

Mapping Eastern Spruce Budworm Cumulative Defoliation Severity from Landsat and SPOT

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ABSTRACT

The eastern spruce budworm (*Choristoneura fumiferana* Clem.) is among the most damaging of forest insects in Canada's boreal forest. In Eastern Canada, aerial observations have recently reported increasing outbreaks that are raising concerns to assess and monitor the location, area and potential impacts from this pest. In this study, field and remote sensing estimates of cumulative defoliation were compared for an outbreak in Baie-Comeau, Québec, to determine the extent that observed spectral response differences on remote sensing images were related to observations derived from the field. A method based on the relative difference in infrared simple ratio as a proxy for detecting differences in leaf area that was previously applied to aspen defoliation was adapted for this study. A post-defoliation Spot 4 multispectral image was registered and normalized to a pre-defoliation Landsat 5 image from which the relative difference in infrared simple ratio was empirically related to field-derived defoliation estimates. While both ocular and branch sample defoliation ratings were statistically correlated, branch sample estimates were more highly correlated to observed image values than ocular ratings. First iteration spruce budworm defoliation severity models were developed and applied to susceptible areas comprising dominant conifer and mixedwood land cover.

Keywords: Spruce budworm, insect defoliation, Landsat, SPOT, natural disturbance, change detection

1 INTRODUCTION

The eastern spruce budworm (*Choristoneura fumiferana* Clem.) is the most widespread forest insect pest in eastern North America that has caused significant timber losses through growth losses and extensive tree mortality from the cumulative loss of foliage over multiple years (MacLean and MacKinnon 1997). Determining the amount of defoliation is necessary to assess the impact of this insect on tree growth or mortality (MacLean and Lidstone 1982), and to monitor and report on the areal extent and severity of outbreaks (Natural Resources Canada 2007). Building upon previous research to map the severity of aspen defoliation (Hall et. al. 2003; 2006), a study was initiated to develop methods to map spruce budworm cumulative defoliation using a study area in Baie-Comeau, Québec in 2007-08. The rationale for this work was that measurable reductions in volume increment have been associated to cumulative defoliation, with one time ocular ratings being used to assess impacts on balsam fir growth rates and growth reductions (MacLean et al. 1996). If spruce budworm cumulative defoliation could be mapped remotely, a tool could be created to help monitor areas of damage that may be conducive towards assessment of mortality and impact.

Aerial surveys, ocular defoliation estimates, and shoot-count methods applied to branch samples are the three primary methods by which spruce budworm defoliation estimates are

obtained (MacLean and Lidstone 1992; Piene 1996). Determining the extent to which results from these methods are similar or complementary is of fundamental importance if relationships to observed spectral response differences on remote sensing images are to be derived. To address this issue, an investigation into scaling field estimates of cumulative defoliation with satellite images acquired before and during an outbreak is being conducted to generate more spatially precise maps of defoliation severity that could complement current aerial survey methods (Franklin 2001; Hall et al. 2006). This study focuses on the emerging spruce budworm outbreak in Québec by comparing field and remote sensing-derived estimates of cumulative defoliation within the context of these research questions:

1. Are ocular and branch sample estimates of cumulative defoliation related?
2. Are field measures of cumulative defoliation related to spectral response differences recorded on pre- and post-outbreak Landsat and SPOT satellite images?

2 METHODS

2.1 Study Area

The study area was selected in consultation with the Province of Québec to address an emerging outbreak of spruce budworm near Baie-Comeau. The area falls within the Central Laurentians Ecoregion in the Boreal Shield Terrestrial Ecozone (Ecological Stratification Working Group 1995). Within the study area were conifer stands dominated by balsam fir (*Abies balsamea* (L.)) and black spruce (*Picea mariana* (Mill.) BSP) with some occurrences of eastern hemlock (*Tsuga canadensis* (L.) Carrière) and white spruce (*Picea glauca* (Moench) Voss), and mixedwood stands with conifer species occurring with trembling aspen (*Populus tremuloides* Michx.), yellow birch (*Betula alleghaniensis* Britt.), red maple (*Acer rubrum* L.) and other deciduous species in varying amounts.

