FOREST REGENERATION: INDIVIDUAL TREE CROWN DETECTION TECHNIQUES FOR DENSITY AND STOCKING ASSESSMENTS

François A. Gougeon and Donald G. Leckie

Department of Natural Resources, Canadian Forest Service
Pacific Forestry Centre, 506 West Burnside Rd.
Victoria, British Columbia, Canada, V8Z 1M5

ABSTRACT

Sustainable forest management depends on successful forest regeneration. The use of remotely sensed aerial images or digitized aerial photographs of high spatial resolution could lead to accurate and timely semi-automatic computerized assessments. Techniques based on individual tree crown detection or delineation can produce information about regenerating areas such as stem density, proper tree spacing and stocking, and even possibly, tree species and health estimations.

Various computerized tree crown detection and delineation techniques already exist. Some are geared towards dense stands, while others are aimed at open areas. An hybrid detection technique is able to detect the situation at hand and switch paradigm accordingly. Delineation techniques require higher spatial resolution and/or tree sizes, but offer more promises for tree species recognition and health estimation. Most techniques can benefit from particular acquisition conditions (e.g., autumn acquisition) and simple pre-processing techniques to increase their detection or delineation capability and accuracy.

This article describes two techniques presently under investigation by the authors: one of crown detection only, and another capable of crown delineation. Their strengths and weaknesses are illustrated and discussed, as are their pre-processing needs and image acquisition criteria. Various pre-processing techniques are explored. Preliminary results with aerial images of regeneration stands of various ages and densities demonstrate more quantitatively these strengths and weaknesses relative to measurements made on the ground and from aerial photographs.

RÉSUMÉ

RÉGÉNÉRATION DES FORÊTS : TECHNIQUES DE DÉTECTION DES HOUPPIERS EN VUE D'ÉVALUER LA DENSITÉ DES PEUPLEMENTS ET LES SURFACES OCCUPÉES

L'aménagement forestier durable repose sur une régénération fructueuse. L'utilisation d'images aériennes télédétectées ou de photographies aériennes numérisées à haute résolution spatiale pourrait mener à la réalisation d'évaluations informatisées et semi-automatiques précises et opportunes. Les techniques basées sur la détection ou la délimitation des houppiers peuvent permettre d'obtenir des informations sur les zones de régénération (densité des tiges, espacement entre les arbres, peuplement, voire même espèces d'arbres et estimations sur leur état de santé).

Il existe déjà diverses techniques informatisées de détection et de délimitation des houppiers. Certaines s'appliquent plus facilement dans les peuplements denses tandis que d'autres sont mieux adaptées aux zones

Automated Interpretation of High Spatial Resolution Digital Imagery for Forestry. Victoria, British Columbia, Canada, February 10-12, 1998. D.A. Hill and D.G. Leckie, editors. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. pp. 169-177.

dégagées. Une technique hybride de détection pourrait s’adapter aux conditions en présence et commuter les paradigmes en conséquence. Les techniques de délimitation nécessitent des résolutions spatiales plus élevées et/ou des arbres plus gros, mais elles sont plus prometteuses en ce qui à trait à la reconnaissance des espèces d’arbres et à l’estimation de leur état de santé. La plupart des techniques peuvent tirer avantage de conditions d’acquisition particulières (en automne, par exemple) et de techniques simples de prétraitement pour améliorer la capacité et la précision de délimitation et de détection.

Cet article présente la description de deux techniques en cours d’étude par les auteurs; la première porte sur la détection des houppiers seulement et l’autre sur la délimitation des houppiers. On y discute des points forts et des points faibles de chacune, avec illustrations à l’appui, ainsi que des exigences relatives au prétraitement et des critères d’acquisition d’images. On y examine également diverses techniques de prétraitement. Les résultats préliminaires des analyses d’images aériennes de peuplements en régénération à divers âges et de diverses densités démontrent ces forces et ces faiblesses d’une manière plus quantitative par rapport aux mesures effectuées au sol et aux photographies aériennes.

INTRODUCTION

Forest regeneration, whether natural or the result of planting, is essential to sustainable forest management. Individual foresters are made increasingly responsible, before cuts are even allowed, for prescribing a course of action after logging, monitoring the results, and taking corrective actions when needed. Consequently, they require accurate, timely, and preferably inexpensive information about the vegetation development in recently cut (or burned) areas. Wagner (1994) describes forest vegetation management as "that part of silviculture directed at manipulating the rate and course of early plant succession to achieve a forest stand of a particular composition, structure, and form, within a specified period of time". Practicing good forest vegetation management is vital to Canada's competitiveness and is increasingly important to forest companies as only areas demonstrated sufficiently restocked to count towards allowable cut quotas.

