Monitoring Annual Aspen Defoliation Patterns by Detecting Changes in Leaf Area from Multitemporal Landsat TM Imagery

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Abstract **– Trembling aspen is the most widely distributed and important deciduous tree species in North America. Repeated outbreaks of insect defoliation have raised the need for more precise monitoring than what aerial surveys are able to provide. A defoliation outbreak of large aspen tortrix in northern Alberta, Canada, was monitored over a 4-year time series of anniversary Landsat Thematic Mapper images from 2001 to 2004. Image models of leaf area index (LAI) based on the infrared simple ratio were related to percent defoliation, resulting in an annual percent defoliation image map from which changes from year to year could be determined. These image maps of aspen defoliation compared favorably to annual aerial surveys conducted independently, and visually compared to aerial photos taken from a survey aircraft that were spatially registered for comparison in a Google™ Earth environment. The image maps produced a similar trend in annual change of aspen defoliation compared to aerial surveys and did so with a much smaller total area of defoliation. This approach results in more precise monitoring of defoliation patterns, and could serve as a locational guide to more detailed field assessments of damage impact caused by defoliation.**

I. Introduction

Trembling aspen (*Populus tremuloides* Michx.) is the most widely distributed deciduous tree in the North American boreal forest [13], and increasing evidence of repeat defoliation, dieback, mortality and reduced growth has been observed since the 1990's [4]. Trembling aspen, which has been estimated to contain >1000 Tg of carbon within Canada's boreal forest, are projected to decrease under global change resulting in significant concerns regarding its sustainability and ability to sequester carbon [6]. Similar to the work of the Canadian Wildland Fire Information System to incorporate satellite mapping of forest fires into operational carbon accounting, there is a need to map the areal extent and severity of disturbances from defoliation for incorporation into this framework.

The use of earth observation data for detecting and mapping insect defoliation is not new but success has been variable [8, 11, 2, 5]. A difficult challenge has been the use of visual estimates of defoliation severity to define a spectral basis for damage class limits that can be mapped from the remote sensing image. This is an important problem requiring resolution if consistent detection and mapping is to be achieved [5]. As a result, despite past research and apparent high potential use for remote sensing to map insect defoliation, it remains a technology that has seen relatively little operational use [10].

Building on previous work that demonstrated the use of pre- and post-defoliation image dates to detect areas of defoliation [5], this study replicated the process over a 4-year time series to determine how trends in remote sensing defoliation maps compare to those from aerial survey.

II. Study Area

The study area was located near the town of High Level in north-central Alberta situated at 58.5° N, 116.2° W. Outbreaks of large aspen tortrix (*Choristoneura conflictana* (Wlk.)) have caused severe defoliation to many trembling aspen stands in this region [5]. The physiographic terrain was nearly level to gently undulating with mostly till as ground moraine [1]. The tree species were characterised by pure and mixed stands of trembling aspen, balsam poplar (*Populus balsamifera* L.) and white spruce (*Picea glauca* (Moench) Voss). The study area was also part of a research project called CIPHA (***Climate** change **Impacts** on **Productivity** and **Health** of **Aspen***) that was established to monitor changes in aspen health from insect defoliation and changes in climate [6].

III. Methods

A. Aerial and Field Data Collection

Annual aerial sketch map surveys depicted on 1:250k topographic maps from 1999 to 2004 were obtained from the Government of Alberta. Defoliated areas were mapped according to three severity levels, defined as Nil to light (<35%), Moderate (35-70%), and Severe (>70%). The delineated polygons may include a combination of light, moderate and severe defoliation, but are labeled by the most dominant severity rating for the polygon.

Field plots were located within the strata defined by the aerial sketch map survey. Defoliation was visually estimated in June, 2001 with the aid of binoculars to 10 percent classes [9]. Ten optical LAI-2000 measurements were also taken in each selected plot and averaged for validating the estimation of LAI on the 2001 image. The optical LAI-2000 measurements were also validated by comparison with up to 10 litter traps that were established in each sample plot [5].

B. Satellite Remote Sensing Data

Landsat TM and ETM+ image data were acquired from early June to early July to map the peak occurrence of aspen defoliation from 2001 to 2004, and a 1999 image was used as the pre-defoliation image. The Landsat data corresponded to Level 1G at sensor radiance systematic corrected data. An iterative dense dark vegetation atmospheric correction approach was applied to all scenes. The 6S radiative transfer code [12] was used iteratively to determine an estimate of surface reflectance given top-of-atmosphere reflectance and an estimate of aerosol optical depth. The images were then georeferenced to the Lambert conformal conic projection using a nearest-neighbour, first-order transformation.