2.2 Data and Analysis

A field campaign was conducted in September, 2008 to collect basic mensurational data and to assess cumulative defoliation using both branch sample (MacLean and Lidstone 1992) and ocular ratings. With spruce budworm defoliation occurring in both coniferous and mixedwood stands, sample plots needed to be located in each stand type. A sample design was created to locate field plots in 3 stand types (balsam fir, black spruce, mixedwood), 3 levels of defoliation (light 10-34%, moderate 35-70%, severe >70%), and 3 age classes (< 40 years, 41-80 years, >80 years), with 2 replicates resulting in 54 sample plots. A total of 50 plots were established to capture as much of the targeted sample design as possible.

The provincial aerial survey, forest inventory maps and satellite data were used to help identify potential plot locations. Each plot was located within a stand suited for association to the remote sensing image and for which a prism sweep using a Basal Area Factor of 2 was undertaken. Within the sample plot, the species, total height and diameter at breast height were measured, and an ocular assessment of cumulative defoliation was rated in 10% intervals for the tree crown as rated in thirds (top third, middle, bottom third). A random sample of 5 conifer trees was also selected within each plot from which a mid-crown branch sample was selected for defoliation assessment. The branch defoliation assessment was based on the Fettes method which is a visual determination of the percentage of needles missing from each age class of foliage. This sampling approach provided the opportunity to compare ocular and branch sample estimates, and to determine if a sample of trees within the plot could provide a practical indicator as to the level of defoliation in the stand. These 5 random trees were also felled and tree sections extracted at DBH (1.3m above ground) and at two additional sections along the bole located between DBH and the

top of the tree for subsequent analysis of growth loss impacts that could be related to the degree of cumulative defoliation.

The satellite image data included a pre-defoliation Landsat 5 image acquired on July 12, 2004, and a post defoliation Spot 4 image acquired on August 27, 2008. An absolute first-order normalization was first performed by correcting all Landsat image bands to Top-of-Atmosphere Reflectance (TOAR) using a physically-based algorithm which has been automated at the Canada Centre for Remote Sensing. Both images were then orthorectified to a baseline Landsat orthorectified image downloaded from Geogratix, using the 1:250 000 Canadian Digital Elevation Data (CDED). The Spot-4 image was subsequently resampled to 30m to spatially register to the Landsat 5 image. Both images were corrected for topography using the C-Correction method. Land cover products created by the Canadian Forest Service in the framework of the Earth Observation for Sustainable Development of Forest (EOSD) project (Wulder et al. 2003) were used to stratify the imagery and focus the analysis on the desired land cover type. The EOSD (circa 2000) product was updated to exclude recent harvesting using a threshold method.

The defoliated image was subsequently normalized for phenology, using the pre-defoliated image as a baseline. The phenological normalization algorithm automatically selects healthy coniferous pixels based on reflectance values in the near infrared and middle infrared image bands. Healthy pixel pairs were then randomly selected and limited to areas outside of the provincial defoliation vectors. A normalization offset consisting of the difference in healthy pixel means between images was calculated and applied to the pure conifer and mixed forest classes thus normalizing the defoliation image for phenology. The normalized relative infrared simple ratio difference between the pre-defoliated and defoliated images was then computed and subsequently related to the field ratings of cumulative defoliation, and a preliminary cumulative defoliation image model was derived.

3 RESULTS AND DISCUSSION

Of the 50 plots, 39 were in conifer and 11 were in mixedwood stands (Table 1). Within the areas defined as conifer, 23 plots were in predominant balsam fir and 16 were in predominant black spruce stands. Defoliation in balsam fir stands were more severe, and occurred over a wider range than black spruce stands. This observation is consistent with previous observations that balsam fir stands tend to be more severely defoliated than black spruce (Potheir et al. 2005). The severity of cumulative defoliation in the mixedwood stands was similar to the conifer stands when balsam fir and black spruce were combined. This figure was perhaps, not unexpected because both conifer species occurred within mixedwood stands. There was a tendency to over estimate defoliation in the field with the ocular ratings generally exceeding the values from the branch sample. Ocular ratings were also less variable than those from branch sample estimates, and this likely reflected the lower sensitivity to defoliation differences compared to branch sample estimates.

