

A SYSTEM FOR INDIVIDUAL TREE CROWN CLASSIFICATION OF CONIFER STANDS AT HIGH SPATIAL RESOLUTIONS

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ABSTRACT

In forestry, the high spatial resolutions of multispectral aerial images, digitized aerial photographs, and the next generation of earth observation satellites force a redefinition of image analysis techniques. This paper briefly describes the theoretical and practical aspects of a new approach which consists of separating individual tree crowns and recognizing their species using a crown-based supervised multispectral classification. The system allows the user to create species signatures and test samples from individually specified tree crowns (in natural stands) or from tree crowns within specified areas (in single species plantations). The approach was tested on MEIS images at three spatial resolutions: 36, 70, and 100 cm/pixel. The crown delineation process proved reliable for conifer stands at the higher resolution, but its effectiveness diminished with decreasing spatial resolution. The classification accuracies of the delineated tree crowns are relatively similar at all three resolutions, ranging between 74 and 81% for four coniferous species.

RÉSUMÉ

En foresterie, la haute résolution spatiale des images aériennes multispectrales, des photographies aériennes numérisées, et de la prochaine génération de satellites d'observation terrestre nous incite à une redéfinition des techniques d'analyse d'images. Cet article décrit brièvement les aspects théoriques et pratiques d'une nouvelle approche qui consiste à séparer les couronnes d'arbres et à reconnaître une par une leurs espèces par une classification multispectrale dirigée. Le système permet à l'utilisateur de créer des signatures représentant les espèces forestières et des échantillons de vérification à partir de couronnes d'arbre spécifiées individuellement (pour les peuplements naturels) ou faisant partie d'une région donnée (pour les plantations d'une même espèce). Cette approche fut testée sur des images MEIS à trois résolutions spatiales: 36, 70, et 100 cm/pixel. Le processus de délimitation des couronnes s'avère fiable pour des peuplements résineux à haute résolution, mais son efficacité diminue avec un décroissement de la résolution spatiale. Les exactitudes de classification des couronnes ainsi délimitées sont du même ordre aux trois résolutions, soit entre 74 et 81% pour quatre espèces de résineux.

INTRODUCTION

Although forest management inventories are still being done by interpreting aerial photographs, it is

easy to envisage a gradual transition toward using digital multispectral aerial images, digitized aerial photographs, or future high resolution satellite images (30-100 cm/pixel). Such images have most of the details needed for good human interpretation, with the added advantage of a digital format making them amenable to computer manipulation and, most importantly, computer analysis (Leckie 1993). However, it is well known that the higher spatial resolutions, compared to today's satellite images, create problems for the current image analysis tools, such as pixel-based classification processes. Even the addition of spatial information in the form of texture parameters often breaks down at such resolutions. We must, therefore, shift our paradigm (Gougeon 1993). Rather than trying to analyse forest stands directly, we could analyse individual tree crowns clearly visible at such resolutions and then regroup them into forest stands. This could lead to much more precise forest inventories, whether or not individual tree crown information is kept or discarded. This paper describes a new methodology to achieve forest classifications based on individual tree crown delineation and crown species identification. Preliminary results are shown at three spatial resolutions.

INDIVIDUAL TREE CROWN DELINEATION AND CLASSIFICATION APPROACHES

With the closely packed formations of trees found in natural stands and plantations, it is generally possible to delineate individual tree crowns by following pixels of shaded material (made of shaded portions of trees, ground, or understory) that surround them. When trees are more scattered and the understory comes clearly into view, a crude *a priori* classification can often be used to discard these sunlit areas from further processing. Using an intensity image or one of the more sensitive spectral bands, the present approach first finds local minima in the shaded material. It then follows V-shaped valleys of this material from one local minimum to another. This delineates tree crowns rather well. A more complete delineation is achieved by using a rule-based system that tries to follow the outline of specific tree crowns one by one. A previous test on a 31 cm/pixel MEIS image of coniferous plantations led to crown locations that were, 84% of the time, similar to those obtained by a visual interpretation of the same image and crown counts that were within 7.7% of those made in the field (Gougeon 1995b).

