INDIVIDUAL TREE CROWN SPECIES RECOGNITION: THE NAHMINT STUDY

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ABSTRACT

The species content of forest stands is an information of paramount importance in conventional forest inventories. Typically, the stands and their content are assessed by human interpretation of aerial photographs. However, using remotely sensed aerial images or digitized aerial photographs of high spatial resolution (10-100 cm/pixel), it is now becoming possible to automatically delineate most of the visible individual tree crowns (ITC) in such images. This led to the development of several ITC multispectral signatures and of an ITC-based supervised classification system making possible ITC species recognition. The resulting information on the individual trees can be preserved, where very detailed information is needed; or collated, to generate very precise information on existing forest stands, or regrouped (statically or dynamically) using new criteria, to help with multi-resource forest management.

This paper primarily addresses the species recognition aspects of this new paradigm for generating precise information useful to forest inventories. The ITC-based delineation and classification system is tested with a geometrically corrected 60 cm/pixel casi image of the Nahmint Lake species demonstration area, Vancouver Island, British Columbia. Simple correction curves to compensate for bi-directional reflectance function (BRDF) effects were applied to the multispectral image in spite of the fact that the image had been previously geometrically corrected by the supplier. The ITC-based supervised classification of five western Canadian coniferous species and a generic hardwood class led to an overall classification accuracy of 59.8% when tested with a conventional confusion matrix approach. These low classification results are attributed to the lack of purity of the training and testing areas. A comparison of the species content of more sizable testing areas with their corresponding field transects led to an overall error of 12%, 19.5% when only the dominant species is considered. The paper concludes with a discussion of the research and operational problems to be resolved before the goal of semi-automatic generation of precise forest management inventories is achieved.

Keywords: forest inventory, remote sensing, image analysis, individual tree crown, species recognition, casi.

RÉSUMÉ

RECONNAISSANCE DES ESPÈCES À PARTIR DE L'ÉTUDE DES HOUPPIERS : L'ÉTUDE NAHMINT

L'information sur les espèces qui composent un peuplement forestier est cruciale pour la réalisation d'inventaires forestiers classiques. L'évaluation des peuplements et de leur composition s'effectue généralement

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par interprétation humaine de photos aériennes. Cependant, grâce aux images aériennes de télédétection et aux photos aériennes numérisées à haute résolution spatiale (10-100 cm/pixel), on commence à pouvoir délimiter la plupart des houppiers (ITC, pour Individual Tree Crown) qui apparaissent sur ces images. Ces progrès ont mené à la détermination de plusieurs signatures spectrales pour les ITC et à la mise au point d’un système de classification dirigée basé sur les ITC aux fins de la reconnaissance des espèces. L’information ainsi obtenue sur les arbres individuels peut être conservée pour répondre aux besoins en information très détaillée. Elle peut également être interclassée, en vue de générer une information de haute précision sur les peuplements forestiers existants, ou encore être regroupée (de façon statique ou dynamique) en fonction de nouveaux critères afin de contribuer à la gestion forestière à objectifs multiples.

Le présent rapport porte principalement sur les aspects de la reconnaissance des espèces à partir de ce nouveau modèle de génération d’informations précises et utiles à la réalisation d’inventaires forestiers. Le système de délimitation et de classification axé sur les ITC est mis à l’essai à l’aide d’une image de 60 cm/pixel ayant subi une correction géométrique et captée par spectromètre imageur aéroporté compact (CASI) au-dessus de la zone de démonstration du lac Nahmint sur l’île de Vancouver, en Colombie-Britannique. Pour compenser les effets de la fonction de réflectance bidirectionnelle (BRDF), on a appliqué à l’image des courbes de correction simple, même si elle avait déjà été géocorrigée par le fournisseur. Mise à l’essai avec une matrice de confusion classique, la classification dirigée basée sur les ITC de cinq espèces de conifères et d’une classe générique de feuillus de l’Ouest canadien a obtenu une exactitude globale de classification de l’ordre de 59,8 %. Ces résultats peu concluants sont attribuables au manque de pureté des zones d’entraînement et d’essai. En comparant la composition des espèces de zones d’essai plus vastes avec les transects correspondants établis au sol, on a obtenu une erreur globale de 12 % et de 19,5 % lorsque seules les espèces dominantes ont été prises en compte. Le rapport présente en conclusion les problèmes opérationnels et les problèmes propres à la recherche qu’il convient de résoudre avant de pouvoir générer de façon semi-automatique des inventaires précis aux fins de l’aménagement forestier.

INTRODUCTION

Representing 10% of the world's forests, Canada's forested lands cover 417.6 million hectares, 57% of which are considered commercial forests (Natural Resources Canada, 1996). Even though only 119 million hectares are currently managed for production, the continuous assessment and monitoring of this renewable resource represents a substantial task. Existing management inventories consist of mapping forest stands and their content from aerial photo interpretation (at the 1:10,000 to 1:20,000 scales), plus volume estimates derived from field sampling and stratification (Leckie and Gillis, 1995). Throughout Canada, whether by government or industry, 24 million hectares are mapped every year. So far, digital remote sensing has not been able to supply information at the required level of detail. In addition, 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, with the advent of higher resolution images, forestry digital remote sensing is presently going through a change in paradigm.

The high spatial resolutions of images available from multispectral airborne sensors, digitized aerial photographs and upcoming earth observation satellites imply a shift from the pixel-based classifications and area-based segmentations typically used at lower spatial resolutions to an "individual tree crown" (ITC) based analysis. Given that crowns are visible in these images, it is especially important for computer analysis tools to deal directly with this essential structural element. Forest stands, a higher level concept, can be tackled later, as a post-processing operation. The ITC-based 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 is an important initial step towards the semi-automatic production of forest inventories in which the species composition of stands or environmental strata could be identified with precision. Other important forestry parameters such as tree crown diameters, canopy closure, stem density, non-forested gaps distribution, etc., could also be easily obtained for each stand. The capability to retain, if desired, the individual tree based information should be particularly useful to plan selective cuts or make some biodiversity assessments. This paper briefly describes the implementation of such an approach and shows preliminary results on the Nahmint experimental site.