Generally, several vegetation surveys are conducted during the early development of a forest stand to assess its progress, decide if corrective actions are needed, or determine if the prescription's goals were reached. Not all surveys are exhaustive, but in any given survey, information may be gathered on density, stocking, distribution, survival, health, species composition, brush competition and regeneration performance. These parameters lead to decisions as to whether an area is judged "under or overstocked", whether brush competition is considered "acceptable" or "unacceptable", whether the regenerating species is determined "free to grow", or whether corrective measures should be applied. Density, "a measure of the number of trees per unit area", and stocking, "the number of well-spaced trees relative to some reference density" (Brand, 1988), are two of the most important parameters and are often costly to acquire. Only density, spacing and crown diameters are addressed in the preliminary work reported here.

Although at this point in time forest managers are still evaluating regeneration success/failure using simple overflight estimations by inspectors, assessments from aerial photograph and/or field measurements as needed, "research is needed in preparation for the imminent digital era" (Pitt *et al.*, 1996). Even if the images from the new generation of high resolution (0.8-5 m/pixel) satellites (Fritz, 1996) are unlikely to be very useful in regeneration assessments, the existence of various digital airborne sensors and the possible digitization of aerial photographs make digital approaches conceivable. Today's stricter requirements make increasingly mandatory the exact quantification of regeneration, rendering ubiquitous the more costly assessments by field sampling. Cost savings and potential gains in efficiency could be achieved if certifiable, preferably automatic, techniques were to be developed based on computer image analysis. This paper presents a snap-shot in time of an ongoing research effort. It describes two techniques presently under investigations: one of crown detection only, capable of stocking and density assessments; and another, of crown delineation, capable of stocking and density assessments with larger trees (or higher resolution images), as well as, crown area assessments and possibly, species recognition and health assessments. Each technique's strengths and weaknesses, as well as, pre-processing and image acquisition requirements, are illustrated and discussed briefly.

TECHNIQUES AND METHODS

In previous work (Gougeon, 1997), a locally adaptive (or hybrid) technique for forest regeneration assessments was developed. It is based on the improvement of a technique originally developed to detect mature trees and identify their species in medium resolution images (1-3 m/pixel) (Gougeon & Moore, 1989), a technique which has been used extensively by others since then (Eldridge, 1993; McLaughlin *et al.*, 1996; Dralle & Rudemo, 1996). The technique consists in detecting, with or without a priori smoothing, local maxima in the most appropriate spectral band (typically the near-infrared). In dense coniferous stands, where individual tree crowns appear separated by areas of shade, the algorithm generally isolates a single pixel per tree, usually corresponding to its well illuminated tree top. However, in sparser stands where sun illuminated ground is also visible, the algorithm picks up numerous false positives on the ground. To remedy this situation, a new version of the algorithm was created that looks for a specific shadow (i.e., an area of shade at a specific distance and direction based on sun angle) for each potential tree top. Later, the two versions of the algorithm were combined into a locally adaptive algorithm that switches between the two modes based on an a priori obtained mask derived from a directionality index based on an accumulation of local gradient directions. This locally adaptive (or hybrid) technique permits the detection of young and older trees, in dense as well as open stands, with few false positives.

Although this new hybrid technique is appropriate for stem density, spacing regularity, and stocking assessments, there is a need to assess older regenerating areas for growth and health. These two factors are better assessed if full crown measurements are available. A system of individual tree crown (ITC) delineation and classification developed to improve the precision and timeliness of forest inventories of mature trees seen at around 30-100 cm/pixel (Gougeon, 1995; 1998) could work well with sizeable regeneration in higher resolution images (10-30 cm). Unfortunately, the existing ITC-based system has problems similar to the original local maxima approach mentioned above. It relies on valleys of shade between tree crowns to separate them from each other and from the background material. It thus works well on moderate to dense coniferous stands, but has not yet been adapted to work with more open stands where bright backgrounds are visible. A simple adaptation scheme is used here. It is based on the idea that if the bright background material can successfully be classified as a distinct feature, it can be removed from the image before the ITC delineation software is run. The generic case may imply the creation of a "rough" classification with an unsupervised pixel-based classifier and the use of certain classes as masks in the ITC-based system. However, here, because of the autumn image acquisition and the senescence of the competing vegetation, a simpler and more automatic approach can be used. It consist in creating the required mask using a simple rule applied to the multispectral image: "retain only areas that have higher normalized near-infrared radiances than their average normalized radiance in the visible bands", where the normalization process consists in dividing any radiance by the average radiance of its channel. This essentially gets rid of the well illuminated background of senescent material without affecting the tree crown themselves, because of their strong near-infrared returns.