The multispectral information contained within each individual tree crown can then be used to create individual tree crown signatures. For example, the simplest such signature could be the mean multispectral value of the crown. Using conventional area delineation for single-species plantations and individually designated crowns for naturally mixed stands, species signatures can also be generated to train and test a crown-based maximum likelihood supervised classification process. Previous tests with manually delineated crowns on a 36 cm/pixel MEIS image led to classification accuracies as high as 76% with five coniferous species (Gougeon 1995a).

INDIVIDUAL TREE CROWN SUPERVISED CLASSIFICATION METHODOLOGY

The approaches described above were implemented as FORTRAN and C programs within the PCI image analysis environment. The methodology to obtain an individual tree crown supervised classification is illustrated in Figure 1. The acronyms found in the process boxes, such as ITCVFOL, correspond to names of distinct programs. The first steps in this methodology (leftmost column of Fig. 1) perform the crown delineation. The multispectral image is transformed to an intensity-hue-saturation

image by IHS (an alternative is to bypass this step and use just the near-infrared channel). The intensity image, sometimes smoothed with a 3x3 mean filter, is fed to the valley-following program (ITCVFOL) that produces a bitmap of partially delineated crowns. This is fed to the rule-based isolation program (ITCISOL) to complete the crown delineation process. The result is a bitmap showing most of the crowns that exist in the original image. This crown bitmap is used throughout the supervised classification process.

Supervised classifications imply user interaction to create training (and testing) samples from which to generate class signatures. This is depicted on the right-hand side of Figure 1. The multispectral image is displayed, preferably enhanced, and samples representative of the various forest species are created. This typically relies on an user interpretation of the image, often backed by additional information such as field observations. To facilitate user interaction, two methods of creating these samples are available, one for single-species plantations and another for natural stands. For the former, sizeable areas of plantations can be roughly outlined in a way similar to the training done with satellite images (for example, using DCP). The program that generates the species signatures (ITCSSG) will combine the mask generated by this procedure with the bitmap of tree crowns to create class signatures based on individual tree crown parameters. For the latter, a program (DCPE) was created to allow the user to simply point at individual representative tree crowns within the more complex mixed natural stands. It uses the tree crown bitmap to display an individual crown as a graphic overlay every time the user points to (i.e., click on) one. These overlaid crowns can just as easily be removed in the same interactive fashion to double-check on one's interpretation and/or to cancel the class assignment. This also allows the user to verify that the crown selected is one that was correctly delineated by the isolation processes. In this way, a bitmap depicting several individual tree crowns is generated for each species of interest. These are used by the signature generation process (ITCSSG) to create class signatures.

The class signatures are generated by extracting multispectral data from the original image for every full crown designated by the training bitmaps, calculating individual crown signatures, and averaging them over all crowns in the same class. A variety of signature types specialized for individual crown parameterisation is available with the ITCSSG program (Gougeon 1995a). For the present research endeavour, only the simplest signature type, calculating the mean multispectral value of a given crown, was used. The class signatures, the crown bitmap, and the multispectral image are fed to the classification process (ITCSC). For each crown, it calculates the individual tree crown signature and estimates the likelihood of it belonging to a particular class. The class with the maximum likelihood is assigned to that tree crown, producing an output bitmap of colour-coded crowns. The classification accuracy is then ascertained using testing crowns and masks that were typically produced in the same way as the training crowns and masks. A confusion matrix indicating species-specific classification accuracies (its diagonal elements) and errors of omission and commission is obtained.

STUDY AREA AND AERIAL DATA

The approach was tested on three images covering coniferous stands of the Petawawa National Forestry Institute Research Forest. The first image was acquired by the airborne MEIS sensor on August 16, 1988, from an altitude of 520 m., giving it a spatial resolution of 36 cm/pixel (Figure 2). The second MEIS image was acquired on October 29, 1985, from an altitude of 1070 m., giving it a resolution of

70 cm/pixel (Figure 3). This image was also resampled to 100 cm/pixel, simulating the data resolution that may be available from the next generation of earth observation satellites. The tree species are as labelled on Figures 2 and 3. It is worth noting that the both images contain single-species plantation stands as well as natural mixed stands where training by individual tree crown was necessary.

