	8	23.7
5	7.2	1	12.3	14	6.0	10	9.9
8	7.2	3	8.4	7	5.4	12	8.0
10	5.1	2	7.4	12	5.2	7	7.4
1	5	5	6.2	16	2.2	14	4.0
2	5	8	2.7	5	1.6	5	3.3
Total	86.4	**Total**	88.7	**Total**	94.7	**Total**	91.0

Table 4. Bhattacharyya distance measures among class 1 to class 4.

Class	**1**	**2**	**3**
2	.903		
3	1.77	1.97	
4	1.67	1.92	.887