Spruce Budworm Damage Assessment in Northern Forests from High Resolution Satellite Imagery*

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Abstract

Ikonos imagery was acquired over a 10 x18 km site centred on Fort Nelson in northeastern British Columbia. The site is typical northern boreal forest predominated by black spruce in upland and wetland areas with white spruce or mixedwood on the better sites and river bottoms. A recent eastern spruce budworm (*Choristoneura fumiferana)* outbreak has resulted in light through severe cumulative defoliation of the white spruce. Site specific information on defoliation is useful for harvest scheduling, salvage, inventory prediction, determining ecological impacts and planning control programs.

Automated individual tree crown isolation was performed with the 1 m resolution panchromatic band and defoliation level classification conducted on a tree basis using fused multispectral data. For a set of test trees, classification results for the automated isolation most associated with each tree was compared to the ground defoliation assessment of that tree. As well, total defoliation of all isolations within a stand was recorded versus ground estimates of stand level defoliation. Isolation was of moderate quality with some clustering of trees into one isolation and isolations of spurious shapes. For three classes of defoliation, accuracies were 50%, 72% and 75% for light, moderate/severe and dead trees, respectively. On a stand basis, accuracies for light, moderate and severe stands were 52%, 67% and 83%, respectively. The 1 m resolution was marginal for the isolation of the small crowned trees typical of northern forests. The 4 m resolution of the multispectral data was problematic for defoliation level classification. For example, the signatures of dead or severely defoliated trees, which were commonly in more open situations, were often contaminated by the high infrared reflectance of surrounding ground vegetation or shrubs.

Résumé

Une image Ikonos de 10x18 km fut acquise pour un site centré sur Fort Nelson, dans la section nord-est de la Colombie-Britanique. Le site est typique d'une forêt boréale nordique où prédomine l'épinette noire en altitude et dans les régions marécageuses, avec de l'épinette blanche ou des peuplements mixtes sur les meilleurs sites et près des rivières. Une

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récente épidémie de tordeuse du bourgeon de l'épinette (*Choristoneura fumiferana*) a produit une défoliation cumulative de l'épinette blanche allant de légère à sévère. L'obtention d'une information spécifique à chaque site est utile à la planification de la récolte, aux coupes de récupération, aux prédictions d'inventaire, à déterminer les impactes écologiques, et à la planification des programmes de contrôle.

Une délinéation automatique des cimes d'arbres fut réalisée avec l'image panchromatique de 1m de résolution et une classification par arbre des niveaux de défoliation fut accomplie à partir des données de l'image multispectrale. Pour un groupe d'arbres de vérification, la classification de chaque arbre fut comparée avec la cime délinée manuellement qui lui est la plus associée. De plus, le niveau de défoliation total de tous les objets à l'intérieur d'un peuplement fut comparé aux estimés au sol de la défoliation de ce peuplement. L'isolation des arbres fut plutôt pauvre, avec la création de plusieurs îlots d'arbres et l'isolation de formes isolites. Pour trois classes de défoliation, l'exactitude fut de 50%, 72% et 75%, pour une défoliation légère, une défoliation modérée à sévère, et une classe d'arbres morts, respectivement. Par peuplements, l'exactitude fut de 52%, 67% et 83%, pour des défoliations légères, modérées, et sévères, respectivement. La résolution de 1 mètre fut marginale pour l'isolation d'arbres à petite cime typique de la forêt boréale nordique. La résolution de 4 mètres de l'image multispectrale fut problématique pour la classification de niveaux de défoliation. Par exemple, les signatures des arbres morts ou sévèrement défoliés, qui se retrouvent souvent où le couvert est plus ouvert, furent souvent contaminées par la réflectance infrarouge élevée de la végétation au sol environnante ou d'arbustes.

Introduction

It is hypothesized that high-resolution satellite imagery, although generally too expensive to be used over broad areas, can provide effective information for particular applications and operational needs. Specific roles would be to sample the defoliation within damage strata, expand the number of detailed plots (providing a surrogate for ground plots for some parameters), and conduct detailed surveys in special interest areas.