After the individual trees are detected, information such as stem counts or density (per ha.), average tree spacing, and percentage of area properly stocked (properly spaced) can be easily obtained for any given forest stand. With the latter technique, crown areas, and possibly species and health information are also available. Since the prescribed stocking is usually known, areas of under and over stocking can be automatically highlighted. If for some reason the prescribed stocking is unknown to the image analyst, areas that diverge from what should be expected given the average tree density can be highlighted. Similarly, if stands are not known a priori, it is possible to get reasonable automatic stand boundaries based on factors such as stem densities (Gougeon *et al.*, 1998). The stand polygons and the information about their content could then be transferred to a forest inventory residing on a geographic information system.

IMAGE AND GROUND DATA

This ongoing research work towards the production of automatic forest regeneration assessments was carried out on a MEIS-II (McColl *et al.*, 1983) image of the Sturgeon area, Petawawa Research Forest, Ontario (approximately 46° of latitude and 78° of longitude). A partial, yet detailed, ground survey of the area was also available. The image was acquired in November 1982, at a spatial resolution of 30 cm/pixel (Figure 1). It contains (Figure 2) plantations of jack pines (*Pinus banksiana*) and Scots pines (*Pinus sylvestris*) of different ages (3-10 years old) and spacings (1.5 - 4 m). In the denser and older stands, the individual tree crowns are completely surrounded by shade. In the more open or younger stands, the ground is clearly visible. It is covered by grasses, sedges and herbaceous plants. For the more open older stands, individual tree shadows are also visible when trees are sufficiently high.

This simple situation, with coniferous trees of uniform size and spacing, and low lying ground vegetation that has senesced, turned brown or lost its leaves, is ideal for initial algorithms development. The main complications from an image analysis point of view are the low sun elevation and the dune-like rolls of the terrain which make the ground of open stands visibly bright in some areas and dark in others. These bright areas present high radiances in all of the spectral bands making difficult the isolation of the young conifers. However, in general, the autumn acquisition should facilitate the separation of the coniferous material from other ground vegetation.

RESULTS AND DISCUSSION

Both techniques were applied to the near-infrared channel of the 30 cm/pixel MEIS image of the Sturgeon Plantation (Figure 1). The mask used with the locally adaptive technique to automatically switch between the shade-based approach and the shadow-based approach is shown in Figure 3. It is based on a directionality index calculated from an accumulation of local gradient directions from the original image. More specifically, an intermediate image was produced where areas that have more directionality in a direction commensurate with that of the sun's illumination are given higher values and a threshold was used to produce the mask itself. It seems to correspond well with the areas where visible tree shadows are present. Occasionally, areas of dense regeneration, where directional shadows are not expected, are also covered by the mask. However, this does not create a problem since both the shade-based and the shadow-based approaches tend to perform well on these areas. The mask also covers an area where scarification lines are visible (upper left corner) and happen to be in the same direction as the typical shadows. Although a potential problem, if considered purely from the point of view of pin-pointing areas containing tree shadows, in this particular case the results from this anomaly are actually beneficial. Indeed, the effect of the mask is to summon the shadow-based approach because it has stricter decision criteria than the shade-based approach, and diminishes the quantity of false positives that an area like this one typically produces.

The results of the locally adaptive technique are shown in Figure 4. A first visual assessment of the trees that were pin-pointed by the locally adaptive approach reveals that it offers great potential for the automatic assessment of regeneration. Most of the young trees present in the image are rather well accounted for. A few false positives are encountered on occasion, mainly in the more open stands, essentially, where the directionality mask failed. Of course, areas devoid of trees also generated considerable false positives. However, it is often possible to mask out these areas a priori with a little preprocessing, as done for the second technique (below), or based on auxiliary information, as was done here by manually creating a mask for the roads. The locally adaptive technique permits a reasonable assessment of all the stands, whether very young, or more mature, in dense or open arrangements, as shown in Table 1.

Figure 5 shows a first attempt (Gougeon, 1996) at tree crown delineation in regenerating areas using the ITC-suite. As expected, it performs well in dense stands where the brighter trees, separated by darker valleys of shade, are easily delineated. However, it fails miserably in open areas where trees are hard to separate from the bright background material. In these areas, the crowns are delineated as very large patches that typically include as much background material as crown material. Numerous patches of purely background material are also delineated, making tree counts, as well as, tree crown area estimations, erroneous. Figure 5 illustrates well the necessity of getting rid of the brightly illuminated background material before the ITC-based techniques can be useful with more open stands.