TECHNIQUES AND METHODOLOGY

INDIVIDUAL TREE CROWN DELINEATION

In most mature coniferous forest or plantation, it is generally possible to isolate individual tree crowns and/or tree clusters using the bands of shade that typically separate them. These bands correspond to shaded ground or understory, or to shaded parts of the crowns. Using a smoothed (FAV[+] , see Figure 1) version of the near-infrared channel, which is typically better for general purpose inventory, the isolation process (ITCVFOL) first thresholds the image to remove large shaded areas. Assuming non-forested areas have been masked out (manually or by some pre-processing of the image), it then finds local minima in the remaining forested areas of the image These minima correspond to the darkest pixels of shade between tree crowns. From these points, it systematically follows the valleys of shade which are found between the higher intensity crowns. This leads to a rather good initial separation of coniferous crowns, but for various reasons (e.g., a protuberant branch), most of them are not fully separated from their neighbours.

A delineation process (ITCISOL), which uses a rule-based approach to systematically follow from the inside a specific crown (or cluster) boundary in a clock-wise fashion, is utilized to produce more distinct crowns. From then on, the individual tree crowns are considered as distinct entities or objects, although for simplicity and compatibility with the image analysis system, the main output of the delineation process is a bitmap of ITCs. These automatic crown delineation techniques (ITCVFOL & ITCISOL), developed and tested using a 31 cm/pixel MEIS image (Gougeon, 1995b), were shown to lead to coniferous crown counts that were within 7.7% of those done on the ground. When errors of omission and commission were taken into account, 81% of the crowns were found to correspond one on one. With 60 cm/pixel casi images (Gougeon, 1998), the delineation is not as efficient, producing substantially more tree clusters. Research to find newer separation criteria and add more rules to the delineation process in order to improve the separation of tree clusters into ITCs is ongoing, although at this point in time, such separation may not be extremely critical to producing good inventory information.

INDIVIDUAL TREE CROWN CLASSIFICATION

Once the individual tree crowns (or clusters) are delineated, a crown-based supervised classification process is initiated (see Figure 1). Spectral signatures are acquired for representative tree crowns of each species and averaged to create the species signatures. For relatively uniform stands or plantations, this implies the delineation on the screen of sample areas for each species (using Imageworks[+]). The software (ITCSSG) then used the ITC bitmap produced by the delineation process to calculate the spectral signatures of the ITCs within the sample areas and amalgamate them to produce the species signatures. For mixed stands, specific ITCs can be picked up one by one to create the species signatures (using Imageworks[+] and DCPE). This procedure is of course more demanding, although necessary, and has the added advantage of allowing the user to check whether he/she agrees with the automatic delineation. Indeed, by clicking on a tree crown in the image (under DCPE), the user is shown the crown that the system will use. ITCs for which the delineation does not appear appropriate can easily be rejected from amalgamation into the species signature by clicking on them again. This procedure should lead to rather pure species signatures, but it requires very precise ground information or a reliance on the user's interpretive capabilities. For these reasons, the first procedure is often used, as it was in this experiment, knowing that impurities are introduced into the species signatures. If not overwhelming in number or drastically different spectrally (e.g., hardwoods in a softwood stand), these impurities will typically slightly shift the means of species signatures and widen their distributions, making the classification process less precise.

After all of the ITC-based species signatures have been acquired, an ITC-based classification is run. For each ITC encountered in the image, its spectral signature is computed and compared with the various species signatures. A maximum likelihood decision rule is used to assign a species (class) to the unknown ITC. A confidence interval threshold is also used so that ITCs with signatures that are significantly different from any species signatures are left unclassified. Bitmaps showing all of the ITCs assigned to a given species (class) are produced and can easily be displayed. The existing classification system (ITCSSG and ITCSC) supports

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[+] Denotes regular programmes from the PCI(c) environment.

various ITC-based signatures (Gougeon, 1995a). Here, the multispectral average (and covariance matrix) of the crowns were used.

At the same time as training areas were delineated on the screen to generate the species signatures necessary for the classification, sample testing areas were also delineated to later test the classification accuracy (ITCCA). Similarly to the training process, these testing areas indicate sections of the image that are judged to be reasonably representative of a single species. They may, and generally do, contain impurities. Again, if detailed information had been available, specific testing ITCs could have been used instead of these more global testing areas. The ITCCA program compares one-on-one the classified ITCs with the ITCs contained in the testing areas and reports on the correctly and incorrectly classified crowns via a confusion matrix. Assuming that the test areas are pure, accuracy percentages are issued for each species, with an average species accuracy (assuming that all species are equally represented and important) and an overall classification accuracy (taking representation into consideration). More robust accuracy estimations are often achieved (as done here) by running two distinct classifications in which training and testing areas are interchanged. Classification results (Gougeon, 1995a, 1995c, 1996) 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).

FOREST STANDS DELINEATION

Although information on an individual tree basis may be of interest to researchers with small pilot studies, or for sampling in an inventory context, or for very specific applications (e.g., selective cut), 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 and even the newest vegetation and multi-resource inventories are based on static or dynamic regroupings. Of course, with the existing interfaces between image analysis and geographic information systems, it is easy to summarize the ITC-based information for existing stand boundaries (ITCPCD). This has the potential to produce detailed stand information on species composition, per species average crown areas, stand density and crown closure, average gap size and distribution, etc. However, for the assessment of new areas, an automatic regrouping of ITCs into forest stands or environmental strata is desirable. Fortunately, these regrouping are possible using image-wide quantification of parameters such as stem density, canopy closure, species concentrations, and others, followed by a simple pixel-based unsupervised classification, some filtering to eliminate areas not meeting minimum size criteria and to smooth out contours, and, a vectorization of the results.

A generic forest stand or environmental strata generation process is illustrated in Figure 2. Using the ITC bitmap produced by the delineation process (ITCISOL), a programme (CCLOSURE) creates an image where each pixel corresponds to the quantity of crown material found in a fixed-size roving window around that pixel. Similarly, 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. The same programmes are also used, once per species, on the species-specific bitmaps produced by the ITC classification. Then, all of the images produced are input to a pixel-based unsupervised classifier. The classification is repeated a few times, asking for a different number of classes, until a regrouping judged reasonable is 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 transferred to a geographic information system (GIS). The ITC-based information within the newly generated boundaries can be extracted (ITCPCD) and also ported to the GIS as polygon attributes. For this experiment, it was found that the stem density information was sufficient to produce the stand boundaries.