This paper reports on an examination of high resolution satellite imagery to assess individual tree and stand level defoliation caused by the eastern spruce budworm (*Choristineura fumiferana*) in a northern forest environment (Fort Nelson region of British Columbia, Canada). It is a part of a larger cooperative project (Alfaro et al., 2003) to describe and quantify the impact of the budworm outbreak on forest resources and ecosystem values and help understand the ecological processes involved. A new paradigm in satellite image analysis was tested (i.e., a single tree or tree cluster approach). Individual tree isolation and classification methods developed by the Canadian Forest Service (Gougeon, 2000) for airborne imagery were tested and tailored to spruce budworm damage assessment with Ikonos imagery.

Data and Methods

Site and Imagery

High resolution Ikonos imagery was obtained over a 10 by 18 km test site centred around the town of Fort Nelson, British Columbia, Canada (58^o 48' 20" N, 122^o 41' 50" W). The study site is typical of northern boreal forests and includes a good variety of defoliation conditions and stand structures in order to test methods. An eastern spruce budworm outbreak has been present at varying levels since 1985 with a recent resurgence over the last several years. It mostly affects the white spruce in the area. Damage levels range from light through severe cumulative defoliation with some mortality. The site contains bottomland along several river valleys and upland sites of white spruce and mixedwood plus both upland and wetland black spruce.

Ikonos has both a panchromatic sensor and multispectral component that records imagery in a near-infrared, red, green and blue spectral band. Imagery was acquired July 9, 2001 (1927h GMT). The view angle was 8.7° from nadir at an azimuth of 142°. Sun azimuth and elevation were 161° and 53°, respectively. Acquisition resolution (angle of view considered) was approximately 0.85 m for the panchromatic and 4.0 m for the multispectral, but these were processed to 1 m and 4 m resolution, respectively by Space Imaging as part of their standard product. Data are recorded with 11 bit quantization and are delivered with 16 bits. Sky conditions were clear, but for a few low cumulus clouds that did obscure small segments of the site.

Field Work

An extensive field program was conducted over the Ikonos site in early October, 2001. This consisted of aerial observation, single tree field assessment and a ground transect. In preparation for the field work a specialized image transformation was conducted that combined the higher resolution detail of the 1 m panchromatic band with a colour infrared rendition of the 4 m multispectral data using a Brovey-fusion transformation (PCI, 1998). Figure 1 gives an example. Quarter scene image maps of this transformation at 1:10,000 scale were then printed with the Brovey near-infrared, red and green channels displayed as red, green and blue, respectively. These were used as a basis for delineating field sites and locating individual trees in the field. BC Ministry of Forests (Ft. Nelson District) provided expertise and logistics for the field work.

Ninety three reference sites (stands or sections of stands) were assessed from helicopter. Most represented sites of predominantly mature spruce of moderate or high closure. Five parameters were recorded:

- overall defoliation class - Healthy, Light, Moderate and Severe (there was however, no sites that could be rated as healthy).
- percent defoliation - total cumulative defoliation of the susceptible species (recorded to the nearest 10%)
- stand grayness - overall gray colour exhibited, generally representing exposed branches (four classes)

- species composition
- closure.

Within each parameter a uniformity description was also used. Site boundaries were predefined from the imagery and modified in the air if required. Oblique 35 mm photography was taken with a 28 - 200 mm zoom lens. In addition, several field plots established for the "ecosystem change" component of the overall study (Alfaro et al., 2001) fell within the Ikonos test site. The detailed plot and tree information for these plots was also used.

One hundred and nine individual sample trees were located on the imagery and in the field. Criteria were a minimum of 20 trees for each of four defoliation classes (light, moderate, severe and dead-fully defoliated). A suite of information was recorded for each tree. This included: cumulative defoliation by third crown sections, overall defoliation (light, moderate, severe and dead), overall grayness, species, dominance, individual tree density (a measure of how open the tree is), plus special features such as top kill. Also assessed was the visual defoliation from above, an estimation of how the entire tree's defoliation would appear from above.

One ground transect was conducted to help qualitatively evaluate the crown isolation results. A transect of 177 m was measured. Within 2 m both sides of the transect line centre, each tree was assessed in a similar fashion as above. In addition diameter breast height of every tree and crown diameter of each spruce was measured.

