AUTOMATED INTERPRETATION OF HIGH SPATIAL RESOLUTION MULTISPECTRAL (CASI) IMAGERY: A DEVELOPMENT PROJECT FOR A FOREST COMPANY*

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ABSTRACT

A project to develop forestry applications of high spatial resolution airborne multispectral imagery from the Casi sensor has contributed to proving several key applications. Progress has been made regarding others. Emphasis is on automated interpretation at the single tree level. The project is a joint collaboration of MacMillan Bloedel Ltd., Itres Research Ltd., and the Canadian Forest Service. Casi imagery at a nominal 70 cm resolution was acquired over 20 sites on Vancouver Island, British Columbia, Canada. Detection of pockets of root rot disease and stream planform mapping have been successful. Tree isolation, stem counting, crown closure, gap mapping and species determination have met with success and some difficulties, depending on forest conditions. In addition, the project provided the impetus for Itres Research to develop operational regeneration assessment and stocking procedures. A key new initiative is in the documentation of partial cuts. An overview of the project with sample results is given in the context of the forest management needs of MacMillan Bloedel.

1.0 INTRODUCTION

Forest companies are facing enormous economic, market, environmental and regulatory pressures. There is increasing need to reduce cost of forest management planning, silviculture activities and the cost of bringing wood to the mills. Competition in the market place is driving the need for efficient operations, but a potentially more important aspect of the marketplace is boycott of wood that the public perceives as not being logged in an environmentally responsible fashion. Environmental issues often become driving factors in management decisions. In this milieu, government regulation of forestry practices have become strict and very onerous in terms of information needs and documentation. Macmillan Bloedel, a major worldwide forest company, is certainly not immune to these pressures. It has major operations on the west coast of British Columbia, Canada. All these issues are particularly relevant there. The cost of surveying the information they need for forest management is one opportunity they recognized to reduce costs. Improved timeliness of this information would help in better forest management decisions. Also considered important are surveys providing information products directly addressing their operational activities (e.g., thinning, fill planting, salvage of diseased trees, planning remedial post-harvest activities in area of root rot). New types of information are also needed to address various environmental issues such as habitat modelling and biodiversity. Research by the Canadian Forest Service and others into the use of high resolution airborne imagery had shown potential for extracting forest information in a timely, efficient, quantitative and potentially cost effective manner (Leckie and Gillis; 1992; Leckie 1994). A small group within the CFS had for some years worked on various aspects of the concept of using high resolution digital aerial multispectral imagery as an alternative to aerial photography and ground surveys for forest inventory, inventory update and damage

assessment (Leckie and Till 1987; Leckie et al. 1995). Automated tree isolation and species classification was a key focus (Gougeon 1995a, 1995b). ITRES Research Ltd., a company with one of its primary foci as developing and selling airborne hyperspectral sensors (casi), was shifting emphasis into also providing applications services and products. Good capabilities to geometrically correct and handle large volumes of data, plus improved imaging resolution were being developed. MacMillan Bloedel recognized these emerging technologies (automated analysis, high resolution image acquisition and efficient data processing) as a potential means of addressing some of its key needs and issues.

These needs, concepts, research and capabilities were merged into a joint project of MacMillan Bloedel Ltd., Itres Research Ltd and the Canadian Forest Service (CFS) termed "Development of Certified Forestry Applications Using Compact Airborne Spectrographic Imager (casi) Data" (Paradine et al. 1996). The research project was sponsored and funded by Forest Renewal British Columbia as a three year development and demonstration project. Its purpose was to investigate, develop, test and evaluate methods and algorithms for computer-assisted and automated analysis of high resolution Casi imagery for various British Columbia forest management needs. Focus was on practical information products for typical operational areas. Methods developed must be robust over varied sites. They must also be appropriate for non-optimal imaging conditions (e.g., mountainous terrain, cloud and low light levels, conditions not uncommon in coastal British Columbia). Information and methods must be suitable for effective integration into current forestry procedures and computing and personnel capacities. It is important that methods and systems are practical and cost effective. A key component is the testing of the accuracy. Not only is it important to be accurate to satisfy forest management needs but methods must be proven sufficiently to obtain approval by regulatory agencies. The overall intent is to make significant progress towards developing and proving cost effective methods of using Casi imagery to address the needs of MacMillan Bloedel, building an operational capability within Itres Research Ltd. and building a comfort level with the technology and efficacy of the methods among the forest management practitioners and regulatory agencies. Ultimately, it is desired to have remote sensing industry providing commercial services to forest companies in order to satisfy some of their key information and operational needs.