IMAGERY, STUDY SITE AND FIELD DATA

The Compact Airborne Spectrographic Imager (casi) is a Canadian-made pushbroom sensor capable of acquiring multispectral imagery in the visible to near-infrared part of the spectrum (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 over an area known as the "Nahmint species trial site". Flown at an altitude of 500m, its 512 across-track pixels with a 38ø field of view led to a spatial resolution of 60 cm/pixel. This data is a subset of a much larger dataset acquired over various areas of Vancouver Island, British Columbia, by Itres Research, in collaboration with MacMillan Bloedel Ltd. and the Pacific Forestry Centre, as part of a 3-year joint project aimed at producing certifiable techniques of forest assessments using high spatial resolution multispectral imagery.

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*). The trees are still very young, having been planted in 1979/80 following logging of the area in 1977/78. Some natural regeneration also took place. Figure 3 shows a geometrically corrected pseudo-colour infrared rendition of the casi image acquired over the Nahmint site. Delineated areas represent specific species that were used to alternatively train and test the classifier. A class of hardwood, composed mostly of alder (*Alnus rubra*) was added for completeness. More information about the existing species composition of the stands was later acquired by gathering data in the field for areas spanning two metres on each side of transect lines. The image channels were also corrected to compensate for the bi-directional effects of the sun and view angles on the trees' spectral signatures using a simple column histogram equalization procedure (Yuan & Leckie, 1992).

RESULTS AND DISCUSSION

Following the methodology depicted in Figure 1, the near infrared channel of the casi image was smoothed with a 3x3 kernel (FAV$^+$), individual tree crowns (or tree clusters) were extracted (ITCVFOL & ITCISOL), species signatures were generated (ITCSSG) and a supervised classification was performed (ITCSC) and tested for accuracy (ITCCA). For these preliminary results, the multispectral mean of the crowns were used to generate the species signatures and classify the individual tree crowns. Because field-based information on an individual tree basis was not available, the six species signatures were obtained by manually delineating areas known to be relatively pure (see Figure 3). The signatures of all ITCs in a given area are averaged to create the species ITC-based signature. The classification process compared the signatures of all ITC's in the image with the six species signatures and attributed classes using a maximum likelihood decision rule. The results of the ITC-based classification process are shown in Figure 4. Classification accuracy was assessed on an ITC basis using distinct testing areas, also assumed relatively pure. The confusion matrix shown in Table 1 is an amalgamation of the two classifications obtained by interchanging the testing and training areas. This is a more robust estimation.

An overall classification accuracy of 59.8%, derived from one classification at 53.1% and the other (with training-testing areas reversal) at 68.2%, was obtained (see Table 1). The western hemlocks were easily separated (83.0%) from other species, with minor confusion (11.3%) with Douglas fir. The hardwoods were also well recognized (68.1%), with some confusion with western hemlocks (12.5%) and western redcedars (18.1%), but no confusion at all with the other conifers. The two types of "real" firs are relatively well recognized (59.0%, 57.5%), with confusion mostly among themselves, and a potential accuracy for fir as a single combined class of the order of 80%. The Douglas firs (Pseudotsuga menziesii) are also relatively well recognized (63.9%), with almost equal minor confusion with the two types of "real" firs (9.3% & 11.1%) and the hemlocks (13.9%), and practically no confusion with the cedars (1.9%). The poorest classification accuracy is obtained with the western redcedars (27.4%), which are significantly confused with the Douglas firs (34.3%) and the amabilis firs (26.5%). This is surprising because the cedars are visibly distinct in the original near-infrared rendition of our image. However, spectrally, the cedars are located in between these two species and both their signatures have broader spreads. Thus, the maximum likelihood criteria being used will tend to favour the firs.

Although the classification looks very good (Figure 4), the classification accuracies, as depicted by the confusion matrix, are rather low. This is can be attributed to the lack of purity of the training and testing areas, mostly due to in-filling of the stands since their original plantation. This degrades the classification in two ways: a) it makes the means of spectral ITC signatures assigned to given species imprecise and creates signatures with broader intra-species variations than expected; b) it brings an a priori confusion to the testing process which is based on the premise that the testing areas are pure. In fact, if in-filling of stands was known to be a uniform 10% or 15%, then classification accuracy figures could essentially be augmented by the same proportions. Alternatively, better classifications and better classification accuracy reports (ITCCA) could be achieved by removing the undesirable trees from both the training and testing areas. This could be accomplished by relying on the user to interpret the image and select the specific ITCs to train and test the classifier or, more efficiently, still use the area-based training and testing, but remove one by one the undesirable trees. Another possible approach relies on iterative classifications to improve accuracy. These various alternatives are being explored.

The individual tree crowns were regrouped into forest stands using the semi-automatic methodology described earlier and depicted in Figure 2. The resulting stand delineation appears very convincing (see Figure 4). Of course, whether using the automatically delineated stands or existing historical forest inventory stands, with the successful use of such approaches, the species contents of such stands could be known with a level of details never achieved before. Information such as average crown area, average tree distances, non-forested gap 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.

Another systematic evaluation of the ITC-based classification results was carried out by comparing the species content of larger test areas with field-based transects through these stands. The approximate location of the transects and their corresponding test areas are shown in Figure 5. The transects consisted in following a compass bearing and noting the characteristics of trees within two meter on each side of the transect lines. Information such as species, dominance, potential aerial visibility, approximate crown size, distance along the transect line, etc., were recorded for each tree. These transects provide more accurate descriptions of the situation on the ground. In addition, they are a well recognized forestry tool. Table 2 shows the differences between the species content of our larger test areas as summarized from the ITC classification and that gathered by the transects when disregarding the small trees judged not visible from the air. On average, the dominant species is off by 19.5%, and the error, when all species are considered equal, is 12%. The average error by site is also of the same order (11.5%). However, for any given site, significant differences are possible. For example, for site J the dominant species is off by 38%.