Figure 6 shows the results obtained with the ITC delineation software after brightly illuminated background areas were removed from the input image by the rule-based pre-processing. It led to better crown delineation and counts in the open areas, while still producing good and sometimes better results in dense stands. However, crown areas may be underestimated in some cases and overestimated in others. The underestimation is most obvious when realizing that the vast majority of the younger trees (<5 years old) are missing (compared with Figure 5). They do not meet the minimum requirement of the ITC-suite for 2x2 pixel of crown material before attempting to delineate a tree crown. This can probably be attributed to the preprocessing rule having a tendency to eliminate pixels that are not of pure crown material and thus, eliminate a lot of the mixels that could otherwise be considered part of the crowns. On the other hand, since the rule is less likely to be triggered in areas with darker background material, the crown areas there may be slightly overestimated because mixels are more readily considered part of the crowns. Finally, another interesting aspect of this approach is that the rule-based preprocessing seems to eliminate almost all false positives in areas devoid of trees.

Table 1 shows some of the regeneration assessment measurements taken on the ground and the corresponding assessments resulting from the first technique (hybrid tree top) and the second technique (masked-ITC). For the latter, areas 2 and 4 were not considered because of the technique's obvious failure at delineating tree crowns there (as explained above). The agreement is generally very good. The two automatic methods seem to agree well (+/- 12%) with each other on stem counts, density and spacing. The two methods also agree well (+/- 15%) with the ground measurements for stem density, spacing, and crown diameters, except for the stem densities of regions 1 and 3. However, the stand areas here are so small (0.3-0.5 ha) that minor imprecisions in delineating the stand boundaries or minor differences in stem counts can change the stem densities significantly. Finally, because the software is still under development and several stock estimating criteria are under consideration, stocking assessments were not reported.

ON-GOING WORK

These encouraging results need to be verified more thoroughly and for repeatability. The area under scrutiny and several other areas have been the subject of a comparison between ground counts and photointerpretation counts done on aerial photographs and on MEIS-II images at different spatial resolutions (Brand *et al.*, 1991). A quantitative comparison with these new techniques is in the works and as are stocking assessments. Also, since one of the available MEIS-II images was acquired in August (vs. November here), it may be possible to assess the significance of image acquisition in late autumn, specially relative to the pre-processing rule used in the second technique. In addition, that rule could possibly be applied to the first technique to help in the automatic elimination of non-forested areas. It also needs to be tested for consistency in other situations and with other sensors. Later, with other datasets, species differentiations and tree health assessments should be explored.

CONCLUSION

Regeneration assessments are a crucial part of managing forests for sustainability. Potential gains in efficiency could be made if reliable assessments can be obtained from the automatic analysis of digital images. This work represents first attempts at detecting individual trees in order to automatically evaluate regeneration density, spacing, stocking, and average tree crown areas. The two techniques presented here permit the detection of young and older trees, in dense as well as open stands, with few false positives. These apparent successes need to be quantified better and checked for repeatability. This is the subject of ongoing work.

REFERENCES

Brand, D.G. 1988. A systematic approach to assess forest regeneration. The Forestry Chronicle 64:414-420.

Brand, D.G., D.G. Leckie, and E.E. Cloney. 1991. Forest regeneration surveys: design, data collection, and analysis. The Forestry Chronicle 67(6):649-657.

Dralle, K. and M. Rudemo. 1996. Stem number estimation by kernel smoothing of aerial photos. Canadian J. of Forest Research 26:1228-1236.

Eldridge, N.R and G. Edwards. 1993. Acquiring localized forest inventory information: extraction from high resolution airborne digital images. Proc. 16th Can. Symp. Rem. Sens. / 8e Congrès de L'association québécoise de télédétection. Sherbrooke, Québec, Canada, June 7-10, 1993, pp, 443-448.

Fritz, L.W. 1996. The era of commercial earth observation satellites. Photogrammetric Engineering & Remote Sensing 62(1):39-45.

Gougeon, F.A. and T. Moore. 1989. Classification individuelle des arbres à partir d'images à haute résolution spatiale. Télédétection et gestion des ressources. Vol. VI - 6e Congrès de L'association québécoise de télédétection. Sherbrooke, May 4-6, pp. 185-196.

Gougeon, F.A. 1995. A crown-following approach to the automatic delineation of individual tree crowns in high spatial resolution aerial images. Canadian Journal of Remote Sensing 21(3):274-284.