Compilation of Test and Training Sites and Their Use

The reference sites observed from the air and outlined on the paper prints of the imagery were delineated on the digital imagery itself and a database of attributes created. The 109 individual trees were also outlined and put into a data base. These ground reference sample trees were divided into training and test trees. Isolation accuracy was assessed qualitatively. Accuracy of the individual tree classification was determined for both the manually delineated test trees and the automated isolations most closely associated with the test trees. Only sunlit trees were considered (i.e., no completely shadowed trees were used). The accuracy of the automated tree classification was also assessed at the stand level by calculating the proportion of isolations in each reference stand classified as each defoliation level and relating it to the overall stand defoliation class as determined from the aerial observation. The reference trees were also used to examine the trend in spectral value with defoliation level at the tree level.

Automated Isolation of Ikonos Imagery

A software suite developed by the Canadian Forest Service, the Individual Tree Crown (ITC) system (Gougeon, 2000), was used to delineate trees or clusters of trees. The ITC isolation process uses a valley following approach, which outlines areas of brighter values surrounded by lower values. The method first seeks low pixel values considered valleys in image intensity between trees, then invokes a rules-based component to help outline the tree boundaries. From previous work with airborne imagery and preliminary trials with Ikonos data, it is known that 1 m resolution is insufficient for accurate tree isolation, especially with the small crowned trees in the Fort Nelson area (Gougeon, 1995; Leckie et al., 1999;

Gougeon et al., 2001; Leckie et al., 2003). Therefore good isolations are not expected. In order to help in the isolation process, the panchromatic image was used and resampled to 50 cm resolution.

Isolation was good for many trees. For example, the isolation count for the stand with the ground transect indicated an isol/ha (tree density) of 495 stems/ha, whereas the ground transect gave 508 stems/ha for the dominant and codominant trees. However, there were clusters of several trees isolated as one entity and trees with spurious outlines. A qualitative analysis indicated that 68% of the isolations of the ground reference trees were considered good or fair.

Classification of Ikonos Imagery

Automatically isolated trees or tree clusters (isols) were classified on an object oriented individual tree basis and formed the basis of the main analysis (e.g., Figure 2). The manually delineated reference trees, however, were also classified to test classification capabilities. Because of the poor isolation of some trees, an additional accuracy analysis was conducted using the automated isolations with good and fair quality and replacing the poor and very poor isolations with the manually delineated outlines. The maximum likelihood classification routines of the ITC software suite were used. Each tree is represented by only one multispectral vector. This can be the mean of all pixels in the tree or isol, the brightest pixel, or the average of the pixels with a value greater than the mean of all the pixels within the tree (mean-lit signature). The latter case proved best and was used for the bulk of the study. Before classification, data was resampled to 50 cm resolution. Different band combinations were examined, including the panchromatic and Brovey-fusion bands. Four defoliation classes, as well as a hardwood class were applied. Results were also condensed into three defoliation classes (light, combined moderate and severe, and dead).

Results

Individual Tree Crown Classification

Examining the individual tree signatures, there was little difference or trend among the defoliation classes. The blue and red bands showed a slight increase in reflectance with defoliation level, the green little change. The panchromatic band showed a slight increase as well. These trends are what one can expect (Leckie et al., 1988). The near-infrared band showed the greatest difference among defoliation level with increasing reflectance with defoliation. This however, is a reverse trend to what is seen for individual tree near-infrared reflectance, which decreases with increased needle loss (Leckie et al., 1988). Examining the situation closely, this is likely related to the 4 m resolution of the multispectral data. The tree crowns, typically being 3 m in diameter and often less, will have spectral contamination from surrounding trees or open areas. The open areas often have shrub or suppressed hardwoods, which have high infrared reflectance. Indeed, a colour infrared display of the image overlaid on the panchromatic band did show that many dead trees had a high near-infrared component. In fact, in several cases there was no trace of the presence of the trees, the spectral characteristic of the damaged trees being merged and the high near-infrared reflectance of the surrounding vegetation dominated.