An ultimate evaluation of the ITC-based classification results would be done on a tree by tree basis. However, even with the availability of today's sophisticated GPS positioning on the ground and the rather precise geometric corrections of aerial images, such an evaluation is still not practical because of the high crown closure and stem density of these stands. None of the test procedures used assess whether the tree crowns were well delineated or even well separated. It is also worth noting that because the image was radiometrically normalized for view and sun angles, which as revealed by other studies on high resolution aerial images (Leckie *et al.*, 1995) can be an important factor in purely multispectral species recognition, off-nadir crowns to the right of the image tend to be classified better than in a previous study that did not used BRDF corrections (Gougeon, 1997)

CONCLUSION

A 60 cm/pixel casi image of forest plantations on Vancouver Island, Canada, was analyzed using a system for delineating individual tree crowns, identifying their species and regrouping them into forest stands. When tested with a conventional confusion matrix approach, the ITC-based supervised classification of five western Canadian coniferous species and a generic hardwood class, led to an overall classification accuracy around 60%. The difficulties in separating some species, mostly western red cedar, are attributed to very close species spectral signature means and broad intra-species variations. The low classification results observed with the confusion matrix approach are also attributed to the lack of purity of the training and testing areas. A comparison of the results with field transects led to an overall error of 12%, 19.5% if only the dominant species is considered. However, the issue of whether the tree crowns were well delineated (for crown area), or even well separated (for stem counts), was not addressed at this time. The radiometric normalization of the image for view and sun angles improved the purely multispectral species recognition of the most off-nadir trees (relative to previous work (Gougeon, 1997)). The semi-automatic forest stand delineation methodology produced stand outlines very similar to the existing ones.

The present body of work indicates that similar and even better results are achievable with a variety of 30-100 cm/pixel multispectral images. Consequently, good possibilities are expected with images from the next generation (Fritz, 1996) of earth observation satellites (82-100 cm/pixel). The possibility of obtaining from digital remote sensing the kind of information that foresters need in order to manage the forest resource may be within reach. An ITC-based paradigm also facilitates the assessment of newer inventory parameters such as non-forested gap distributions, snag locations, and other biodiversity and wildlife criteria and indicators needed for the multipurpose management of our forests.

These encouraging conclusions should be tempered by the fact that there are still several research and operational problems to resolve before the 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, etc. A different type of system may be needed to take all of these factors into account. Figure 6 shows a system where decisions to identify the species of an individual tree crown are made in an incremental fashion by accumulating, as needed, evidences from the spectral, textural, structural and spatial realms. Such a rule-based species recognition system is more akin to the human photointerpretation thought process.

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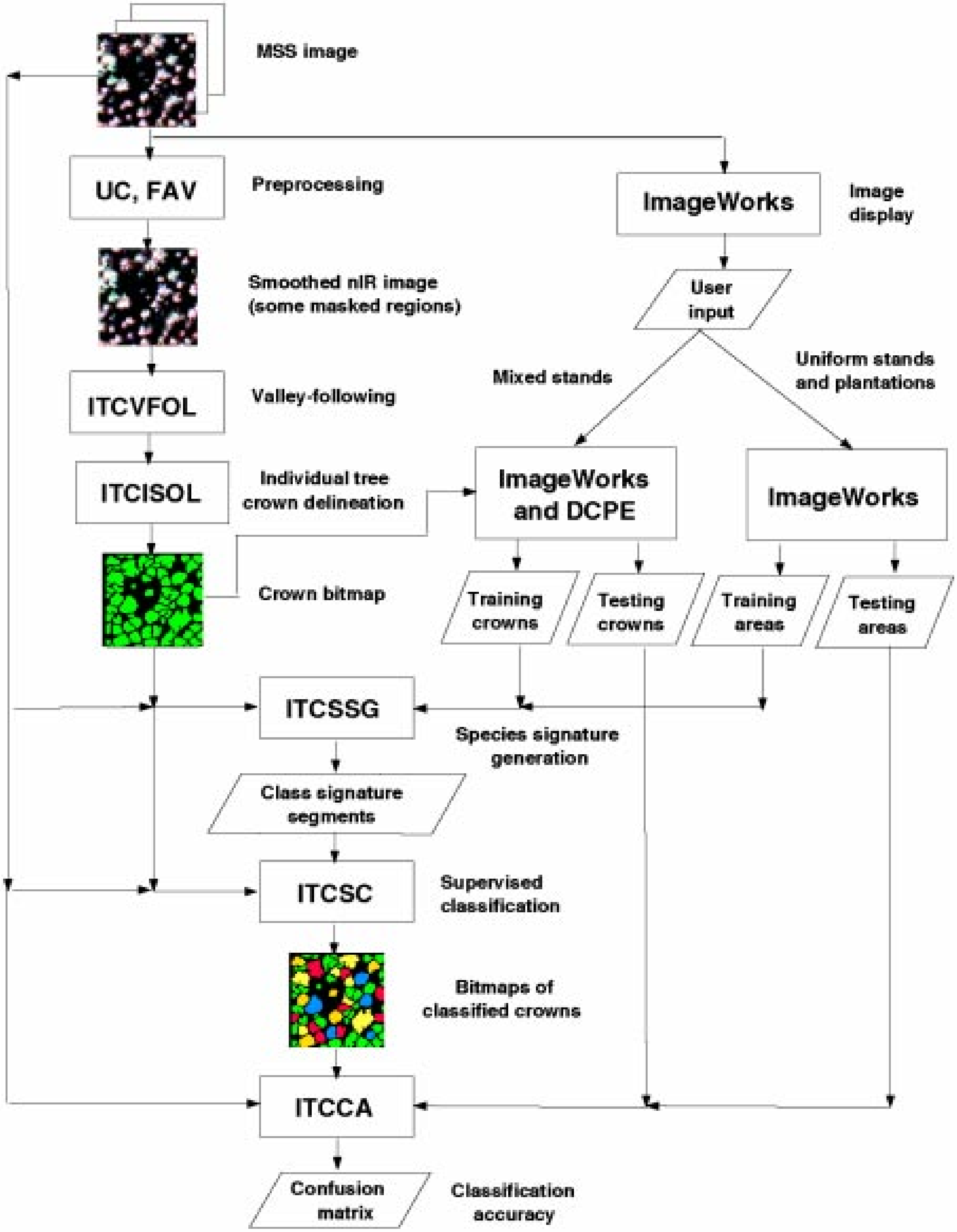

Figure 1. Methodology for individual tree crown delineation and supervised classification from high spatial resolution multispectral images (from Gougeon, 1997).