Gougeon, F.A. 1996. Vers l'inventaire forestier automatisé: reconnaître l'arbre ou la forêt? 9ème Congrès de L'association québécoise de télédétection. Québec, April 30 - May 3. CD-ROM.

Gougeon, F.A. 1997. A locally adaptive technique for forest regeneration assessment from high resolution aerial images. In CD-ROM of Proc. of 19th Can. Symp. Rem. Sens., Ottawa, Ontario, Canada, May 24-30.

Gougeon F.A. 1998. Automatic individual tree crown delineation using a valley-following algorithm and a rule-based system. International Forum on Automated Interpretation of High Resolution Digital Imagery for Forestry, Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia, Canada, February 10-12, 1998.

Gougeon, F.A., D.G. Leckie, I.Scott, and D. Paradine. 1998. Individual tree crown species recognition: the Nahmint study. International Forum on Automated Interpretation of High Resolution Digital Imagery for Forestry, Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia, Canada, February 10-12, 1998.

Labonté, M., F. Bonn, G.-H. Lemieux, and G. Daoust. 1987. Évaluation préliminaire des données du capteur MEIS II pour la cartographie des surfaces forestières en régénération naturelle après exploitation. Proc. 11th Can. Symp. on Remote Sensing, Waterloo, Ontario, June 22-25, pp. 239-246.

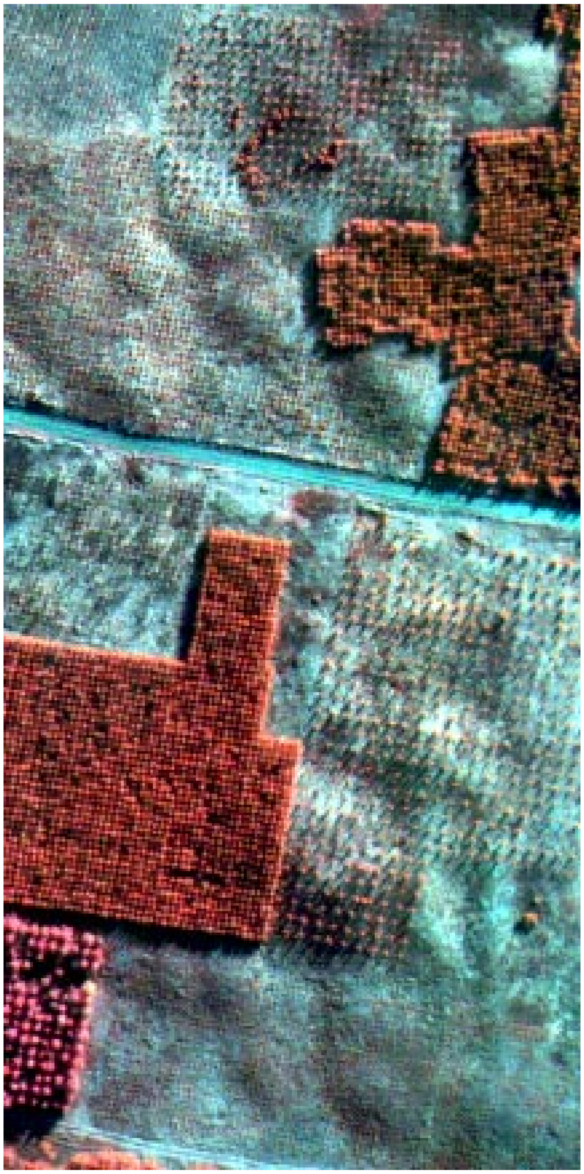
McColl, W.D., R.A. Neville, and S.M Till. 1983. Multi-detector Electro-optical Imaging Scanner MEIS II. Proc. 8th Can. Symp. on Remote Sensing and 4th Conf. L'association québécoise de télédétection. May, Montréal. pp. 71-79.

McLaughlin, S., R. Verreault, and D. Berthiaume. 1996. Inventaire automatisé de la densité du couvert forestier à l'aide de la vidéographie aérienne multispectrale (VAM) et du logiciel BORÉA. 9ème Congrès de L'association québécoise de télédétection. Quebec, April 30 - May 3. CD-ROM.

Pitt, D.G., R.G. Wagner, R.J. Hall, D.J. King, D.G. Leckie, and U. Runesson. 1996. The potential use of remote sensing for forest vegetation management: synopsis of a North American workshop. Proc. of the Application of Remote Sensing in European Forest Monitoring International Workshop. Vienna, Austria, October.