This paper outlines the project, its specific objectives, sites, image and field data acquisition, analysis procedures and results to date.

2.0 SPECIFIC OBJECTIVES AND PROJECT COMPONENTS

Project priorities were determined by MacMillan Bloedel Ltd. in consultation with the CFS and Itres Research based on their operational information needs and potential of the technology to fulfill them. A consideration was also the down stream business opportunities and market size for techniques and operational surveys. Core inventory parameters were an obvious focus (e.g., stem counts, crown closure and species discrimination). Crown size and volume were other inventory parameters considered but were exploratory and high risk. Extensive consultation with MacMillan Bloedel personnel from various aspects and districts of their operations identified additional priority applications. Operational forest managers desired a cost effective method to locate and quantify trees and pockets of root rot infestation in order to conduct salvage and plan remedial silviculture activity on infected areas. Current ground survey methods are time consuming and expensive at $40-$70/ha. The impact of forest activities on streams and fisheries habitat is a major environmental issue. There are requirements to map stream courses and their nature (e.g., British Columbia Channel Assessment Procedures). The width and requirements for riparian leave strips depends on the presence of fish and channel width. Forest and road engineers are concerned with volumes of sediments and large woody debris available for transport, especially in relation to catastrophic events during flooding. It may be desirable to monitor the effects of any logging activities. As well, many millions of dollars are being spent on stream rehabilitation. A stream mapping component was included in the project.

Openings in the canopy, their size, number and shape, are important environmental parameters related to habitat, biodiversity and fragmentation. These are examined as part of the crown delineation and closure estimation techniques. A special project was initiated in 1998 to derive and map closure and gap distribution as input to a habitat modelling procedure (Dunsworth and Northway 1997). This modelling uses biogeoclimatic variant, site

productivity in terms of tree growth, and forest age plus closure data to predict and map habitat diversity, quality and fragmentation. Obtaining good quantitative information on closure and gaps is a current weakness in the method. A study area was chosen to coincide with an existing pilot project testing the model and an area of good ground truth. Unfortunately, foggy conditions during the 1998 data acquisition campaign prevented implementation of this component of the project and the testing of integration of Casi data analyses into the habitat model.

Recently MacMillan Bloedel announced that they would phase out all clearcutting of old growth forest within five years. Therefore methods to record, prove, quantify and map partial cuts became a high priority. It was felt that Casi imagery and automated techniques could provide a viable tool. The requirement is to quantify the residual trees including their species. A system to map and quantify the nature of the stand before and after the cut is desirable in order to plan the partial cut activities and ensure the planned silviculture objectives were achieved. A new initiative within the project was implemented to develop and prove techniques for stem mapping, tree isolation and species identification of the residual trees. Although seemingly easier, illumination conditions on residual trees, the varied nature of the exposed ground vegetation, and cast shadow present new technical challenges for automated techniques. A series of partial cut test sites were selected and a new data acquisition campaign conducted in the fall of 1998.

3.0 SITES

The study sites are distributed throughout Vancouver Island on the west coast of British Columbia, Canada. They are designed to represent a suite of west coast ecosystems, forest types and forest management practices. They range from coastal rain forest to high altitude alpine to the drier conditions of the Douglas-fir eastern region of Vancouver Island. Most sites are on land operated on by MacMillan Bloedel Ltd. through Tree Farm Licenses or land ownership. The sites were also designed to be within a number of MacMillan Bloedel management districts to facilitate technology transfer and elicit input from local forest managers. Sites also represented various terrain, many sites having significant topographic relief with several being severe. Flight lines and data blocks were often aligned along valleys. As well, weather conditions will vary among such a variety of sites with poor illumination, overcast, cloud shadow, topographic shade and varying illumination on slopes. Optimum sites and weather conditions were deliberately not selected in order to exercise acquisition, processing and analysis under conditions which will be typical of west coast and MacMillan Bloedel land.