CLASSIFICATION RESULTS AND DISCUSSION

Using the above methodology, individual tree crown supervised classifications were run on the 36, 70, and 100 cm/pixel images. The results are shown in Figures 4, 5, and 6, with corresponding confusion matrices in Tables 1, 2, and 3. In all cases, the Norway spruces, which have very large crowns, were not considered because of poor crown isolation (except at 1 m/pixel) and a lack of sufficient individuals. The classification results (76.1%, 80.9%, and 73.9%) are surprisingly good considering that the different species have very similar multispectral signatures, with rather wide variances. White pine crowns are poorly classified at all spatial resolutions, but more so at the higher resolutions. This is partially attributed to their crowns not being isolated properly by the crown delineation process. Due to their large size and often distinct individual branches, their crowns are often broken down into several sections considered distinct trees. The well-lit red pines on the sunny side of the pure stand are often classified as white pines. Because this stand is higher than its neighbour, its crowns receive more direct illumination and grow an unusually dense foliage, as is evident in the raw images. Also, in all cases, the stand made of mostly red pines with occasional white spruces shows numerous red spruces and white pines. Similarly, the stand of white and red pines seems to contain a substantial amount of red spruces. The former situation is not accounted for by the confusion matrices, as there was no testing area in that stand. The latter situation should be partially accounted for in view of the existence of white pine testing crowns, but seems to occur more often than reflected in the confusion matrices. Apart from the fact that, at the lower spatial resolution (100 cm/pixel), some crowns are missing from the more dense stands (e.g., red pine pure stand) and that crowns of larger trees are generally better defined, the classifications of 70 and 100 cm/pixel data seems to agree rather well visually.

CONCLUSION

Previous work has shown that good crown isolation and classification results can be expected using images with spatial resolution in the 30-40 cm/pixel range. These preliminary results demonstrate that good classification results and potentially, good individual-tree-based inventories, can be realized at 70 cm/pixel, a spatial resolution around which computer-assisted interpretation is expected to occur, and at 100 cm/pixel, a resolution soon to be obtained from satellite imagery. The poorer crown isolation obtained with the lower resolutions is likely attributable to the development of ITCISOL's rules at a 31 cm/pixel resolution and to their simple unaltered applications to 70 and 100 cm/pixel images. Also, even at 36 cm, problems occur due to an oversplitting of larger crowns such as those of Norway spruces and white pines into several distinct parts. As well, because of the nature of the verification process, missing crowns due to delineation problems are not accounted for in the accuracies stated in this paper. The compound effects of both the crown isolation and classification processes should lead to lower accuracies when the missing crowns are counted as unclassified. On the other hand, the system also provides more complex crown signatures than the simple crown multispectral means used here. Most have yet to be tested at spatial resolutions of 70 or 100 cm/pixel. Of course, there are numerous other outstanding issues with this new approach, such as its applicability to the

detection and classification of hardwood crowns, the importance of off-nadir effects and the possible need for radiometrically corrected images, its applicability to individual tree crown damage assessments, and its adaptability to deal with crown texture or structure parameters.

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Table 1. Confusion matrix of the 36 cm/pixel individual tree crown based supervised classification.				
	White spruce	Red pine	Red spruce	White Pine
White spruce	69 (78.4%)	0	3	7
Red pine	1	83 (95.4%)	4	9
Red spruce	16	1	29 (78.4%)	9
White Pine	0	2	0	51 (54.8%)
Unclassified	2	1	1	17
Average accuracy = 76.8%		Overall accuracy = 76.1%		Kappa = 0.75

Table 2. Confusion matrix of the 70 cm/pixel individual tree crown based supervised classification.				
	White spruce	Red pine	Red spruce	White Pine
White spruce	51 (87.9%)	0	0	0
Red pine	0	72 (81.8%)	7	5
Red spruce	5	2	45 (81.8%)	4
White Pine	2	8	2	14 (58.3%)
Unclassified	0	6	1	1
Average accuracy = 77.5%		Overall accuracy = 80.9%		Kappa = 0.77

Table 3. Confusion matrix of the 100 cm/pixel individual tree crown based supervised classification.				
	White spruce	Red pine	Red spruce	White Pine
White spruce	36 (83.7%)	0	0	0
Red pine	0	43 (82.7%)	3	11
Red spruce	4	0	29 (66.4%)	3
White Pine	0	2	7	25 (62.5%)
Unclassified	3	7	6	1
Average accuracy = 73.3%		Overall accuracy = 73.9 %		Kappa = 0.75