Pitt, D.G., R.G. Wagner, R.J. Hall, D.J. King, D.G. Leckie, and U. Runesson. 1997. Use of remote sensing for forest vegetation management: a problem analysis. The Forestry Chronicle 73(4):459-477.

Wagner, R.G. 1994. Towards integrated forest vegetation management. Journal of Forestry 92(11):26-30.



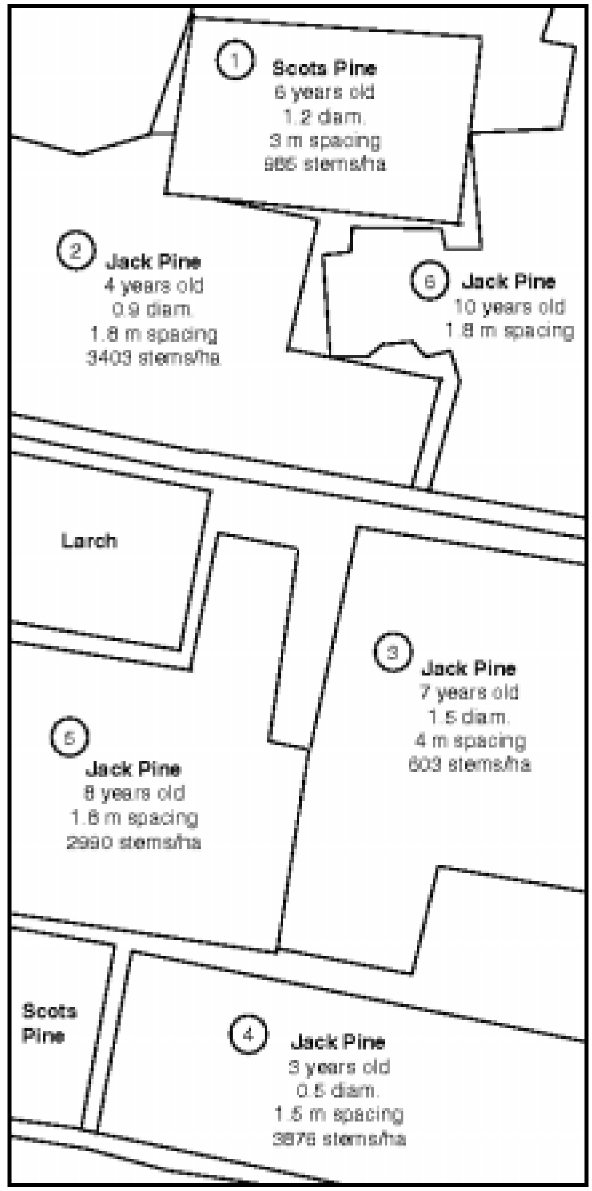
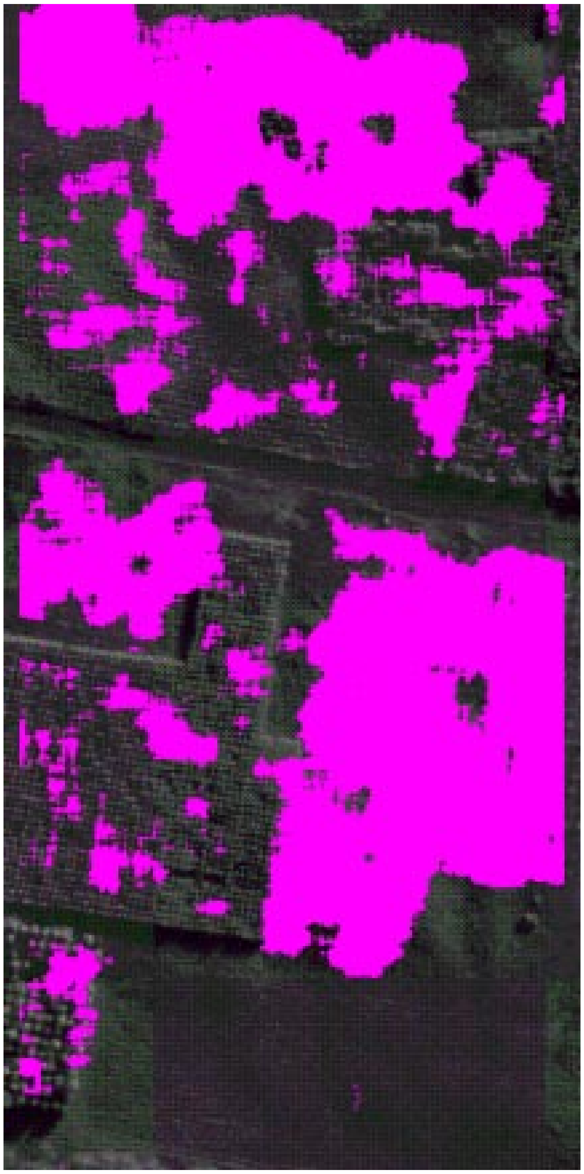


Figure 1 (left). Pseudo-colour infrared view of a MEIS-II image (30 cm/pixel) of the Sturgeon Plantation in the Petawawa Research Forest near Chalk River, Ontario (from Gougeon, 1997).

