FOREST PARAMETER EXTRACTION THROUGH COMPUTER-BASED ANALYSIS OF HIGH RESOLUTION IMAGERY*

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ABSTRACT

Various algorithms and procedures were tested for isolation of single trees, determining crown closure, assessing gap distributions and species identification using 60-80 cm multispectral airborne imagery over a range of forest conditions on the west coast of Canada. Crown closure and forest gaps were estimated by thresholds, various band ratio filter techniques and tree delineation algorithms. These were tested against ground estimates from field plots representing immature stands of variable density and old growth sites. Most methods did not produce the range of closures that ground estimates indicated. Tailored threshold methods produced the best results. An algorithm was developed to create gaps from the various crown and vegetation masks produced through the closure estimation methods. Gap statistics were demonstrated for an old growth and immature stand. Tree counts were sensitive to methodology. For immature sites varying in density from 500 to 1600 stems/ha, best correspondence occurred at the 600 to 900 stem/ha range. Trees were omitted at high densities. Mixed success was achieved with species classification of an old growth site. Variability of the spectral reflectance, illumination conditions and tree health were the major confounding factors in species classification.

1.0 INTRODUCTION

New sensor technology and airborne image geometric correction systems, as well as the growing demands for detailed site specific data for various forest management activities, makes appropriate the development of automated interpretation and forest parameter extraction from high resolution digital multispectral imagery. This paper gives results and examples from a large study which examines, develops and tests various techniques for analysing high spatial resolution Casi multispectral imagery to fulfil forest management information needs (Leckie et al. 1999). Data were acquired over 20 sites on MacMillan Bloedel Ltd. forest holdings on Vancouver Island, British Columbia. These sites cover a variety of forest types and environments. This paper focuses on preliminary analysis of tree isolation, stem counting, closure estimation, gap analysis and species classification using a subset of sites and ground plots.

2.0 STUDY SITES, IMAGERY AND FIELD DATA COLLECTION AND COMPILATION

This study examines three areas on Vancouver Island, British Columbia, Canada. Two are areas dominated by immature stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). One is referred to as Tlatlos North (126°16’46’’W, 50°22’29’’N**)**, the other Highway 19 (126°19’19’’W, 50°17’35’’N). Stands have been manipulated to produce areas of differing densities ranging from 500 to 1600 stems/ha. Typical ages are 24 years and heights are between 10-14 m. The denser stands contained considerable intermediate dominance trees. The third site (125°27’01’’W, 40°50’50’’N) is the location of a large interdisciplinary project which examined various

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silviculture alternatives for modern forest management in Canada's west coast montane forest environment (MASS, Montane Alternative Silviculture Systems). It consists of old growth stands of predominantly western hemlock, amabilis fir (A*bies amabilis* Dougl. Ex Loud.), and western red cedar (*Thuja plicata* Donn ex D. Don). The site is divided into segments with different partial cut patterns as well as uncut control areas. Tree heights of the old growth trees were between 36-40 m.

Casi imagery (Anger at al. 1994) was flown over the study sites between September 25-27, 1996. Data was acquired at a nominal 70 cm resolution in eight spectral bands (438 nm, 489 nm, 550 nm, 601 nm, 656 nm, 715 nm, 795 nm, 861 nm; with generally a +/- 25 nm bandwidth). Imagery was geometrically corrected to 70 cm resolution with the aid of GPS, aircraft attitude data and digital elevation models. A nearest neighbour re-sampling was used. Acquisition and processing was conducted by ITRES Research Ltd., a partner in the overall project. Because of topographic relief in these mountainous areas, care was taken to process the imagery to an optimal ground resolution (Burnett et al. 1999). Minor spurious bright and zero pixels occurred in the imagery due to errors in the recording system. This noise was cleaned using the program (PIXCLNR) developed at PFC under PCI's Easi environment. Aberrant pixel values were replaced by a mean of the eight surrounding non-noise pixels.

Field plots were established in areas considered representative of the forest types found in the sites. They were 20x20, 20x10 and 40x80 m areas. Within each plot, the location of each stem was mapped on a grid system and the species, dominance (classes 1 to 4 from dominant to suppressed), diameter breast height and health condition of each tree were recorded. Tree heights and crown diameters of sample trees were measured. Crown closure percent was estimated visually by two observers ("observed field estimates"). As well, closure/openness was determined at locations on a 2 or 5 m grid network within the plot and the percent closure calculated. For this study the Tlatlos site had six plots, the Highway site seven plots and the MASS site three.