Figure 1 shows the distribution of sites. There were two acquisition campaigns, one in September 1996 and a second smaller one in September 1998. Most sites in the 1996 acquisitions consisted of 2 or 4 adjacent flight lines of 3 to 9 km long. Several areas including the MASS site were flown in larger blocks of 6 to 8 flight lines. The 1998 data concentrated on acquiring blocks of data covering partial cuts. Several sites (MASS and Shawnigan) were reflown in 1998 in order to test robustness of techniques with different data. Each site cannot be detailed here but some description is warranted. There were a series of sites of young western hemlock or Douglas-fir 24 and 30 years old which are associated with trials of different spacings 400 - 1600 stems/ha (Eve River-Tlatlos North, Eve River-Highway 19 and Menzies Bay). Another site is associated with a large interdisciplinary study (MASS, Montane Alternative Silviculture Systems) to investigate different silviculture practices in high elevation settings. It contains blocks of different partial cutting, regeneration and undisturbed old growth regimes. The Shawnigan Lake site is attached to a Douglas-fir spacing and fertilizer trial of the Canadian Forest Service. Other sites were selected to map streams and root disease damage. Among the sites there is a variety of ages from regeneration to old growth, species, density, productivity and ecological niches.

4.0 IMAGE DATA

The Casi sensor is based upon integrating the photon-induced electric charge on a CCD (charge coupled device) array for periods as short as about 15 msec. The optical elements of the Casi focus the light from a line on the ground perpendicular to the flight path to those array elements perpendicular to the flight path. Since this is a real optical system, there is a geometric scaling of the width of the area imaged on the ground (the swath width) to the height of the aircraft. Hence, the lateral dimension of the pixels is determined by height above ground. The spectral information is generated by an optical slit that causes the CCD elements along the flight direction to receive

the photons depending upon their spectral wavelength. After a fixed integration time, the CCD is emptied and a new integration period starts. The size of the image data pixels along the flight path is thus determined by the ground speed of the aircraft and the integration time. This instrument design means that the area on the ground covered by each pixel will vary throughout the image. In areas of complex topography and in conditions of variable wind speed and direction, the variations in the actual imaged area in each pixel will be larger.

The standard processing of the Casi imagery involves both radiometric and geometric corrections to the data. The first stage are the radiometric corrections that allow for the inherent differences in sensitivity of the optics and detector for differing wavelengths and for differing look angles. These corrections are not meant to correct for atmospheric effects. The second stage is the geocorrection or georeferencing of the imagery.

The September 1996 imagery was flown with a nominal pixel size of 60 cm and 8 spectral bands. The system at that time had a 2-dimensional gyro for correction of aircraft motions. This meant that the image could be geocorrected for roll and pitch aircraft motions, but not readily georeferenced. The September 1998 imagery was flown with a CASI-2 sensor (Babey et al. 1999) and a full three-dimensional motion detection system (a POS system manufactured by Applanix Ltd). This combination permitted full georeferencing, orthorectification of the imagery using a digital elevation model, generation of image mosaics of multiple flight lines, and an increase in the number of spectral bands from 8 to 10, with the same 60 cm nominal pixel size.

The primary band sets for the two acquisitions are shown in the Table 1 below.

Table 1. Spectral Bandsets Used for the Two CASI Image Acquisitions

1996 Acquisition		1998 Acquistion	
Band Number	Centre Frequency [nm]	Band Number	Centre Frequency [nm]
1	438	1	484
2	489	2	550
3	550	3	588
4	601	4	613
5	656	5	643
6	715	6	668
7	795	7	701
8	861	8	742
		9	782
		10	862

Note that the CASI-2 permitted more spectral bands due to a faster integration time. The spectral bands were also changed with more bands in the green to red range (550 nm to 660 nm) and more bands in the "red edge", the portion of the spectrum from the "red well" (at about 660nm, where healthy trees have a minimum spectral value), to the larger values in the near-infrared. The changes in bandset were based upon consultations between Pacific Forestry Centre, MacMillan Bloedel and ITRES and experience that ITRES has gained on many forestry programs. The changed bandset permits better health and species separations.

The geocorrection or georeferencing of the imagery involves selecting a nominal pixel size. A nearest neighbour resampling method of populating the analysis pixels was used. Because of the varying terrain elevation within many of the flight lines care was taken in choosing the best nominal geocorrected resolution to fit the application (Burnett et al. 1999). Data were geometrically corrected and orthorectified using DEM data to nominal resolutions of 60 to 80 cm. Radiometric and geometric processing of the data was conducted by ITRES Research. In certain cases, before using the imagery in analysis, imagery was corrected for view angle radiometric effects due to bidirectional reflectance and other factors by adaptive empirical methods (Leckie et al. 1999a).

