RECOGNIZING THE FOREST FROM THE TREES: INDIVIDUAL TREE CROWN DELINEATION, CLASSIFICATION AND REGROUPING FOR INVENTORY PURPOSES*

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ABSTRACT

In forestry digital remote sensing, the high spatial resolutions of images available from multispectral airborne sensors and digitized aerial photographs, as well as from the upcoming earth observation satellites, forces a shift in image analysis paradigm to deal directly with the essential structural element of forest stands: the individual tree crown (ITC). This paper briefly describes techniques for separating tree crowns from one another and from the background vegetation, recognizing one by one their species and, if desired, regrouping them into forest stands. A system developed and tested using high spatial resolution (30-100 cm/pixel) MEIS images is used for the first time on a Casi image. For five coniferous species, the overall accuracy of the ITC-based classification is 68.3%. The trees are then successfully regrouped into forest stands using image-wide quantifications of stem density, canopy closure and species concentrations. On-going research with this ITC-based approach suggests that these are significant steps towards the semi-automatic production of precise and versatile forest inventories.

1.0 INTRODUCTION

Forestry is major component of Canada’s landbase and economy. Canada has 10% of the world’s forests. About one half of the country’s one billion hectares is covered by forest, of which half is considered "productive". Nearly 880,000 Canadians are employed directly or indirectly by the forestry sector, or 1 in 15 jobs. Canadian forest products constitute about 16% of Canada’s export revenues and 20% of world trade. Canadian forests are 94% owned by the public, mostly via their provincial governments (Nat. Res. Can., 1996). The continuous assessment of this renewable resource is a perennial commitment and a substantial task.

Existing management inventories consist of stand mapping and content assessment derived from aerial photo interpretation, plus volume estimates derived from field sampling and stratification. They are typically generated by the provinces on a 10 to 20 year cycle using 1:10,000 to 1:20,000 aerial photographs (Leckie and Gillis, 1995). Throughout Canada, 24 million hectares are mapped every year. Digital remote sensing has not yet been able to supply the detailed information required for these traditional forest management inventories. Modern management inventories, meant to manage the forest resource in accordance with much stricter rules taking biodiversity, wildlife, environmental and recreational concerns into account, require even more details. Fortunately, forestry digital remote sensing is also going through a metamorphosis.

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The high spatial resolutions of images available from multispectral airborne sensors, digitized aerial photographs and upcoming earth observation satellites should imply a shift in image analysis paradigm. Ideally, one should leave behind the pixel-based classifications and area-based segmentations typically used at lower spatial resolutions and deal directly with the essential structural element of forest stands: the individual tree crown. This paper briefly describes such an approach and shows various preliminary results. This "Individual Tree Crown" (ITC) approach consists of separating the crowns from one another and from the background vegetation, recognizing one by one their species and, if needed, regrouping the crowns into forest stands. It offers a good potential towards a semi-automatic production of forest inventories in which the species composition of stands would be known with precision. Other forestry parameters such as tree crown diameters, canopy closure, stand density, non-forested patch distribution, etc., are also easily obtained for each stand. It also offers the capability to retain the individual tree-based information, which may be particularly useful for silviculture treatments, selective cuts or biodiversity assessments.

2.0 TECHNIQUES AND METHODOLOGY

2.1 INDIVIDUAL TREE CROWN DELINEATION

In most mature conifer stands, it is generally possible to isolate individual tree crowns using the areas of shade in between them. These areas correspond to shaded ground or understory, or to shaded parts of the crowns. Using only one spectral band, typically the near-infrared, the isolation process (ITCVFOL, see Figure1) first thresholds a smoothed version of the image (FAV[+]) to remove large shaded areas. It then finds local minima in the remaining image. From these points, it systematically follows the valleys of shade which are found between the higher intensity crowns. Visually, this leads to a rather good separation of coniferous crowns, but most of them are not fully separated from their neighbours. A delineation process (ITCISOL), which uses a rule-based approach to systematically follow a specific crown boundary in a clock-wise fashion, is utilized to produce completely distinct crowns. These automatic crown delineation techniques, described and tested in (Gougeon, 1995b), were shown to lead to coniferous crown counts that were within 7.7% of those done on the ground. They are the subject of on-going research and are being continuously improved, more recently, to function with 16-bit image data and to accommodate a mask preventing certain image areas from being considered by the delineation process. This last feature is typically used in conjunction with a pre-classification (UC[+])of roads or well lit forest openings.