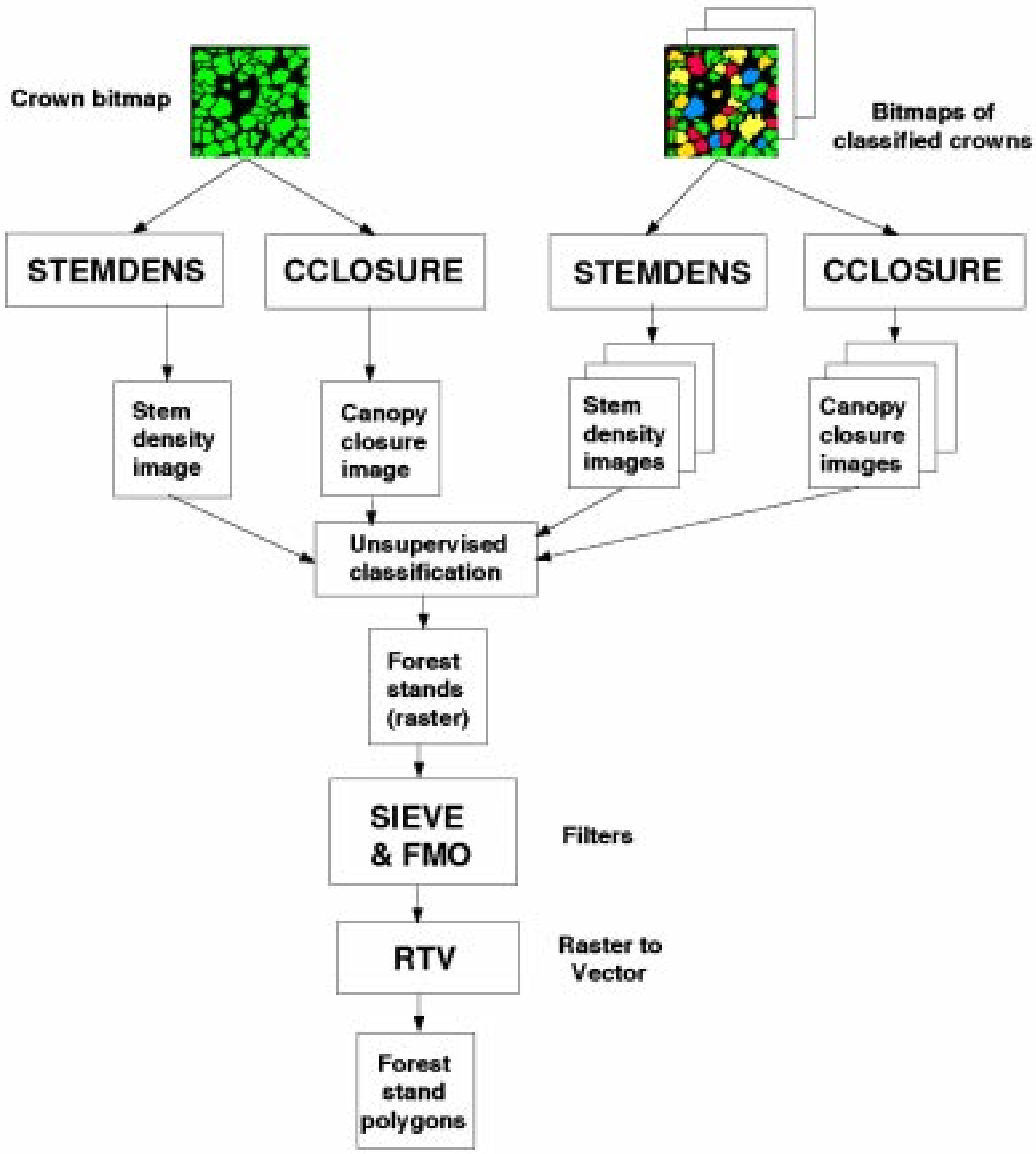

Figure 2. Methodology for generating forest stand or environmental strata outlines from individual tree crown information (from Gougeon, 1997).

Table 1. Average confusion matrix of two classifications obtained by interchanging the training and testing areas (Fd=Douglas-fir, Bg=grand fir, Ba=amabilis fir, Cw= western redcedar, Hw=western hemlock , and Hard= hardwood).

Nahmint Study - Average Confusion Matrix (GT)						
	Fd	Bg	Ba	Cw	Hw	Hard
Fd	**69 (63.9%)**	16 (16.0%)	3 (7.5%)	35 (34.3%)	12 (11.3%)	0 (0.0%)
Bg	10 (9.3%)	**59 (59.0%)**	10 (25.0%)	9 (8.8%)	3 (2.8%)	0 (0.0%)
Ba	12 (11.1%)	21 (21.0%)	**23 (57.5%)**	27 (26.5%)	2 (1.9%)	0 (0.0%)
Cw	2 (1.9%)	3 (3.0%)	2 (5.0%)	**28 (27.4%)**	1 (0.9%)	13 (18.1%)
Hw	15 (13.9%)	1 (1.0%)	2 (5.0%)	3 (2.9%)	**88 (83.0%)**	9 (12.5%)
Hard	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**49 (68.1%)**
UnClas.	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.4%)
Crowns	108	100	40	102	106	72
Average accuracy: 59.8%		Overall accuracy: 59 .8%				

Table 2. Comparisons between the species compositions of ground transects and classified forest stand sections.