5.0 GROUND TRUTH

Since one of the main focuses is to develop methods that were proven to satisfy forest management and inventory needs, considerable extra effort was placed on acquiring ground truth data to test and document accuracies. Accuracy can be tested on an area basis, assessing how well forest parameters are estimated within the area on average. It was strongly felt important to also assess results on a tree-for-tree basis as much as is practical. The core procedure was to select a suite of representative plots and document these on a single tree basis. Plots were generally 20x20 m. Within each, the coordinates of all stems were mapped. For each tree, species, diameter breast height (dbh), dominance and health condition were recorded. Height and crown diameter were measured for a sample of trees. Crown closure was estimated with two approaches. First, two field crew members made a visual percent crown closure call. Secondly, a grid based system was used. At each point in the grid, the location was registered as open (no crown opening directly above) or closed (canopy above) and closure was calculated for the plot. Grid spacing was 2 m. While in the field, reference points were located on the imagery in order to relate the plot and plot trees to the imagery. Eighty plots were established and measured. Some sites corresponded to MacMillan Bloedel permanent sample plots so historical and additional height and volume information could be used. Specialized field procedures were used to provide ground truth for root rot damage assessment, partial cuts, and stream mapping.

Plot data were compiled into a data base and transferred to the Casi imagery through a process which locates and outlines plot trees and plot boundaries on the imagery. Except on a few plots, trees were not mapped onto the imagery while in the field. Mapping onto the imagery in the field was desirable, but logistical considerations dictated otherwise. Mapping was time consuming and would have significantly limited the number of plots which could have been measured. In order to locate ground truth trees on the imagery, a plot of stem location, dominance and tree number was placed over the imagery. Along with this and the reference locations marked on the imagery, the plot boundaries were established on the imagery. Trees were located and outlined using all available species, dominance, dbh and health information plus image interpretation of different band combinations and zoom factors. The field data included trees of intermediate and suppressed dominance. Some of these were not detectable. In addition, some tree crowns were clustered and individual tree crowns were not separable. Therefore the ground truth trees outlined on the imagery were not always perfect one-for-one matches with the ground truth. The confidence level in the tree delineation and identification of trees was documented. For clustered tree delineations, the trees associated with each cluster were recorded. A software system was developed to integrate the tree vector outline on the imagery to the data base so that one could interactively query the field data and highlight selected trees on the imagery display.

6.0 APPLICATIONS

6.1 FOREST PARAMETERS

Core forest inventory parameters such as species composition, stem density (stems/ha), and crown closure are a primary focus for the project. Automated tree isolation algorithms based on various approaches are being tested. Methods include:
-   valley following (Gougeon, 1995a) where trees are considered peaks in image intensity separated by lower values; valleys in the image intensity are determined and followed upward to separate trees; a second phase follows the boundaries produced by the valley following step and a rules based system further separates or refines the tree boundaries;
-    tree top methods in which local maxima in the imagery are determined within a moving window usually 3x3 or 5x5 pixels; this only creates a single point for each tree;
-   thresholding or classification methods which produce masks of potential conifer or hardwood pixels and then these may be refined by various morphological or other operators;
-   other techniques such as template matching (Pollock, 1998) or cost surface analysis (Walsworth and King, 1998) may also be explored.

It is anticipated that the best approach will ultimately be combinations of these approaches together or applied adaptively depending on the forest type or various image features.

Species classification with high resolution imagery is a different paradigm from traditional remote sensing classification. The variation within a tree and its surrounds is very large. New approaches are being developed and used within this project. Once trees are isolated then signatures of various types can be generated and species classification conducted. Traditional maximum likelihood techniques applied in an object oriented approach are being tested as well as methods specifically adopted for high resolution imagery (e.g., tree colour line method (Gougeon 1995b) and rules based systems based on various band relationships).

Closure estimation is being approached in several different fashions. One is to use the delineations from the tree isolation step. These, however, generally underestimate closure. Threshold rules based on the relationship among bands and band ratios have proven best to date. They also have potential for being reasonably independent of illumination conditions. A challenge for crown closure algorithms is to minimize their sensitivity to look angle. If a simple spectral criterion is used to define conifers and/or hardwoods, then openings in the crown at larger off-nadir look angles can be lost. Several approaches were used to address this problem. In the 1998 image data, the look angle was included with the spectral values for each pixel in the georeferenced mosaic. This procedure permitted refinement of the crown closure techniques based upon a combination of spectral and spatial characteristics and tree structural spatial techniques for better crown closure estimations.