2.2 INDIVIDUAL TREE CROWN CLASSIFICATION

Once the individual tree crowns are well delineated, a crown-based supervised classification process is initiated (see Figure1). Spectral signatures are acquired for representative tree crowns of each species (using Imageworks[+] and/or DCPE) and species signature are calculated (ITCSSG). The classification system (ITCSSG and ITCSC) supports various ITC-based signatures (Gougeon, 1995a). Here, the multispectral average of the lit side of crowns signature-type (AVG_LIT) is used. Sample crowns of each species are also acquired to later test the classification accuracy (ITCCA). Classification results (Gougeon, 1995a, 95c, 96) with four or five coniferous species have usually been in the 72 to 81% range, depending on the spatial resolution used (30-100 m/pixel).

[+] Denotes regular programmes from the PCI© environment.

2.3 FOREST STANDS DELINEATION

Although having information on an individual tree basis may be of great interest to researchers for small studies and pilot projects, it is barely conceivable at this point in time to gather and keep this type of detailed information over large areas. Forest stands are still the preferred units of Canadian forest management inventories. Fortunately, it is possible to regroup crowns into forest stands using image-wide quantifications of parameters such as stem density, canopy closure and species concentrations, followed by a simple unsupervised classification and a vectorization of the results.

Firstly, using the bitmap of isolated tree crowns produced by ITCISOL, a programme (CCLOSURE, Fig.2) creates an image where each pixel corresponds to the quantity of crown material found in a fixed-size roving window around that pixel. Secondly, using the same input bitmap, another programme (STEMDENS) creates an image of stem density by reducing every crown to its center of gravity and summing the stems found in a fixed-size roving window. Thirdly, the same programmes are used once per species on the species-specific bitmaps produced by the ITC classification. Fourthly, all of the images just produced are input to an unsupervised classifier. The classification is repeated a few times asking for a different number of classes until reasonable forest stands are achieved. When satisfied, stands smaller than a given minimum area are removed ($SIEVE^{+}$) and a mode-based filtering (FMO^{+}) is done to smooth out the stand boundaries. Finally, the classes are fed to a raster to vector conversion programme (RTV^{+}) in order to obtain polygons that can be passed on to a geographic information system.

3.0 IMAGERY AND STUDY SITE

The Compact Airborne Spectrographic Imager (Casi) is a Canadian-made pushbroom sensor acquiring visible to near-infrared multispectral imagery (Anger *et al.*, 1994). Originally built as a sampling spectrometer, it now offers various modes in which trade-offs are made between the spectral and spatial resolutions. For this study, eight spectral bands (~25nm) were acquired for 512 across-track pixels using a 38° field of view from an altitude of 500m (60 cm/pixel) over an area known as the "Nahmint species trial". This data is a subset of a much larger dataset acquired over various areas of Vancouver Island, British Columbia, Canada, by Itres Research and MacMillan Bloedel Ltd., to demonstrate the usefulness of Casi data for forestry applications.

The Nahmint site is located by the Nahmint River, south of Port Alberni. It was established to compare height and volume growth of five coastal coniferous species (Dunsworth, 1990): Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), amabilis fir (*Abies amabilis*), western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). Figure 3 shows a pseudo-colour infrared rendition of the Casi image acquired over the Nahmint study area, with the known stand boundaries and our classification training and testing areas.

4.0 RESULTS AND DISCUSSION

Following the methodology described above and depicted in Figure 1, the near infrared channel of the Casi image was smoothed with a 3x3 kernel, individual tree crowns were extracted, species signatures were generated and a supervised classification was performed and tested for accuracy. The results of the classification process are shown in Figure 4. For these preliminary results, the multispectral average of the lit side of crowns were used to generate the species signatures and classify the individual tree crowns. Other signature-types led to relatively similar results. Classification accuracy is assessed on an ITC basis using separately generated testing areas. The confusion matrix shown in Table 1 is an average of the two classifications obtained by interchanging the testing and training areas. This is a more robust estimation.