Field data was transferred to the digital imagery. The first step was to locate the plot boundaries and digitize them into a vector layer. Then the individual tree or tree clusters were delineated into a separate vector layer. Locations and tree boundaries were interpreted with the help of plots of the x and y locations of tree stems measured in the field, overlaid upon a print of the plot image, and by using tree dominance, species and health information. Some clusters of trees could not be separated into individual trees due to merging crowns or smaller trees adjacent to or overtopped by dominant trees. These were digitized as tree clusters and the tree numbers associated with each tree cluster were recorded. A database was populated with field measurements and field observations of each tree (e.g., species, dbh and dominance). Some trees identified on the ground could not be located on the imagery with confidence and are not in the database. As well, trees near the edges of the plots (which have a high probability of being stems outside the plot but with crowns at least partially within the plot area) were marked as edge trees so that they may be ignored in the analysis. Once the plot and tree vectors were added to the file, subsets of the whole flight line were created.

3.0 TREE ISOLATION AND COUNTS

3.1 METHODS

Trees were isolated using a "valley following" approach. This approach is part of the Individual Tree Crown (ITC) software suite developed at the Pacific Forestry Centre for automated analysis of individual trees (Gougeon et al. 1998). The ITC suite is written to be compatible with and run within the PCI image analysis software system environment. The valley following approach assumes trees are areas of high spectral values that form peaks of brightness in the intensity image separated by valleys of shade or lower intensity. Actual tree isolation was accomplished with a three stepped process. First the non-forest areas (i.e., water, road and grassland) were separated from the forest areas using a program which automatically compares the relationship of different spectral bands. The second step of the automatic delineation process was the valley-following program. By comparing the hills and valleys of the digital values within an image, the program begins to delineate the individual crowns. The last stage of the program uses a rule-based approach to precisely outline the boundaries of each crown (Gougeon, 1995). Resulting suspected trees or tree clusters will be referred to as ITC "isols".

A “tree-tops” method was also used to identify the presence of trees and then count them. This method also relies on trees having a spectral peak (Gougeon and Moore, 1988). The method does not outline the tree but simply marks the location of potential tree tops (ITC “tree-tops”). Local maxima within a moving window filter (3x3 pixels in this case) are identified and their location recorded.

Isolation accuracy was assessed on two bases: an area based measure and a tree-for-tree method. Analysis of the ITC isols and tree-tops falling within the plot allows for an estimation of stems/ha of the plot which can be compared to ground counts. A software tool VMARA was developed within the ITC suite to analyze isolation results on a tree-for-tree basis. The valley following isolation produces the isols in a bitmap format. These isols were first converted to vector polygons. Then every manually delineated tree polygon in a plot is compared with every isol inside or touching the plot boundary to determine the amount of manual:isol overlap. A table is generated that gives, for each manually generated ground truth polygon, the percent of the polygon that is overlapped by each of the isols. A second table gives the percent of each isol which is overlapped by each ground truth polygon. In this way one can determine which ground truth and isol polygons are associated with each other and their respective amount of overlap. A set of queries on these tables have been implemented. Various categories of polygon overlap can be defined and accuracy of tree isolation assessed in detail. Figure 1 illustrates the categories reported in this study. For example, a 1:1 perfect match can be defined as an isol which overlaps with only one ground truth polygon (“gtp”) and where greater than 50% of the isol is covered by the gtp and that gtp also has only one isol associated with it and 50% of that gtp is occupied by the isol. The separated tree category occurs when more than one isol occupies a gtp, and at least one of the isols occupies greater than 35% of the gtp area and the second isol occupies at least 10% of the gtp. Grouped trees occur when more than one gtp is associated with one isol (greater than 35% of their areas must be within the same isol). These “overlap” tables can be connected to the ground truth database or any species classification, crown size or other analysis on the isols. Therefore, accuracy of the isolation or subsequent processing such as species classification can be assessed in relation to the ground truth attributes of trees.