Gaps are openings in stands which have significance to wildlife habitat, biodiversity and other ecological issues. There is no accepted definition in terms of minimum size, width and shape. A software suite was developed to determine gaps under varying definitions and then determine gap statistics on individual gaps or the nature of all gaps within an area.

Figure 2 shows imagery from one of the flight lines from the MASS site. Figure 3 gives example results of an automatic tree isolation and classification, gap analysis (based on the isolation) and preliminary crown closure results for a subarea of an old growth block with minor patch cutting. Within the subarea there are 82 gaps with an average area of approximately 100 m^2. The crown closure analysis estimated closure at 68%. Leckie et al. (1999) details the methodology for extracting the above forest parameters and provides more detailed results on similar data.

Figure 4 gives results of the entire process of extracting and mapping inventory parameters through isolation, species classification and closure estimation. An algorithm to formulate environmental strata or stands was used to generate polygons of similar species, stem density and closure (Gougeon et al. 1998). The stands generally had one predominant species but also mixtures of other species usually less than 35%. Species composition assessed on an area basis against species determined from ground plots or transects were within on average 10% for the dominant species. Composition of species with greater than 25% composition was estimated to within 0% to 30% of ground data; average discrepancy being in the order of 15%.

6.2 VOLUME ASSESSMENT

Volume is a key attribute in forest inventory. Individual tree information such as stems/ha, species, crown size and perhaps stem distribution are elements that could be input parameters to volume relations. Tree height, however, is a key element that is needed. Height information is lacking from the data of this study. Pixel based methods were explored to determine relationships of Casi imagery to volume. Data from the Shawnigan Lake site were used. It has detailed ground measurements of volume for forty two 20x20 m plots. Means, variance and autocorrelation of the NDVI of pixels within the plots were related to plot volumes. It was felt a measure of the spatial variability or patterns might be important for volume estimation, therefore the autocorrelation of NDVI and wavelet analysis were investigated. NDVI itself was the best individual predictor of volume. A multiple parameter linear regression using NDVI, variance of the green channel and correlation coefficients produced the best prediction with an r^2 of 0.61 and prediction error of 10%. This work demonstrated that good relationships were developed for a controlled situation, but the application of model predictions to a wide variety of conditions and different images is a challenge (Magnussen and Boudewyn 1998).

This site is also being used as a test area in a separates study developing and testing techniques of stand height estimation from airborne laser data (Magnussen and Boudewyn 1998; Magnussen and Eggermont 1999). One study uses stem counts from a tree top isolation applied to the Casi data of this study to improve height estimates (Magnussen pers. comm.).

6.3 PARTIAL CUTS

Work regarding partial cuts is preliminary as this application was an added objective in 1998 based on changing MacMillan Bloedel forest management practices. Isolation of residual trees is confused by regeneration and other ground vegetation on the cuts and the often very bright illumination on the exposed open trees. Variable shadow and illumination in more dense cuts is also problematic. It is however anticipated that appropriate and reliable techniques can be developed. The spectral signatures of residual trees in the open were often different from those in closed canopies, perhaps indicating difficulties in species classification or the need for methods specifically tailored to partial cuts. Figure 2 demonstrates imagery over various types of partial cuts (green tree retention, shelterwood, patch cuts) and some of these potential difficulties.

6.4 REGENERATION ASSESSMENT

An original focus of the study was in assessing regeneration. Key is to determine the location of stems and determine stocking levels. Understocked or overstocked areas needing remedial fill planting or thinning should be identified. Level of competition from shrubs or hardwoods is also important in some cases. Development and testing of techniques has largely been accomplished outside this project. Itres Research through initial interest and contacts generated by this project has conducted several successful trials and commercial stocking surveys of regenerating areas (Brown and Fletcher, 1998; Price and Davison 1998). Some of the method development research for this work was sponsored by this project. Itres now offers assessment of regeneration stocking for trees taller than one meter on an operational basis. Approximately 100,000 ha of forests have been imaged with the Casi at a 60 cm resolution and conifer stem counts generated, primarily in British Columbia. Adaptive techniques to permit counting over a wider variety of tree sizes were introduced in a 1998 demonstration program in Ontario (Davison et al. 1999) and in British Columbia boreal forest analysis being undertaken in the spring of 1999 (Achal et al. 1999). An adaptive method employing different techniques depending on stem spacing and crown size has also been developed at the Pacific Forestry Centre (Gougeon and Leckie 1998).