The overall classification accuracy (68.3%) is approaching the typical range of 70-80% previously achieved with MEIS imagery for a comparable number of coniferous species, although in eastern Canada. The western hemlocks (89%) were easily separated from the other species. However, both training and testing areas are in parts of the stand closer to nadir and the rest of the stand seems to experience recognition difficulties. This could also be related to the presence of relief. Visually (Fig. 4), the western cedars appear easily recognized. Their known stands are dominated by the species. Their poorer classification accuracy of 59% may be attributed to the location of the testing area. The firs are relatively well recognized: Douglas-firs (64%), grand firs (57%) and amabilis firs (66%). It is noteworthy that while confusion exists among the firs, there is little confusion with the western redcedars or hemlocks. In fact, if sub-species recognition among firs is not critical, then their recognition accuracy can be estimated to be above 95%. Some of the confusion on the right-hand side of the Douglas-fir and hemlock stands can be attributed to their off-nadir position. Trees on that side of the image are essentially backlit. Similarly, the stand in the upper-right-corner should mostly consist of redcedar. Since the image was not radiometrically corrected for view and sun angles, which as revealed by other studies on high resolution aerial images (Leckie *et al*., 1995) can be a significant factor, the crowns most off-nadir to the right tend be classified as lower reflectance species. This is the subject of ongoing research.

The regrouping of individual tree crowns into forest stands was achieved using the methodology described earlier and depicted in Figure 2. The approach appears very promising as demonstrated by the resulting stand delineation (Figure 4). A more systematic evaluation by forest inventory practitioners is needed to address the implementation of various criteria specific to provincial or forest management inventories. In addition, a more quantitative way to compare automatically generated stands with manually delineated photointerpreted stands may be desirable.

Of course, because of the ITC information, the species contents of such stands can be known with a level of detail never achieved before. Information such as, average crown area, average tree distances, non-forested patch sizes, canopy closure, stem density, etc., and parameters about their spatial distributions, can also be calculated for each stand, and if desired, for each species within a stand. Similarly, this type of information can be also be accumulated for wider areas.

5.0 CONCLUSION

A system for delineating individual tree crowns, identifying their species and regrouping them into forest stands was tested with a 60 cm/pixel Casi image. Separating five western Canadian coniferous species, the supervised classification led to an overall classification accuracy of 68.3%. The computerized forest stand delineation methodology produced stand outlines very similar to the existing ones. Previous work (Gougeon 1995c) has shown that for coniferous species, similar results are achievable with 30-100 cm/pixel multispectral images. Some success is expected with images from the next generation (Fritz, 1996) of earth observation satellites (80-100 cm/pixel).

These encouraging results should be tempered by the fact that there are still several research and operational problems to resolve before our goal of semi-automatic generation of precise forest management inventories is achieved. To address these concerns, research is ongoing with issues such as: deciduous tree crown delineation, crown-based texture and structure signatures, height, merchantable wood volume and biomass estimations; unsupervised classification, radiometric corrections and signature extension, view and sun angle effects, topography, ...

The possibility of achieving from digital remote sensing the kind of information that foresters have always wanted in order to manage one of our most important renewable resource may be within reach. An ITC-based paradigm also facilitates the assessment of stands after selective logging and of newer inventory parameters such as, non-forested patch distributions, snag locations, and other biodiversity and wildlife criteria and indicators needed for the multipurpose management of our forests.