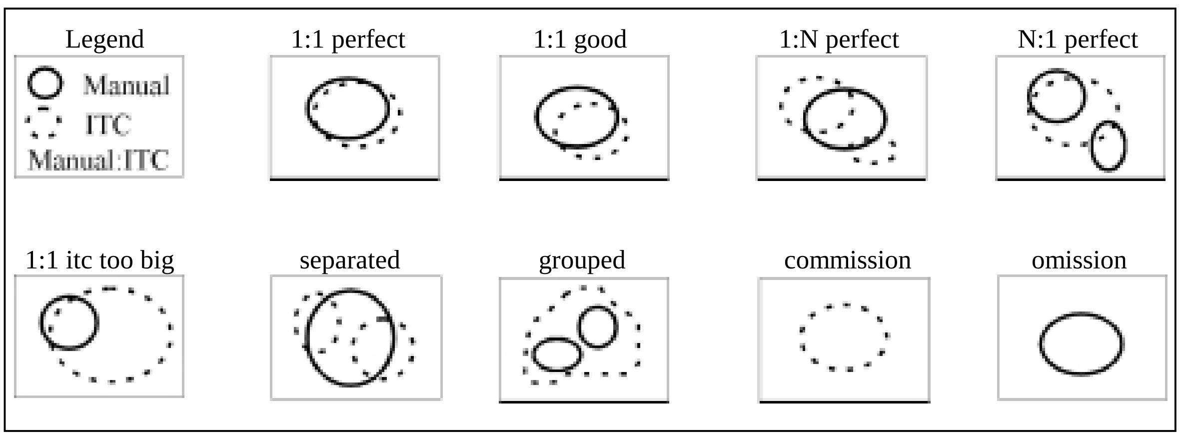

Figure 1. Categories for the tree-for-tree comparison of ground truth polygons (gtps) and ITC isols.

3.2 RESULTS

Figure 2 shows the results of the area based analysis of automated isolation and compares ITC “isol” and “tree-tops” estimates of the number of crowns in a plot to the actual field counts. Only dominance class 1, 2 and 3 are considered. Dominance class 4 , the smaller suppressed trees, were not included. Both methods do well at lower densities. At 500 stems/ha there is a slight tendency to create too many trees. Beyond 900 stems/ha there is an increasing underestimation of tree counts. This reflects the increasing closeness and overlap of tree crowns at the higher densities. The same trend is noted on the manually delineated trees. Even visual interpretation of the imagery with knowledge of the presence of each crown did not allow delineation of some of the crowns in the high density plots.

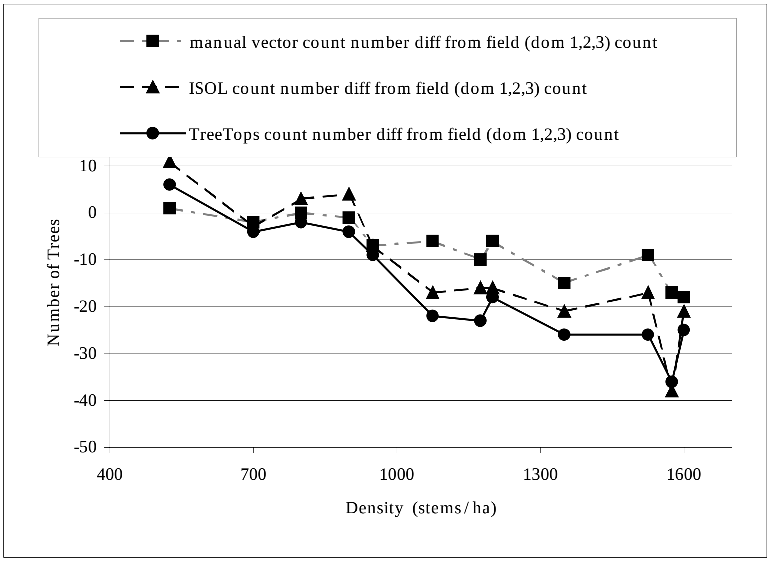

Figure 2. Comparison of number of trees identified by ITC isol and tree-tops algorithms with density. The Y axis shows number of over or under counts.

Table 1 examines the automatic isolation results on a tree-for-tree basis. This closer look reveals the nature of the tree isolation and potential compensating errors of commission, omission and partial overlap. It must however, be remembered that not all trees are represented in the ground truth database, only those that could be visually isolated. Overall 1:1 correspondence was low for the younger variable density plots. The number of good matches decreased with stand density. Grouped ground truth trees with one isol encompassing several trees increased in number as density became higher. This inability to break up clustered trees seems to be the largest source of error in the isolation process for the dense stands. For the larger trees of the old growth plots (41, 42, and 43) good matches were better, in the order of 55% to 65%. Of the trees which were either omitted or poorly matched 62% were shaded, 25% normally illuminated and 15% either severely damaged or anomalously bright. In terms of tree dominance, 57% of the omitted or poorly matched trees were co-dominant, 33% intermediate and 10% suppressed. None were dominant trees. Commissions, however, can become a problem.