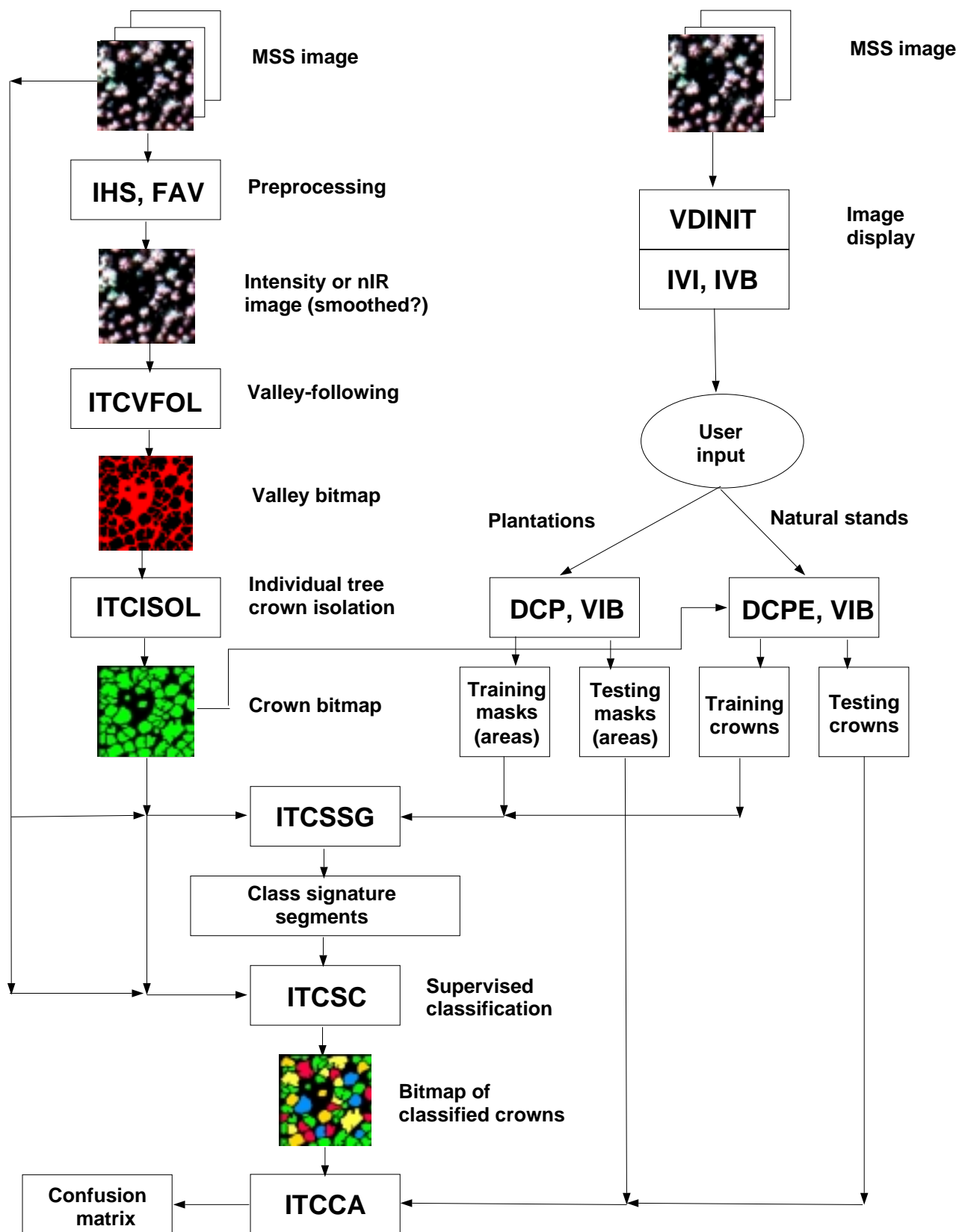


Fig. 1 - Methodology for individual tree crown supervised classification

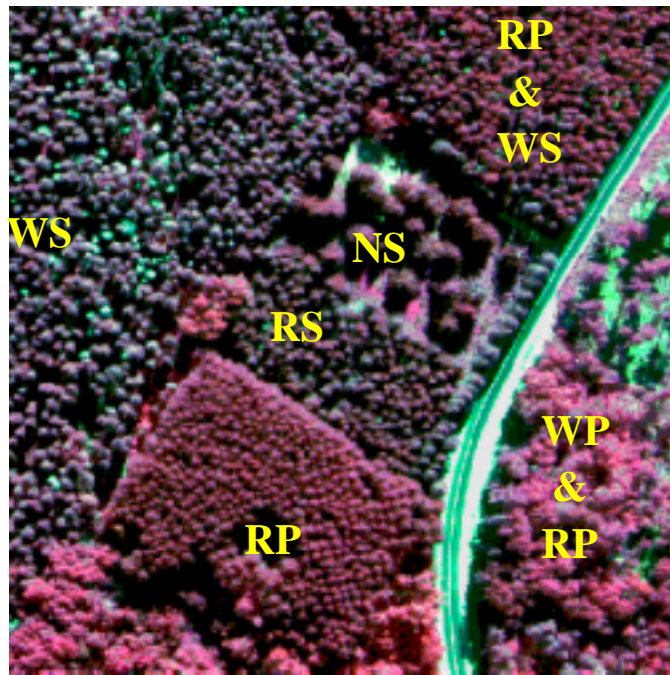


Figure 2 - MEIS image (600 lines x 600 pixels) of the Hudson plantation at PNFI acquired on August. 16, 1988, with a spatial resolution of 36 cm/pixel (WS = white spruce, RP = red pine, RS = red spruce, NS = Norway spruce, and WP = white pine).

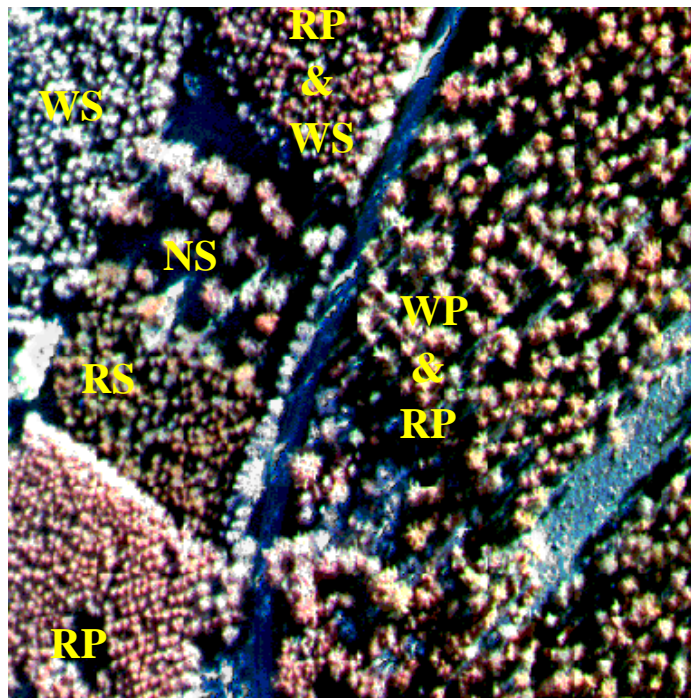


Figure 3 - MEIS image (400 lines x 400 pixels) of the Hudson plantation at PNFI acquired on October 29, 1985, with a spatial resolution of 70 cm/pixel. (WS = white spruce, RP = red pine, RS = red spruce, NS = Norway spruce, and WP = white pine).