It was not viable to classify four defoliation classes (light, moderate, severe and dead-defoliated), although most confusion was with adjacent classes. The moderate and severe classes were strongly confused. Three classes, light, moderate/severe and dead (fully defoliated) were used for the rest of the single tree analysis (the four classes were kept but trees classified as moderate or severe were labeled as the moderate/severe class). Best results were obtained using the mean-lit signature of the Brovey transformed green, red and near-infrared bands. Accuracy for the automatically isolated crowns (replacing the poor and very poor isolations with manual delineations) was 50%, 72% and 75% for light, mod/severe and dead, respectively (average class accuracy was 66%). Switching the test and training data sets produced poorer accuracy (average 56%). Using the four spectral bands plus the panchromatic band gave similar results but a poorer accuracy for the dead class (average class accuracy of 57%). Using only the automated isolations, even the poor and very poor isolation cases, average accuracy was 7% less. Using the manually delineated tree crowns, average accuracy was 4% more at 70%. Because of the mixing of reflectance from trees and their surrounds, and the resulting higher reflectance for dead trees, there were some notable errors of lightly damaged trees being classed as dead. It should be noted that the dead trees in the region often had smaller crowns and were generally in more open situations. The hardwood class successfully separated the hardwood trees and prevented confusion with the defoliation classes.

Stand Level Defoliation Assessment

The above analysis is a comparison of results on an individual tree basis. The success of the whole isolation and classification process for input into forest management decision making was also assessed on a stand basis. In addition, the classification was examined over the whole landscape of the study area. There was a tendency to miss light defoliation and overestimate moderate. Those stands with variability and patchiness in the defoliation, often showed a similar variable pattern in the classification. A black spruce class was not included in the classification and black spruce was generally classed as moderate defoliation. The black spruce stands were eliminated based on inventory data and only stands with white spruce as the main softwood component were assessed and mapped. For each test stand, the number of isolations (trees) classed as each damage level were summarized and the proportion of these classed as each defoliation level calculated. Rules based on these proportions were established to assign stands or test units to defoliation classes of light, moderate and severe. These rules took into account the overestimation of the moderate defoliation class. Table 1 compares the class assigned to the stand through this process versus the description from the aerial and ground observations. There were no stands assigned to mortality from the field work. Overall, there was some underestimation of the light class and overestimation of the moderate class.

Table 1. Percentage of test stands assigned to light, moderate or severe based on individual tree crown analysis

Observed Class	**Classification Assigned Class**		
	Light	**Moderate**	**Severe**
Light	52	35	13
Light-moderate	50	50	0
Moderate	4	67	29
Moderate-severe	5	56	39
Severe	0	17	83

Discussion

The concept of using an automated isolation process to alleviate the problem of open stands and intermixing of hardwoods was reasonably successful. The compilation of the automated isolation classifications on a stand basis showed promise and may be able to be improved to produce results operationally. However, results of this study indicate that the Ikonos imagery combined with individual tree isolation and classification techniques was not sufficient to form an operational tool to assess trees on an individual tree or tree cluster basis in the Fort Nelson area and other regions where the forest and nature of the defoliation conditions are similar. The small crowns, openness of many trees and indeed the defoliation itself at the Fort Nelson site can lead to poor tree isolation. These factors plus intermixing of species and defoliation levels among adjacent trees can also lead to difficulties in classification of defoliation on a tree basis. Additional development of tree isolation methods and use of higher resolution imagery such as the Quickbird satellite system of DigitalGlobe may increase capabilities sufficiently. Quickbird has a 61 cm panchromatic band and four 2.44 m visible to infrared bands (resolution at nadir). Other high resolution multispectral satellites are expected in the future and airborne sensors such as casi, MEIS and digital frame cameras are also available to acquire imagery at competitive prices.

The potential role of high resolution satellite imagery was defined in the context of the survey and management of eastern spruce budworm damage in the Fort Nelson area. Also tested was a new paradigm in satellite image analysis of damage assessment (individual tree crown isolation and classification). The usefulness of the concept of applying automated isolation processes to alleviate the problem of open stands and intermixing of hardwoods was demonstrated despite limited data resolution. The compilation of the classifications on a stand basis proved effective. Sensor capabilities and analysis procedures will improve and it is worthwhile to continue to develop, test and eventually operationalize such procedures.