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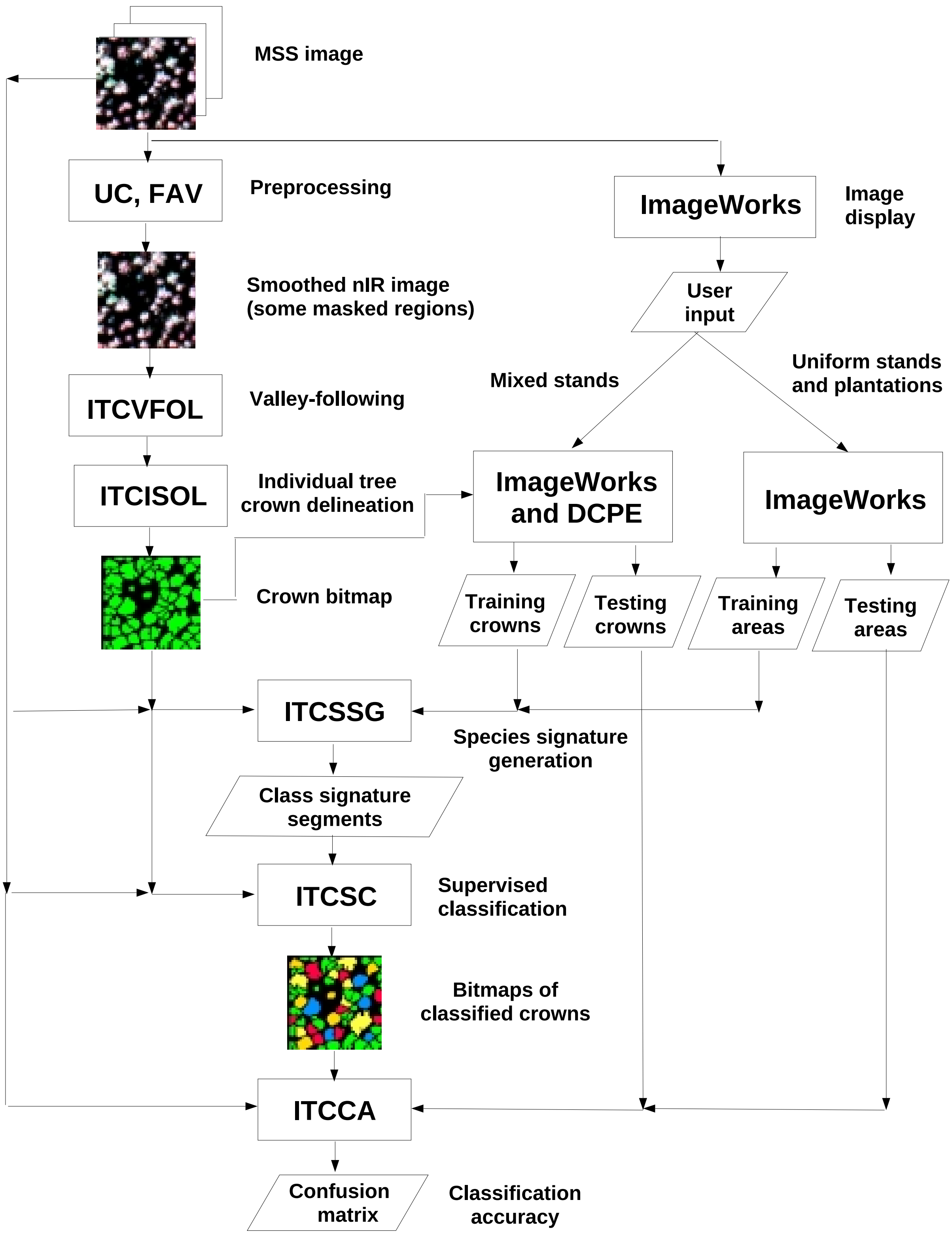