Figure 2 (right). Characteristics of the regeneration stands in Figure 1 (after Gougeon, 1997).



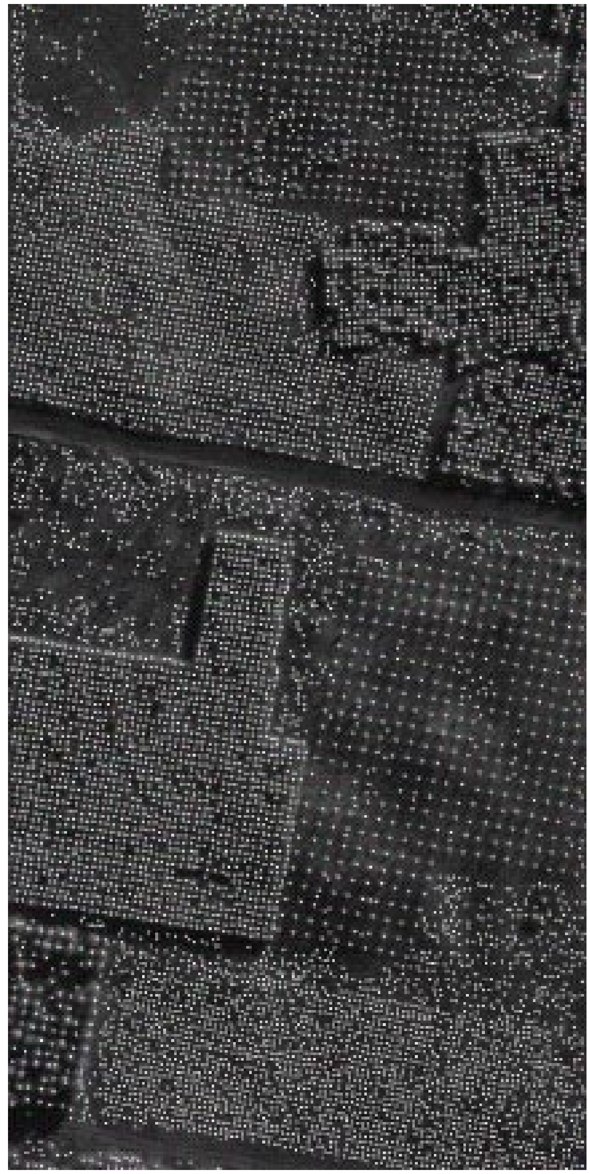
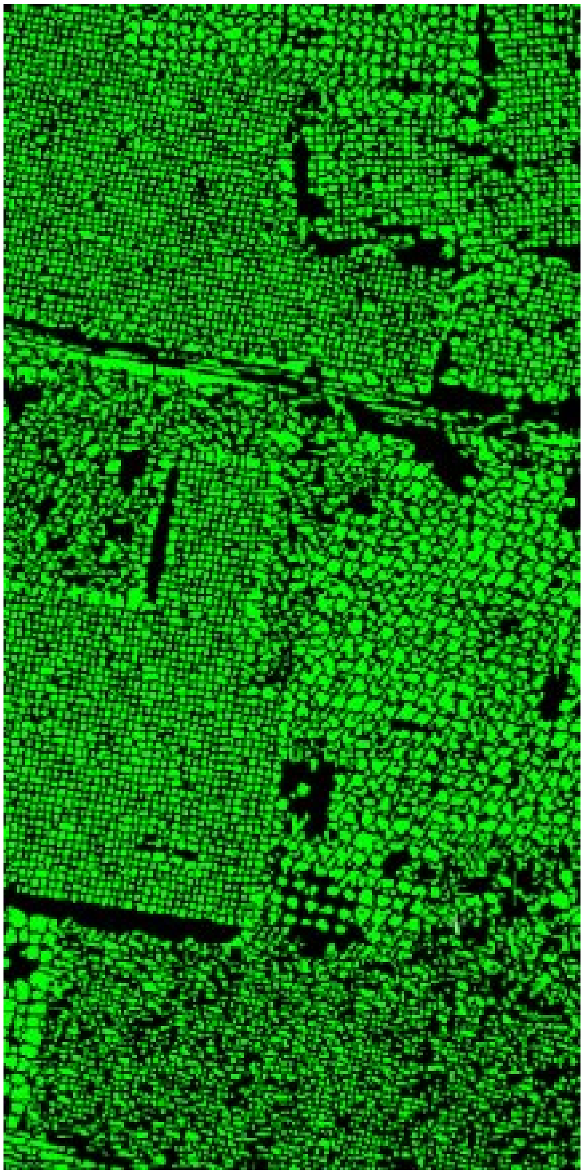