4.0 CROWN CLOSURE

4.1 METHODS

Two general methods of separating tree cover from openings in the canopy were applied: tree delineation from the isolation process and thresholding techniques. The ITC isols used for the tree delineation and counts above were utilized to create a canopy mask and determine crown closure. Threshold techniques can be simple or quite complex. Several methods were implemented. The best results were obtained using a rules based threshold approach on multiple image features including the bands and band ratios. These were tailored through visual interpretation for different forest types, plots, and different flight lines. For example, a pixel was considered part of the forest canopy if the green over blue band ratio (550 nm / 489 nm) is > 1.5 and green band (550 nm) >700 and near-infrared band (795 nm) > 2600.

Table 1. Tree-for-Tree Isolation Results for the Variable Density Plots. Values represent the percent of ground truth trees for each plot in each correspondence category of Figure 1.

Plots	(stems/ha)	1:1 perfect match (%)	1:1 good match (%)	N:1 perfect (%)	1:N perfect (%)	**Total Good (%)**	1:1 with itc too big (%)	Poorly matched (%)	Separated (%)	grouped (%)	Omission (%)	**Total Poor (%)**	Commission
53	400	31.6	15.9	0.0	0.0	**47.4**	5.3	21.1	15.8	10.5	0.0	**52.7**	4
54	600	3.9	11.5	3.9	7.7	**26.9**	11.5	11.5	3.9	46.2	0.0	**73.1**	3
76	600	25.0	0.0	9.4	3.1	**37.5**	0.0	3.1	0.0	59.4	0.0	**62.5**	2
52	800	21.9	6.3	3.1	6.3	**37.5**	0.0	9.4	3.1	46.9	3.1	**62.5**	6
71	800	24.2	6.1	0.0	3.0	**33.3**	6.1	30.3	3.0	21.2	6.1	**66.7**	2
56	1000	20.0	0.0	5.7	5.7	**31.4**	2.9	8.6	0.0	54.3	2.9	**68.6**	1
73	1000	18.9	2.7	2.7	0.0	**24.3**	0.0	10.8	0.0	54.0	10.8	**75.6**	0
51	1200	11.8	5.9	2.9	0.0	**20.6**	8.8	14.7	5.9	41.2	8.8	**79.4**	3
74	1400	19.6	1.9	0.0	3.9	**25.5**	0.0	9.8	1.9	60.8	1.9	**74.4**	1
50	1600	11.4	2.3	4.6	2.3	**20.5**	0.0	15.9	11.4	43.2	9.1	**79.6**	2
75	1600	6.7	2.2	0.0	0.0	**8.8**	6.7	15.6	2.2	62.2	4.4	**91.1**	2
41	1375	36.1	19.4	2.8	2.8	**61.1**	2.8	30.6	2.8	0.0	2.8	**38.9**	8
42	1400	36.7	16.7	0.0	3.3	**56.7**	0.0	20.0	6.7	6.7	10.0	**43.4**	11
43	1525	37.2	18.6	2.3	7.0	**65.1**	7.0	18.6	4.7	4.7	0.0	**35.0**	13

4.2 RESULTS

Results are preliminary, however, they do highlight some interesting trends. As might be expected, there is a proportional relationship between stand density and crown closure (Figure 3). The threshold method shows a reasonable relationship to ground observations of closure and stems/ha. Tree delineation methods, whether based on the manually delineated vectors or automatically delineated isols, underestimate the crown closure. This was anticipated for the isols and the manually delineated crowns, since they often represented mainly the lit portions of the crowns and therefore are not always representative of the total crown closure. Also, the isolation procedure creates non-crown pixels from the image intensity valleys between adjacent and touching trees. Both the manual and isol crown closures, however, also have a weaker relationship to increasing stand density than the ground estimate of closure and threshold technique.