Branch sample and ocular defoliation ratings were statistically correlated for conifer ($r=0.88$, $p=0.000$), balsam fir ($r=0.78$, $p=0.000$) and black spruce ($r=0.76$, $p=0.000$) and poorly correlated in the mixedwood ($r=0.53$, $p=0.09$). When tested for statistical differences, black spruce stands appeared to be the most difficult to rate for defoliation with ocular ratings being on average, 16% higher than branch sample estimates (Table 1). Conversely, the differences were smallest for balsam fir with an average difference of only 0.2% (unpublished data), a figure that may appear misleading since the range of defoliation from ocular ratings were 17% smaller than branch sample values (Table 1).

Table 1. Descriptive statistics summarizing branch and ocular cumulative defoliation ratings by species.

Statistic	Conifer n=39		Balsam fir n=23		Black spruce n=16		Mixed wood n=11	
	Branch	Ocular	Branch	Ocular	Branch	Ocular	Branch	Ocular
Mean	48	55	65	65	24	40	48	53
Std deviation	27	19	19	16	17	10	25	13
Minimum	7	20	11	23	7	20	9	33
Maximum	90	85	90	85	58	59	91	73
Range	83	65	79	62	51	39	82	40
CV	57	34	28	25	73	26	52	24

While both the branch sample and ocular defoliation ratings were generally correlated with the relative difference in infrared simple ratio, the branch sample values were consistently higher across all species (Table 2). These results would suggest branch sample values provide a more definitive basis for severity model development. Future work will determine if ocular defoliation ratings can be calibrated to branch sample estimates because the cost and effort in ocular ratings are more favourable and quicker to generate from an operational perspective.

Table 2. Correlation between branch sample and ocular cumulative defoliation ratings with the relative difference in infrared simple ratio.

Species	Branch sample		Ocular	
	Correlation	p-value	Correlation	p-value
Conifer	-0.74	0.000*	-0.66	0.000*
Balsam fir	-0.76	0.000*	-0.67	0.000*
Black spruce	-0.72	0.002*	-0.51	0.04*
Mixed wood	-0.91	0.000*	-0.32	0.33

* statistically significant at probability (p-value) = 0.05

Preliminary models of spruce budworm cumulative defoliation severity were generated for the conifer (Adjusted $r^2=0.53$, RMSE=19.5%) and mixedwood (Adjusted $r^2=0.82$, RMSE=12.5%) stands. The prediction error from this preliminary model suggests remote sensing could estimate defoliation to within 20% of field values and while encouraging from only a single season of field data collection, further work is necessary to improve upon these values. Because these models were generated from normalized images that were applied to both conifer and mixedwood areas, replicating the image normalization to be more specific to these stand types may improve model performance.

4 CONCLUSIONS AND FUTURE WORK

Ratings of cumulative spruce budworm defoliation varied by method of collection, with ocular ratings showing a tendency to overestimate and be less sensitive to the range of defoliation when compared to branch sample values. Branch sample defoliation values were more highly correlated than ocular ratings to relative differences in infrared simple ratio observed on the image. These results would suggest branch sample estimates should be the recommended method of field evaluation. Future work will explore if ocular ratings could be calibrated to branch sample values because they are more quickly derived at lower cost, factors that merit operational consideration. While preliminary severity models for conifer and mixedwood stands were generated, these will be revisited following a modification to the phenology normalization method that would be applied to conifer and mixedwood stands independently. Based on the distribution of field defoliation sampled, subsequent field work targeted at the sample distribution may also result in further improvements to severity model development.

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