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Figure 1. Subsection of the imagery showing the Brovey transformation colour infrared fused data at 0.5 m resolution (section is 410 m by 470 m).

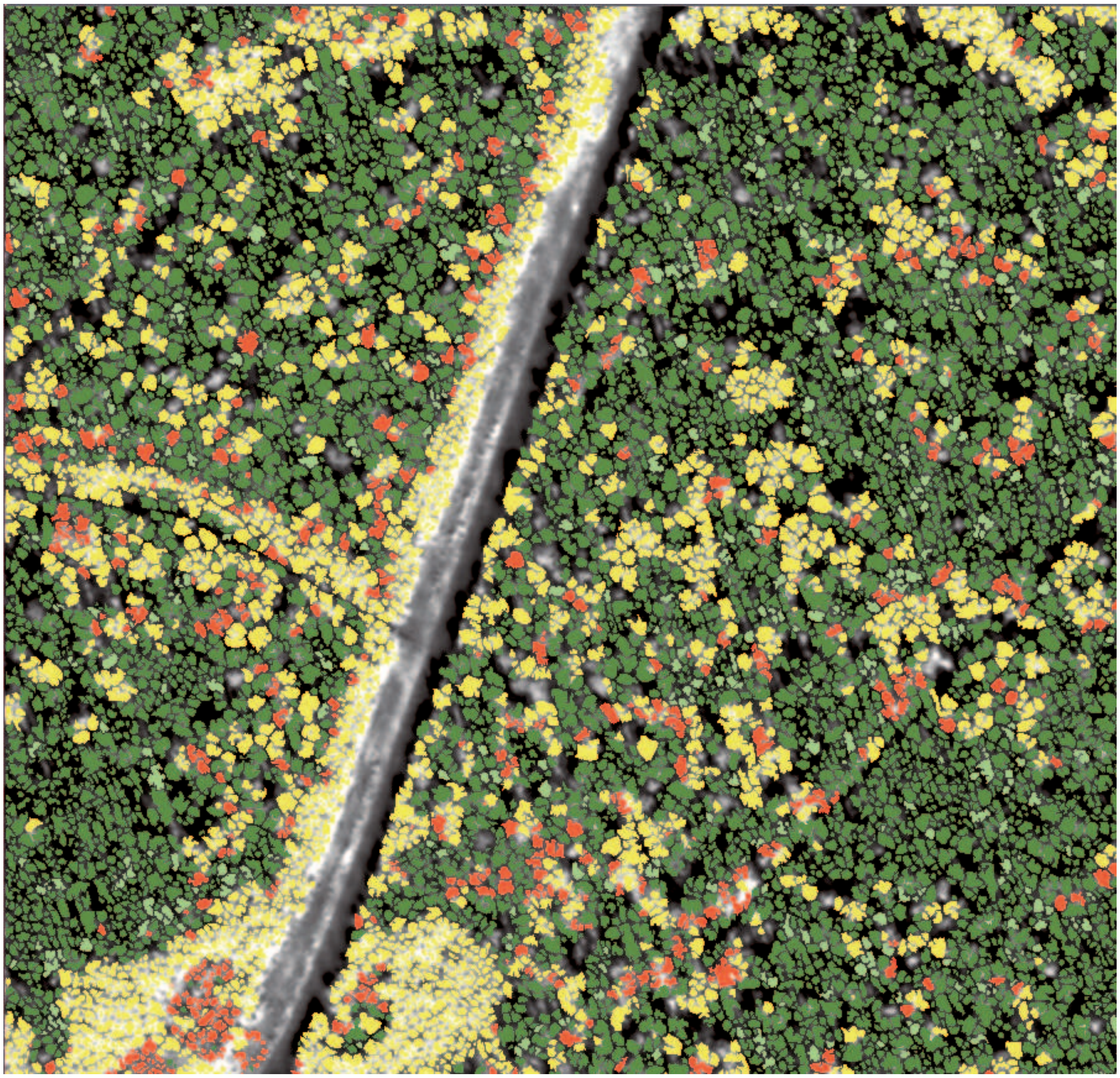

Figure 2. Automated isolation and classification for subsection shown in Figure 1. (red = dead, dark green = moderate/severe defoliation, light green = light defoliation, and yellow = hardwood)