5.0 GAP ANALYSIS

5.1 METHODS AND RESULTS

The crown closure masks produced by the various methods above (e.g., isols and thresholds) were used to generate masks of non-crown open areas. A gap generating algorithm was then run on these open area masks to create gap maps or masks. The algorithm uses rules based on pre-specified minimum width of gap and minimum size. A second algorithm analyses the gap statistics for each gap within a specified region or stand and overall gap statistics for the area. Locations, area, perimeter, distance to nearest gap, perimeter to area ratio and diversity index are calculated for each gap. Also, general gap statistics were calculated for the plot or image area: the percent area occupied by gaps, gap density (gaps/ha), dispersion index, canopy edge (as a percent of total area) and mean fractal dimension of the gaps. Figure 4 shows the gaps of two subareas of the Tlatlos North site (an old growth area and young site containing plot 76). Gaps were generated from the crown mask derived from the ITC valley following tree delineation process (isols) and a minimum gap width of 2 m and gap size 4 m^2. Tables 2 and 3 give example statistics for a sample of gaps and overall gap statistics for the two subareas (see Figure 4). Note the gaps produced in the old growth area (Subarea 2) are bigger, more complex, and occupy more area than in the younger subarea.

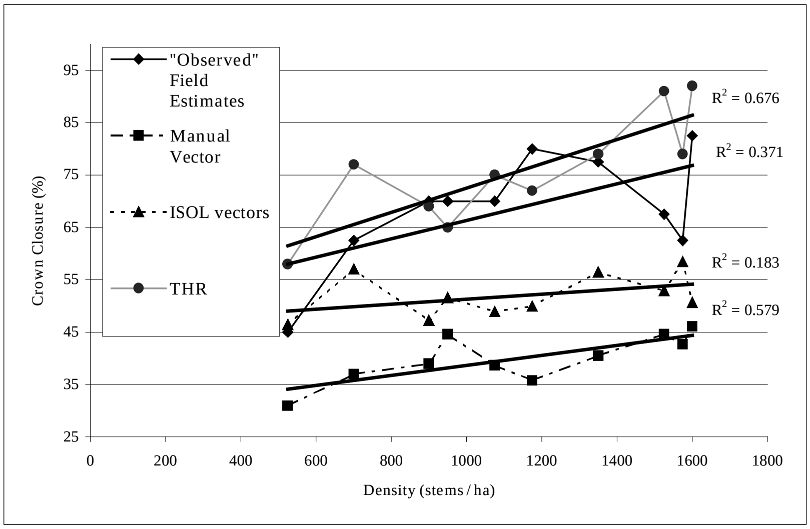

Figure 3. Comparison of crown closure estimates from field measurements, threshold techniques, automated tree delineation (isols), and manual crown delineations for the variable density plots.

6.0 CLASSIFICATION

6.1 METHODS AND RESULTS

Preliminary species classification were performed on two plots of old growth trees from the MASS site. The dominant species found in this image are western hemlock and amabilis fir, however small numbers of western red cedar, yellow cedar and mountain hemlock were also present. There are also some sick, damaged or anomalously bright trees of various species. Classification was performed on only three species western hemlock, amabilis fir and western red cedar. The minor species and sick or dead trees were not considered. In the old growth stands trees within shaded areas of the canopy can be common. To account for this, classes of shaded hemlock and shaded amabilis fir were also included. Due to low numbers of trees within the two plots, training, testing and classification was done on the same set of data.

Classification was conducted using an object based maximum likelihood classifier within the ITC software suite (ITCSC; individual tree crown supervised classifier). A combination of band ratios and individual spectral bands were used. The input spectral features were: a ratio of an infrared and red band (795nm/656 nm), a ratio of red and green bands (656 nm/550 nm), and the 861 nm and 715 nm bands. All the pixels within a tree crown delineation were used to calculate a mean band value for that tree. Signatures were then generated using the mean of all the trees included in a class. The mean values for each tree were then compared to particular class signatures and classified using a maximum likelihood rule. Each tree was therefore represented by only one value for each spectral feature and was classified as one object.