DIFFERENCES BETWEEN GROUND AND CLASSIFICATION RESULTS - Nahm Int Area										
Global Covariance Matrix Classification Crown Size: <= 3 Canopy Dominance: <= 4										
	Site	**Df**	**Bg**	**Ba**	**Cw**	**Hw**	**Ch&A**	SumDiff	CumAbsDiff	AbsDifAvg
Ground	N	1%	48%	0%	7%	30%	13%			
Classified		21%	47%	13%	5%	13%	0%			
Diff		-20%	1%	-13%	2%	17%	13%	0%	66%	11%
Ground	J	0%	0%	0%	4%	95%	1%			
Classified		27%	6%	5%	5%	57%	0%			
Diff		-27%	-6%	-5%	-2%	38%	1%	0%	79%	13%
Ground	PA1	0%	0%	12%	8%	74%	6%			
Classified		19%	3%	7%	31%	39%	1%			
Diff		-19%	-3%	6%	-23%	35%	5%	0%	91%	15%
Ground	B1	63%	0%	0%	25%	6%	6%			
Classified		64%	8%	8%	3%	17%	0%			
Diff		-1%	-8%	-8%	22%	-10%	6%	0%	57%	9%
Ground	H	96%	0%	0%	0%	4%	0%			
Classified		69%	11%	3%	13%	5%	0%			
Diff		27%	-11%	-3%	-13%	-1%	0%	0%	54%	9%
Ground	W	67%	0%	0%	0%	33%				
Classified		59%	26%	4%	4%	7%	0%			
Diff		7%	-26%	-4%	-4%	26%	0%	0%	67%	11%
Ground	U	0%	0%	0%	0%	100%	0%			
Classified		21%	21%	8%	3%	49%	0%			
Diff		-21%	-21%	-8%	-3%	51%	0%	0%	103%	17%
Ground	Sg	6%	47%	0%	0%	43%	4%			
Classified		23%	52%	11%	6%	8%	0%			
Diff		-17%	-5%	-11%	-6%	35%	4%	0%	78%	13%
Ground	I	6%	0%	0%	65%	21%	8%			
Classified		16%	5%	0%	68%	11%	1%			
Diff		-10%	-5%	0%	-3%	11%	7%	0%	36%	6%
Ground	F	88%	0%	0%	0%	9%	2%			
Classified		61%	11%	3%	10%	15%	0%			
Diff		27%	-11%	-3%	-10%	-6%	2%	0%	59%	10%
SumDiff		-53%	-96%	-48%	-38%	196%	40%			
CumAbsDiff		177%	97%	59%	87%	231%	40%			
AbsDifAvg		18%	10%	6%	9%	23%	4%			
Avg Error(by row) = 12%										
Average Error Species% (by col) = 12%										

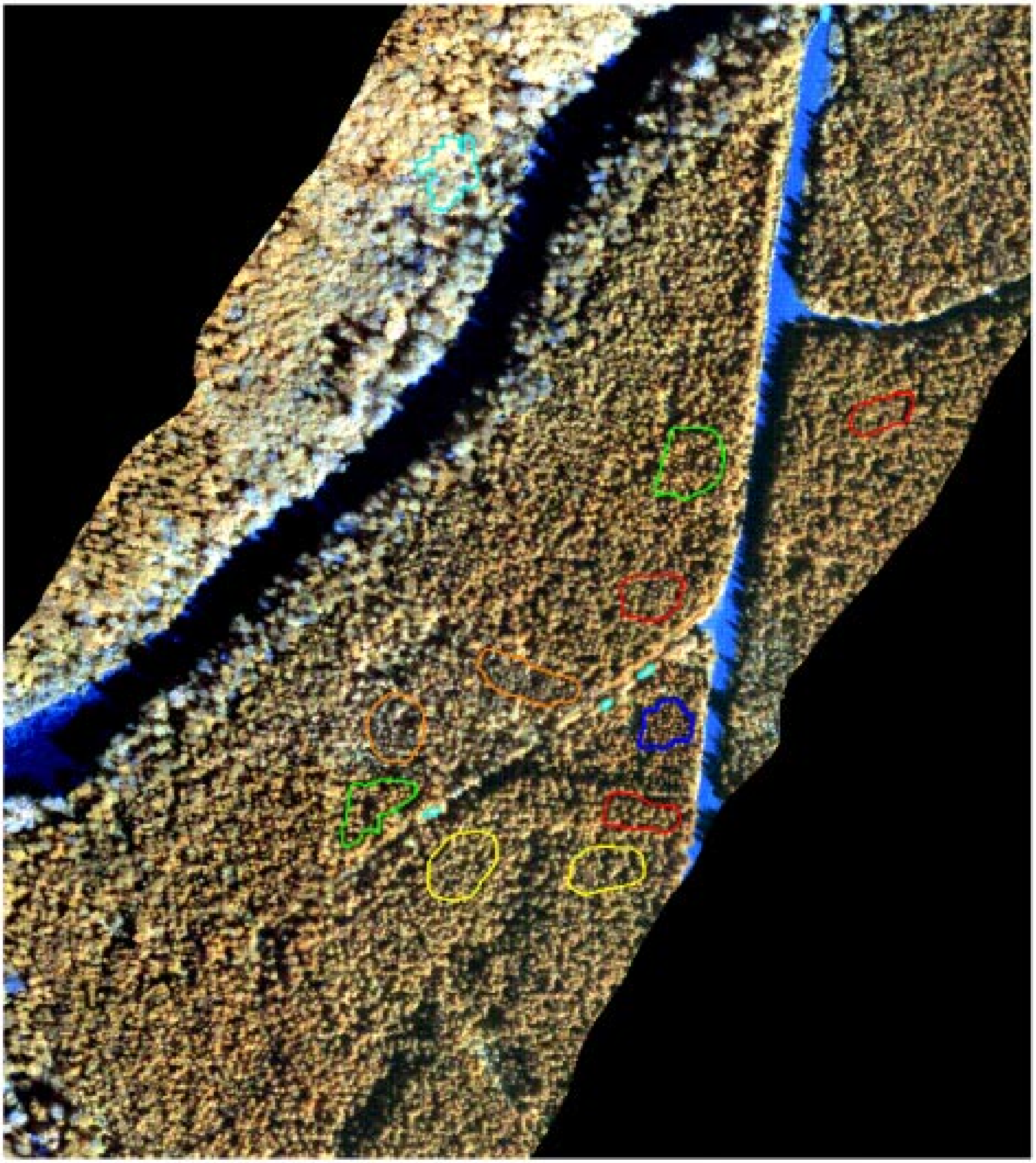

Figure 3. Pseudo-colour infrared rendition of a sub-area of a geometrically and radiometrically corrected Casi image (60 cm/pixel) of the Nahmint Lake species trial area in the central forest of Vancouver Island, British Columbia, Canada. The training and testing areas used for the classification were delineated where species are known to be almost 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, western hemlock (*Tsuga heterophylla*) in yellow, and hardwoods in light blue.