6.5 ROOT DISEASE DAMAGE ASSESSMENT

Phellinus weirii is an endemic root disease in the Pacific Northwest region of North America. It causes trees to slowly lose vigour and needles and eventually die. It spreads from a centre and therefore often results in an infection centre with a gap in the canopy sometimes with dead snags and defoliated trees near its centre and trees with only subtle crown shape or chlorotic symptoms at its edge. The Cassidy site near Nanaimo was investigate to determine capabilities for assessing root disease damage level on an individual tree basis and for mapping root disease centres. Imagery was corrected for view angle effects and classification of manually delineated trees showed promising results of greater than 80 % for healthy, light, moderate, severe and dead classes (Leckie et al. 1998). There was considerable confusion of the light and healthy class. False alarms are expected to be a problem, but the pattern associated with a root rot pocket (open centres and decreasing damage level outward) should help alleviate this problem. Screening out false alarms on this basis could be done manually or algorithmically through, for example, a rules based expert system. Figure 5 gives an example of a damage level classification of automatically isolated trees.

6.6 STREAM PLANFORM MAPPING

Sand, gravel, cobble, woody debris (logs and concentrations of smaller debris) and deep moderate and shallow water were classified for a mosaic of 80 cm resolution Casi image of Tofino Creek. A spectral angle mapping approach was used. Preliminary results indicate accuracies in the 80 percentile range for these classes (Paradine et al. 1998). Confusion was larger, but reasonable results achieved, in shadow areas except in extensive deep shadowed stretches.

7.0 DISCUSSION

Key information needs of MacMillan Bloedel Ltd. which might be addressed by high resolution Casi imagery were identified and method development and testing studies were designed. It appears that viable methods of stream planform mapping and detection of *Phellinus weirii* root disease damaged trees and infection pockets are feasible. The initiative of this project led Itres Research to pursue and develop operational regeneration assessment methods in separate projects in northern British Columbia. Methods of forest parameter extraction and partial cut documentation remain under development and testing but significant positive results have been achieved and problem issues identified. Robustness, cost and practicality of methods are important considerations. Real success will be the development of a capability within the remote sensing service sector, acceptance of methods by MacMillan Bloedel and regulatory agencies, and operational use to effectively meet the forest management needs of forest companies in a cost effective manner.

8.0 ACKNOWLEDGEMENTS

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FRBC-CASI Project
Flight Locations 1996-1998

Port Hardy

Brooks Penisula

5b
5a
5d
5c
3

Courtenay

11
Port Alberni
12
10
Nanaimo
1
4a
2a
9
8a
2b
4b
6d
6c
6a
6b
Tofino

7

Victoria

1996	1998			
●		1	Tofino Creek	to
●		2	Kennedy Flats	kf
●	○	3	Mass	ma
●		4a	Nahmint Lake	nl
●		4b	Nahmint Species	ns
●		5a	Eve River (Tlatlos North)	tn
●		5b	Kelsey Bay	cf
●		5c	Menzies Bay	sr
●		5d	Eve River (Highway 19)	hy
●	○	6a	Cassidy & Block 841	ca
●		6b	Jump Lake	jl
●		6c	Dunsmuir Creek	du
●		6d	Mt Hooker	
●	○	7	Shawnigan	sh
●		8	Cameron Valley	cr
●		9	Nahmint Fire	nf
	○	10	Partial Cut 1	pc1
	○	11	Partial Cut 2	pc2
	○	12	Partial Cut 3	pc3