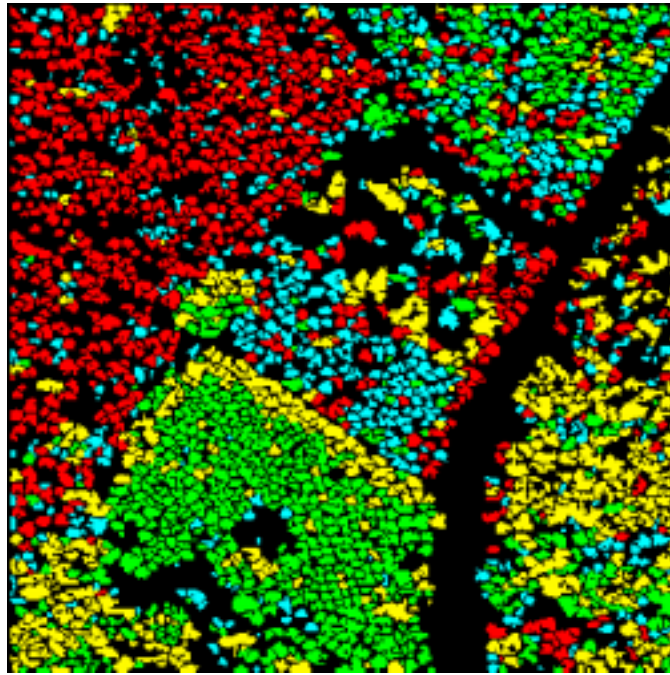


Figure 4 - Individual tree crown supervised classification of the 36 cm/pixel image (Figure 2) with white spruce in red, red pine in green, red spruce in blue, and white pine in yellow. (corresponding to confusion matrix in Table 1)

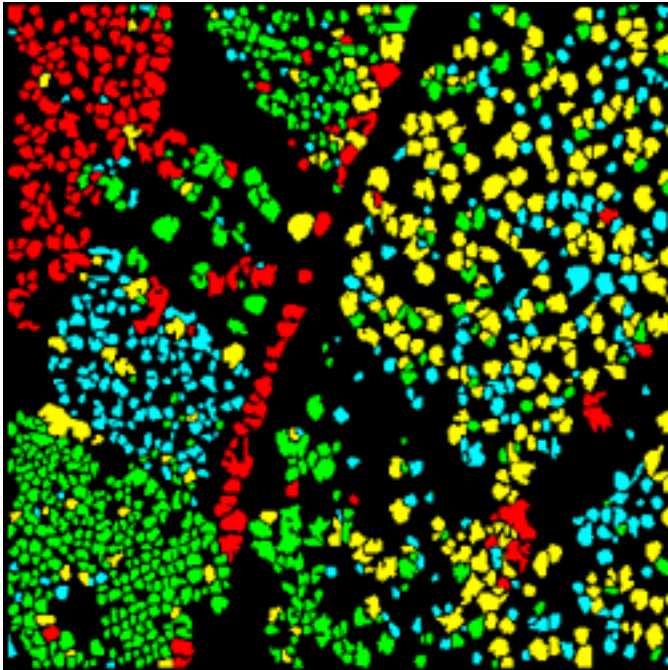


Figure 5 - Individual tree crown supervised classification of the 70 cm/pixel image (Figure 3) with white spruce in red, red pine in green, red spruce in blue, and white pine in yellow. (corresponding to confusion matrix in Table 2)

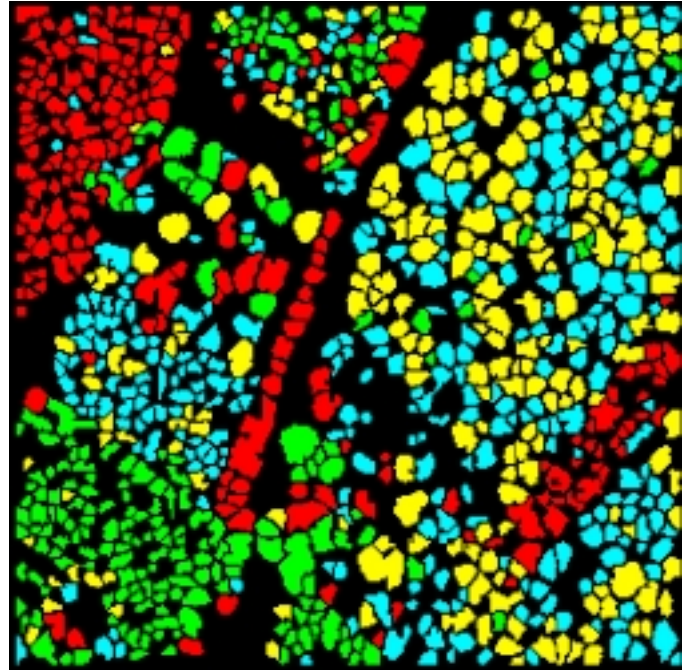


Figure 6 - Individual tree crown supervised classification of the 100 cm/pixel image (Figure 3 resampled to a one meter/pixel resolution, and now of size 280 lines x 280 pixels) with same colour scheme as Figure 5.