The average species classification accuracy was 73% after the shaded class results were combined with the species classes representing the normally illuminated trees. Table 4 gives the confusion matrix for the five

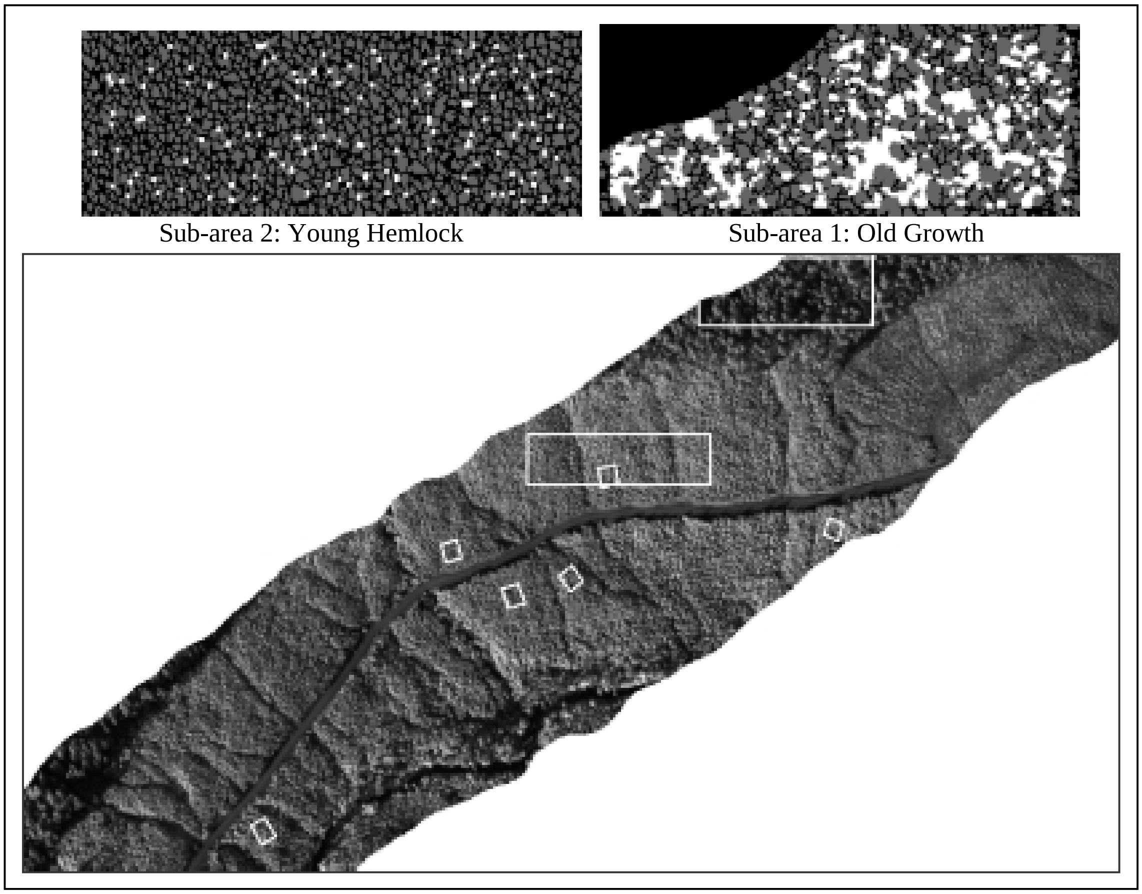

Figure 4. Gaps calculated from ITC isols are shown for two subareas of the Tlatlos Site. Grey proportions of the subareas are the ITC isols and white is the gaps produced with a minimum gap size of 4 m^2. Imagery shows location of field plots at the Tlatlos site and the two subareas.

Table 2. Individual Gap Statistics for a Sample of Gaps from the Two Subareas

Subarea 1 Young Hemlock

Gap_ID	8	9	10	11
Area (m²)	15	11	6	12
Perimeter(m)	6	7	4	5
N. N. Distance (m)	7	11	5	5
Ratio P/A	0.43	0.59	0.62	0.45
Diversity Index	0.66	0.79	0.60	0.63

Subarea 2 Old Growth

Gap_ID	11	12	13	14
Area (m²)	58	43	18	63
Perimeter(m)	35	22	15	33
N. N. Distance (m)	14	11	18	15
Ratio P/A	0.61	0.53	0.82	0.53
Diversity Index	1.85	1.37	1.39	1.68

Table 3. Sample of Summary Gap Statistics for the Two Subareas

Subarea 1 Young Hemlock

% of Gap Area:	13
Gap Density (#gaps/ha):	151.2
Dispersion Index:	1.07
Canopy Edge (% of area):	5.0
Mean Patch Fractal Dimension:	0.03

Subarea 2 Old Growth

% of Gap Area:	28
Gap Density (#gaps/ha):	99.3
Dispersion Index:	0.98
Canopy Edge (% of area):	12.1
Mean Patch Fractal Dimension:	0.78

classes. Note that these results are generated using manually generated tree boundaries and with all trees being used for training and testing. Variability of the spectral reflectance, illumination conditions and tree health were the major confounding factors affecting classification. There were difficulties in distinguishing between the two shaded classes. Use of the ratio bands improved the classification results when compared to a classification which solely uses the spectral bands.