Fig. 1 - Methodology for individual tree crown supervised classification

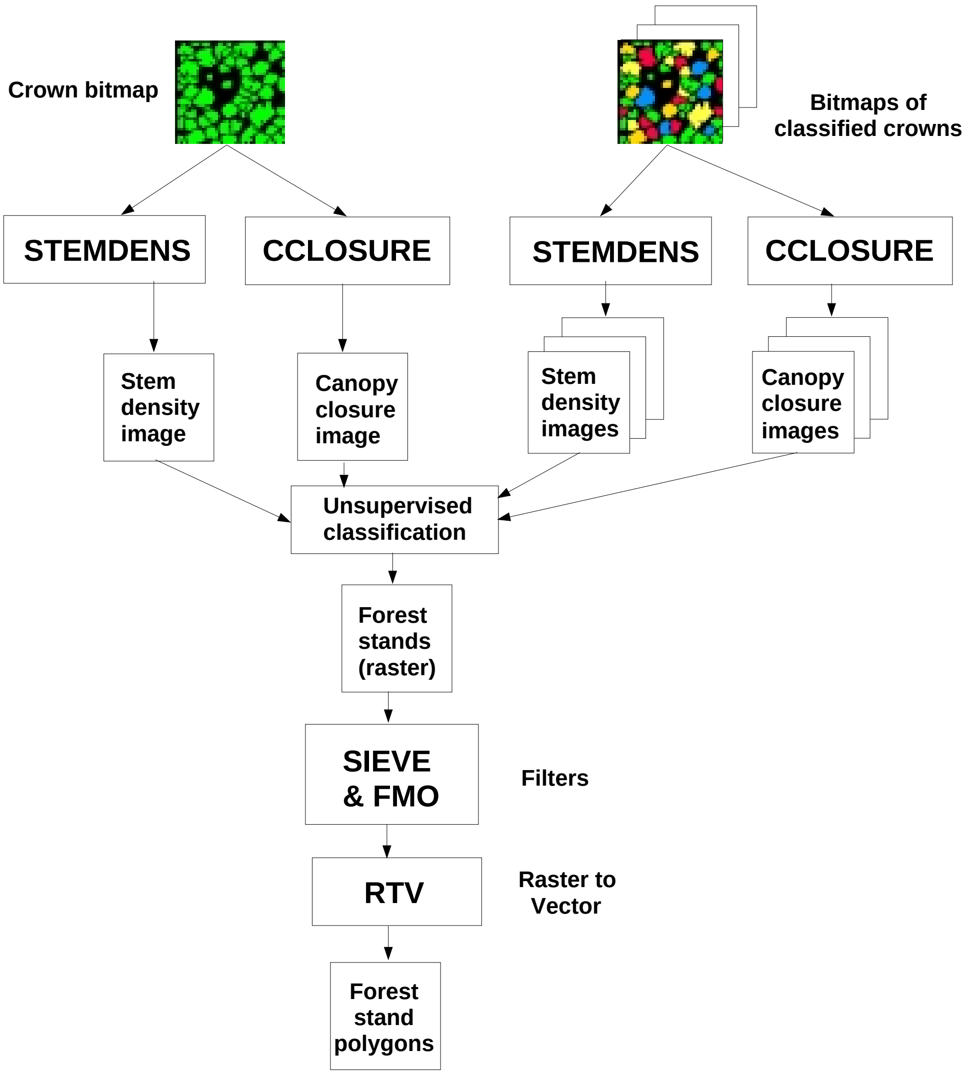
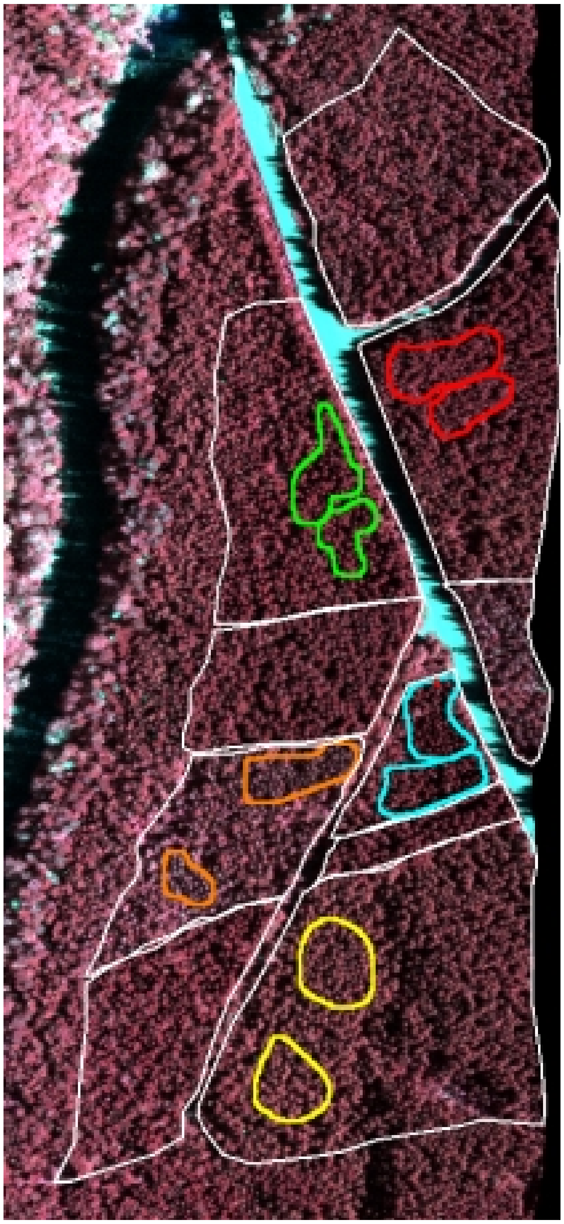