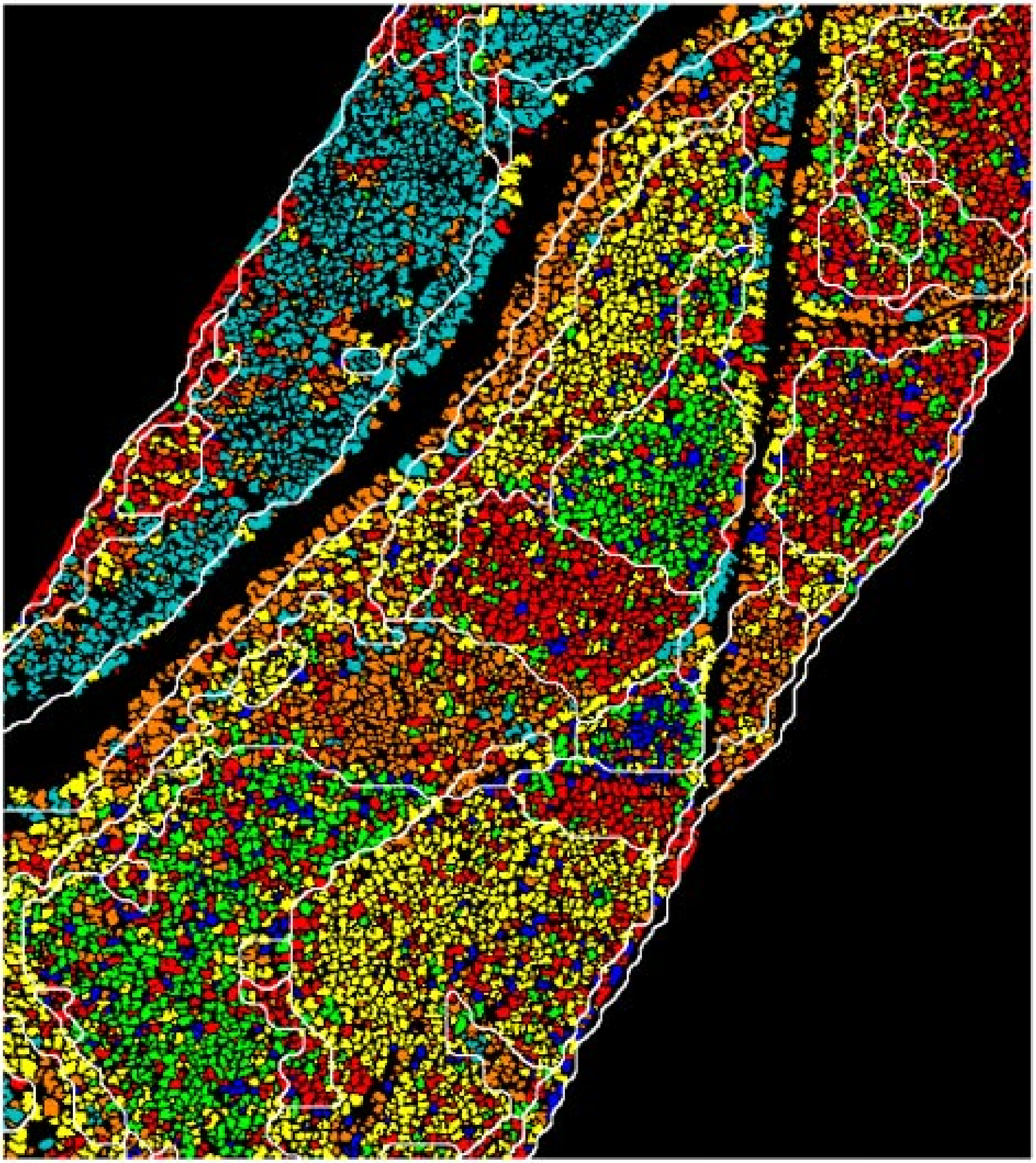

Figure 4. The individual tree crown (ITC) classification of Figure 3 and its computer generated forest stand outlines using the same colour scheme as Figure 3.