Figure 3 (left). Image of high directionality in directions commensurate with the sun angle (Gougeon, 1997).

Figure 4 (right). Results from the hybrid locally adaptive approach which can deal with most open and dense stands. In open stands, a shadow in a specific direction (commensurate with that of the sun's direction) has to be detected before the local maxima is considered to represent a tree. Non-forested areas could have been masked out (Gougeon, 1997).



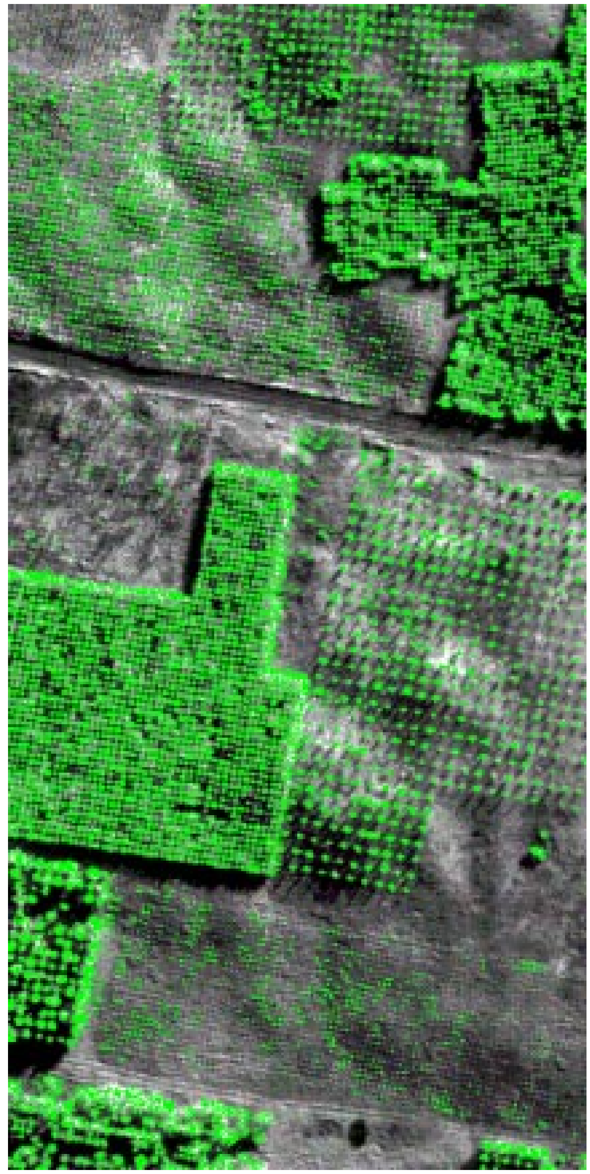


Figure 5 (left). Previous attempt at tree crown delineation using the ITC-suite without any pre-processing to eliminate the bright background of competing, but senescing vegetation (Gougeon, 1996).

Figure 6 (right). Delineation of tree crowns with the ITC-suite after bright background areas were removed from consideration using a simple multispectral rule. Provides crown areas and more potential for species identification and health analysis.

Table 1 - Regeneration Assessments

Ground assessment						**First technique (hybrid TT)**			**Second technique (masked-ITC)**			
Site	Species	Age	Diam.	Spacing	Density	Stems	Density	Spacing	Stems	Density	Spacing	Diam.
1	Ps	6	1.2	3.0	985	517	1407	2.7	463	1259	2.82	1.28
2	Pj	4	0.9	1.8	3403	1219	3247	1.75				
3	Pj	7	1.5	4.0	603	554	864	3.4	553	862	3.4	1.36
4	Pj	3	0.5	1.5	3876	317	4333	1.52				
5	Pj	8	—	1.8	2990	1611	3020	1.82	1796	3367	1.72	1.27
6	Pj	10	—	1.8	—	936	2477	2.01	998	2641	1.95	1.29