Table 4. Confusion Matrix of Classification Results

	Hw	Hw-shade	Ba	BA-shade	Cw
Hw	75.0	0.0	0.0	10.0	0.0
Hw-shade	0.0	44.4	0.0	20.0	0.0
Ba	0.0	0.0	80.0	0.0	16.7
Ba-shade	25.0	55.6	0.0	70.0	0.0
Cw	0.0	0.0	20.0	0.0	83.3
Unclassified	0.0	0.0	0.0	0.0	0.0

In order to demonstrate the procedures for conducting a classification on automatically delineated trees, a second classification was performed. This classification used the signatures from the manually delineated trees to classify the ITC isols. Assessment of accuracy becomes complex in this situation (Leckie and Gougeon 1998). The isols will not correspond directly to the ground truth tree outlines. Results can be analyzed in many ways. Table 5 shows the classification accuracy analyzed on a tree-for-tree basis using the classes of isol-ground truth tree overlap used in the tree isolation accuracy assessment (Table 1). Of the good match trees 58% were classified correctly (14 of 24 trees) and the average overall classification accuracy was 62%. A confusion matrix can be created for the "good match" trees and isols. Of the grouped ground truth trees, all were classified as the correct species (in this case two ground truth trees of plot 42 were grouped into one isol, both were of the same species and the isol was classified as that species). Approximately 42% of the committed (unmatched) isols were classified as shaded hemlock, 26% as shaded fir and 26% as western hemlock. None were sunlit amabilis fir and 6% were classified as western red cedar. It is interesting to note that most of these spurious isols were classified as one of the shade classes and none were unclassified. There were four trees omitted (no isol match) and 9 poorly matched trees; these were 69% hemlock, 23% fir and 8% cedar. One ground truth tree was separated into two isols. It was a fir tree, but the isols were classified as shaded fir and shaded hemlock.

Table 5. Species Classification Accuracy Analysed on a Tree-for-Tree Basis

plots	(stems/ha)		1:1 perfect match	1:1 good match	N:1 perfect	1:N perfect	**Total Good**	1:1 with itc too big	poorly matched	separated	grouped	omissions	**Total Poor**	commissions
41	1375	ALL	8	4	0	0	**12**	1	6	0	0	1	**8**	8
		SP Correct	6	3	0	0	**9**	0	n/a	0	0	n/a	**n/a**	n/a
42	1400	ALL	7	4	0	1	**12**	0	3	1	2	3	**9**	11
		SP correct	4	1	0	0	**5**	0	n/a	0	2	n/a	**n/a**	n/a

7.0 SUMMARY

Techniques were described for the extraction of forest parameters from high resolution airborne multispectral imagery. These techniques were tested and demonstrated using 70 cm resolution imagery and field plots from two sites of 24 year old predominantly hemlock areas with varying density (500-1600 stems/ha) and an old growth site in the west coast forest environment of Vancouver Island, British Columbia. A tree isolation method based on a valley following approach followed by a rule based crown delineation worked reasonably well for the large old growth trees but underestimated the tree counts and had poorer tree-for-tree matching for the denser younger stands. The different crown closure techniques had mixed success for estimating crown closure with a tailored threshold technique producing the best results. Algorithms to extract gaps and gap statistics were demonstrated. Preliminary species classification of the old growth showed success and difficulties. There was considerable variability in the reflectance for trees due to species, health, and illumination conditions. A method was demonstrated for quantifying species recognition of automatically delineated ITC isols against ground truth trees which were manually delineated on the imagery.

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Dennis Paradine (formerly of Macmillan Bloedel) initiated the project and led the site selection and field data collection phases of the project. The support and input of Dr. Nick Smith of Macmillan Bloedel is also gratefully acknowledged. This study was financially supported by Forest Renewal of British Columbia as part of a co-operative project among MacMillan Bloedel Ltd., ITRES Research Ltd., and the Canadian Forest Service (Pacific Forestry Centre) entitled “Development of Certified Forestry Applications Using Compact Airborne Spectrographic Imager (casi) Data”. Data acquisition and processing, plus input into overall project design by ITRES Research Ltd. is gratefully acknowledged.

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