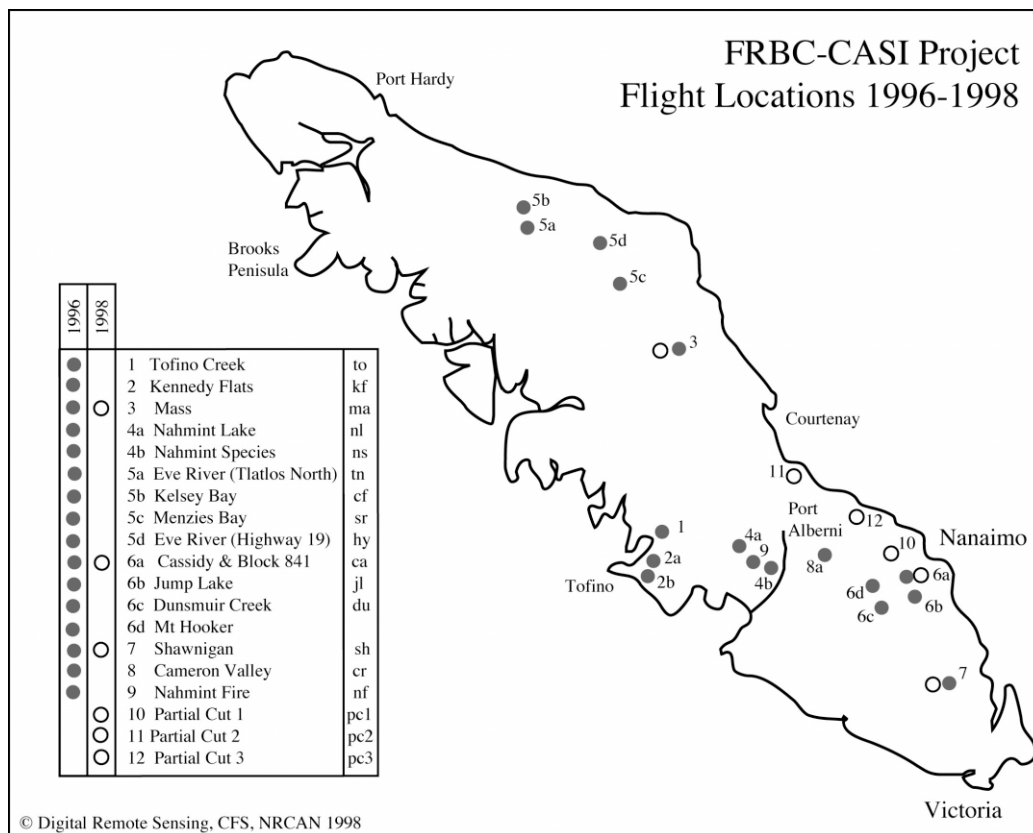© Digital Remote Sensing, CFS, NRCAN 1998

Figure 1. The Distribution of Study Sites on Vancouver Island.
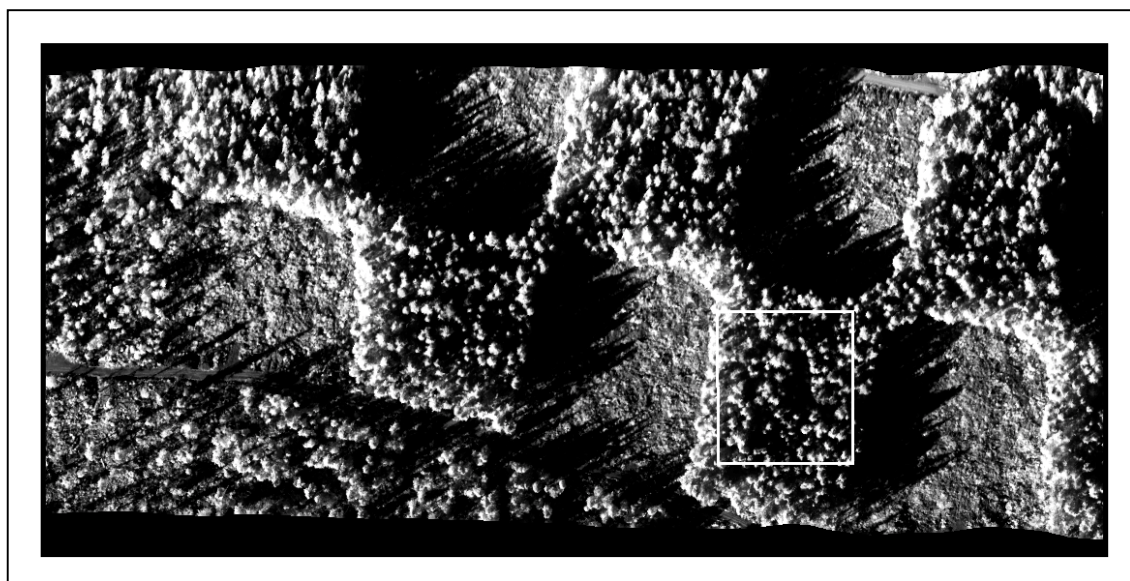