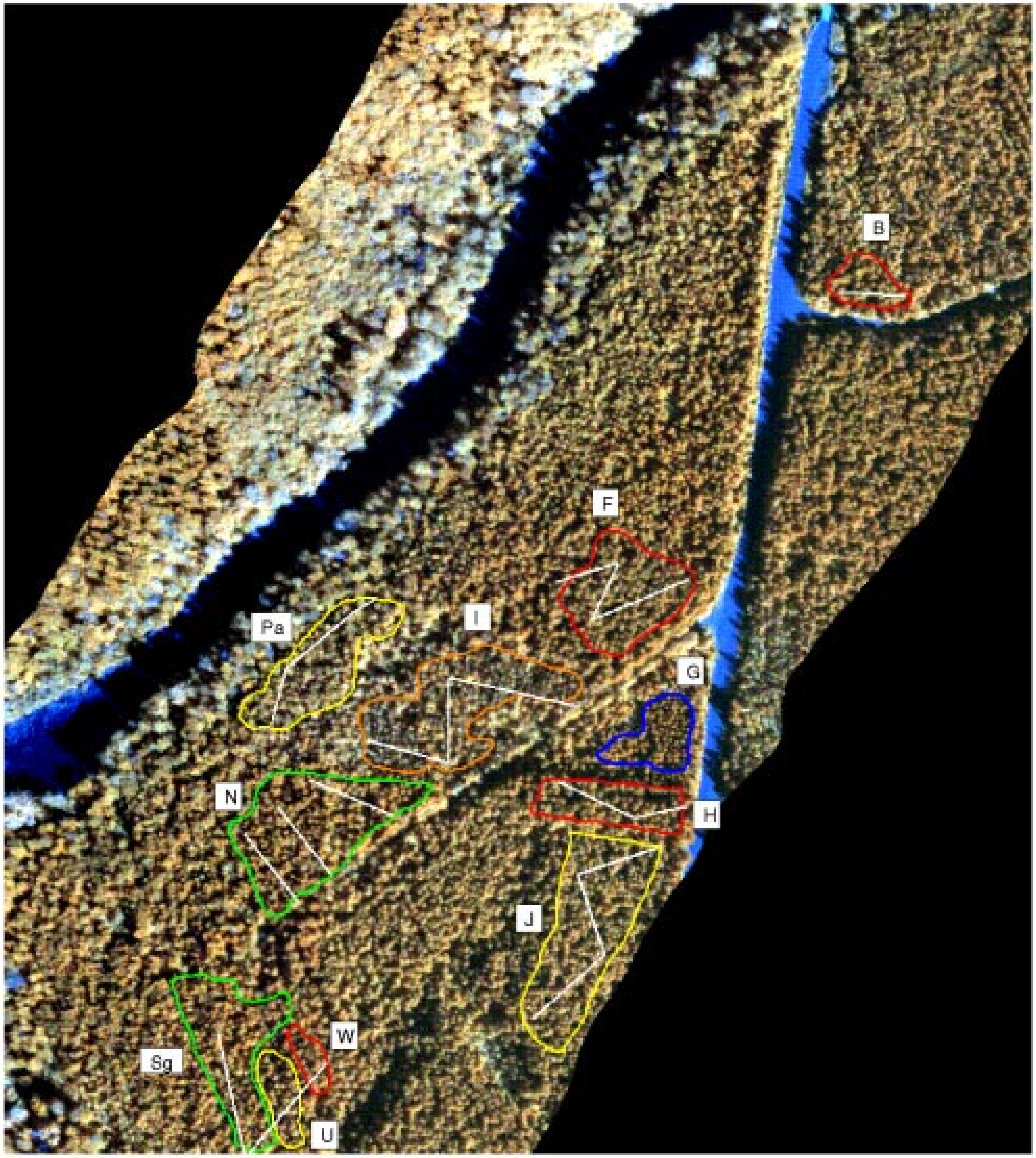

Figure 5. Sample sections of forest stands and ground transect locations used in producing the species composition comparisons of Table2. The species colour scheme is the same as in Figure 3.

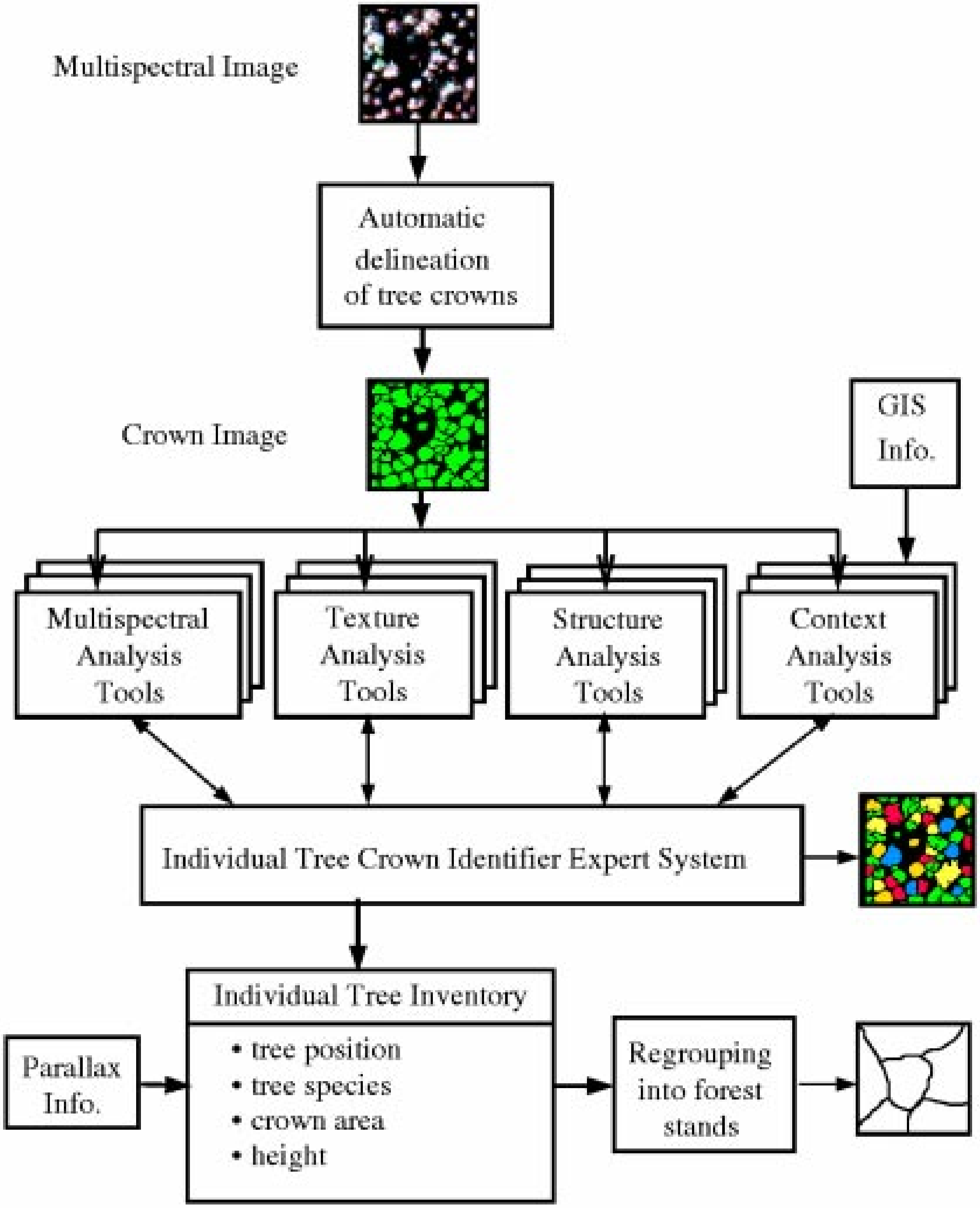

Figure 6. Proposed knowledge-based system making species decisions on an individual tree basis by accumulating evidences from different domains in order to produce a forest inventory from high spatial resolution multispectral images (30 - 100 cm/pixel).