Fig. 2 - Methodology for forest stand delineation from individual tree crown information

Table 1 - Individual tree crown classification accuracies

	Fd	Bg	Ba	Cw	Hw
Fd	25 (64.1%)	12 (27.3%)	14 (26.4%)	7 (21.9%)	1 (1.9%)
Bg	7 (17.9%)	25 (56.8%)	2 (3.8%)	3 (9.4%)	4 (7.5%)
Ba	6 (15.4%)	6 (13.6%)	35 (66.0%)	1 (3.1%)	1 (1.9%)
Cw	0 (0.0%)	0 (0.0%)	0 (0.0%)	19 (59.4%)	0 (0.0%)
Hw	1 (2.6%)	1 (2.3%)	2 (3.8%)	2 (6.2%)	47 (88.7%)
	39	44	53	32	53

Average Accuracy = 67.0% Overall Accuracy = 68.3%



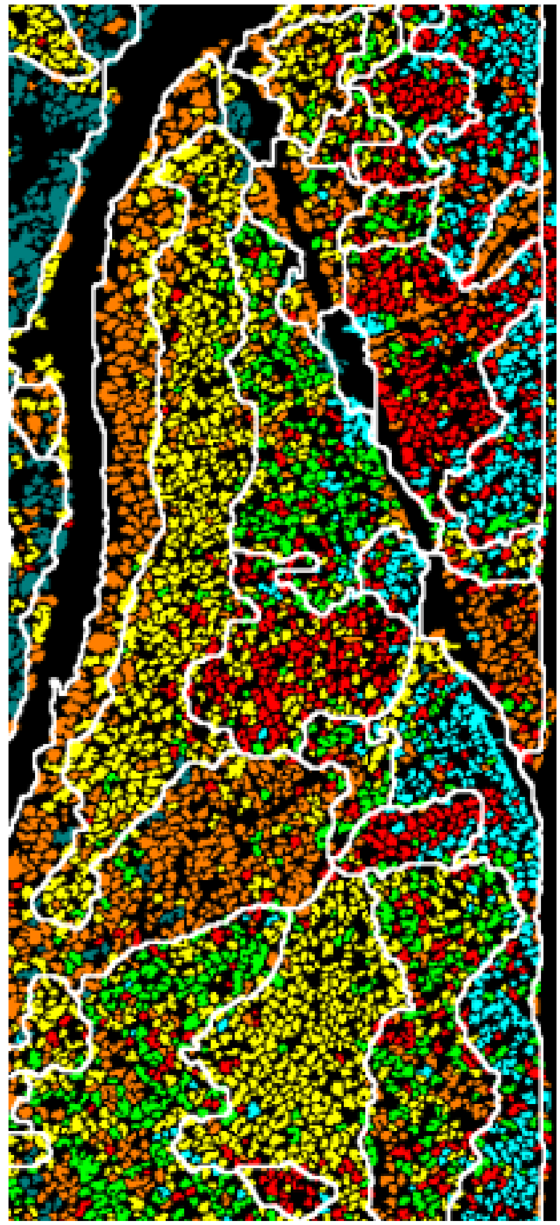


Fig. 3 (left) - Pseudo-colour infrared rendition of a sub-area of a Casi image (60 cm/pixel) of the Nahmint Lake species trial area in the central forest of Vancouver Island, British Columbia, Canada. The delineated areas (in white) correspond to stands judged relatively uniform by a forester. The training and testing areas used for the classification were delineated where species are known to be homogeneous (Dunsworth, 1990). Their respective species and colours are: Douglas-fir (*Pseudotsuga menziesii*) in red, grand fir (*Abies grandis*) in green, amabilis fir (*Abies amabilis*) in blue, westerm redcedar (*Thuja plicata*) in orange, and western hemlock (*Tsuga heterophylla*) in yellow.

Fig. 4 (right) - The individual tree crown (ITC) classification of Figure 3 and its computer generated forest stand outlines using the same colour scheme as Figure 3.