Figure 2. MASS - Partial Cut Site. This is an example of the Casi imagery used in this study. This particular example has a resolution of 70 cm. The subarea shown in Figure 3 is outlined.
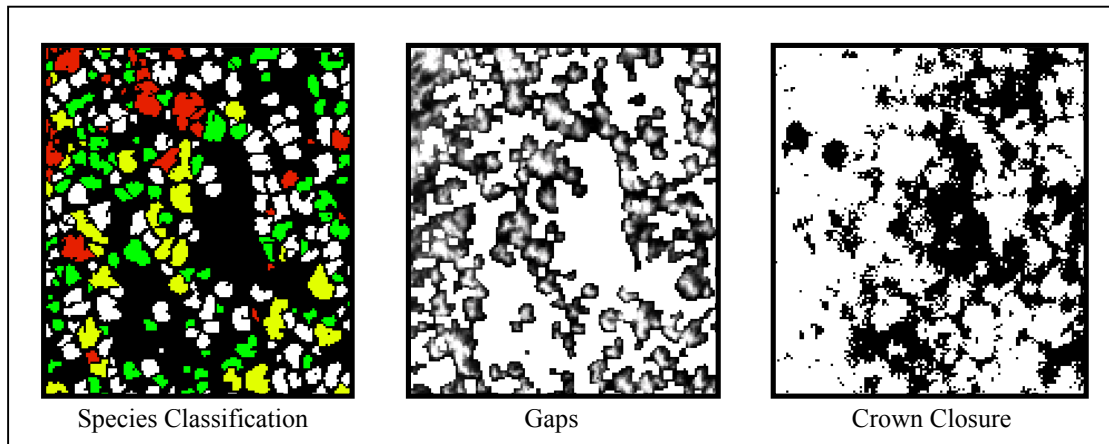
Figure 3. Species Classification, Gap and Closure Masks. Species are as follows (in the order of lightest to darkest): western cedar, western hemlock, amabilis fir and unclassified. The white areas indicate the gaps and crown areas for the gap and closure images, respectively.
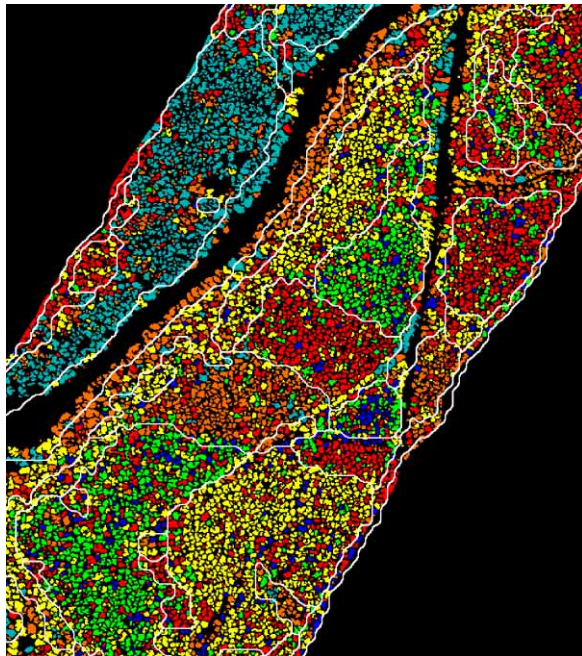

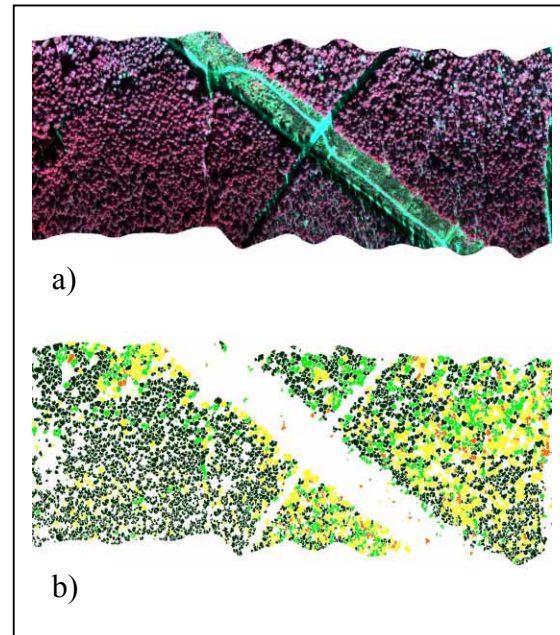Figure 4. Example of Results from Automated Isolation, Classification and Stand Delineation.

Figure 5. Classification Results on Automatically Isolated Trees. Classification shows different levels of tree health from healthy to mortality resulting from *Phellinus weirii* root disease which occurs in pockets throughout the site. The image is approximately 750 m long. a) is the imagery and b) is an example of a health classification.