C. Mapping Aspen Defoliation from Remote Sensing

To determine the change in leaf area attributable to defoliation, an empirical model that related a vegetation index to leaf area for each image date was used so that differences resulting from defoliation could be computed. An infrared simple ratio (ISR) model was first generated on each image date using Landsat bands 4 and 5. An LAI model based on in situ optical LAI measurements and ISR values was then developed for deciduous and mixedwood land cover types. The LAI models were applied to each image date stratified by deciduous and mixedwood land cover types using the classified land cover from the Earth Observation for Sustainable Development (EOSD) of forests [14] program, produced in collaboration with the Alberta Ground Cover Characterization (AGCC) project. This procedure ensured areas classified as coniferous, shrub, or agriculture would not be incorporated into areas where aspen defoliation could occur.

The percent change in LAI from 2001 to 2004 was then computed relative to LAI in 1999. A model to estimate percent defoliation as a function of the change in LAI was derived based on percent defoliation values measured in the field. This model was an exponential function with an R^2 of 0.77 [5]. Application of the model generated a continuous percent defoliation image, which was then classified into 3 broad defoliation severity classes: <35%, 35-70%, and >70% to produce a thematic map depicting the pattern of defoliation severity for that year. Maps of defoliation severity from the aerial sketch map survey and remote sensing images were then compared because they both used the same class limits of defoliation severity.

IV. RESULTS AND DISCUSSION

The aerial sketch maps are a broad indicator of the annual areal extent of aspen defoliation that tend to overestimate defoliation because they incorporate non-susceptible areas such as conifer forest, agricultural lands and water bodies. Within the study area, the total defoliated area derived from aerial sketch mapping was nil in 1999, but increased annually between 2001 and 2003, followed by a reduction in 2004 due to the collapse of the large aspen tortrix outbreak (Table I).

TABLE I
AREA OF DEFOLIATION AND PER CENT CHANGE FROM REMOTE SENSING AND AERIAL SKETCH MAP FROM 2001 – 2004.

	Remote sensing		Aerial sketch map	
	Area (ha)	% Change	Area (ha)	% Change
2001	38 200	0	165 000	0
2002	41 900	10	178 400	8
2003	47 200	13	228 600	28
2004	16 300	-66	56 600	-75

Translating the percent reduction in leaf area from the satellite images to percent defoliation resulted in a much smaller area of defoliation. When assessing the relative change from year to year, there was a similar trend in the patterns of defoliation mapped from the remote sensing time series compared to that mapped from the aerial surveys (Table I). The similarity in these yearly trends is a strong indicator that the remote sensing approach does provide a reasonable representation of the actual trends as represented in the aerial sketch map data over the 4-year time period. The key difference in these results is that the aerial sketch map surveys represent the total areal extent of defoliation, whereas the remote sensing estimates is identifying areas of change that more likely represents areas that have sustained defoliation.

Validating the remote sensing defoliation maps is difficult because comparable data of similar resolution is not available. Aerial survey photographs taken independently can be a visual source of validation if positioned spatially correct. The recent release of Google™ Earth provided the opportunity to register and orient aerial survey photographs obtained from the Government of Alberta to generate similar perspective views with the remote sensing classified defoliation maps (Figure 1). The result shows that similar patterns of defoliated areas identified in the aerial survey photographs can be found on the classified image map. While this procedure is not empirical, the visual correspondence does suggest the remote sensing-leaf area change approach presented is correctly representing reality, at least to the extent we have been able to observe.

V. CONCLUSIONS AND FUTURE WORK

Aerial sketch map surveys represent a long-standing record of the areal extent of defoliation that captures the relative trend in defoliation activity from year to year. In order to move towards quantitative estimates of damage, more precise mapping of insect defoliation to varying degrees of severity is necessary. An approach based on an empirical relationship between percent defoliation and changes in leaf area resulted in maps of defoliated areas that were similar in relative change of affected area from year to year, with much smaller areas than reported from the aerial survey. Validating these more spatially precise remotely sensed damage maps was previously difficult, but visual comparisons with aerial survey photographs represented in a Google™ Earth environment provides a resolution to this problem. Future work will build on these methods along with field sampling to quantify impacts from wood volume and growth loss perspectives that will result in the ability to assess consequences to carbon.

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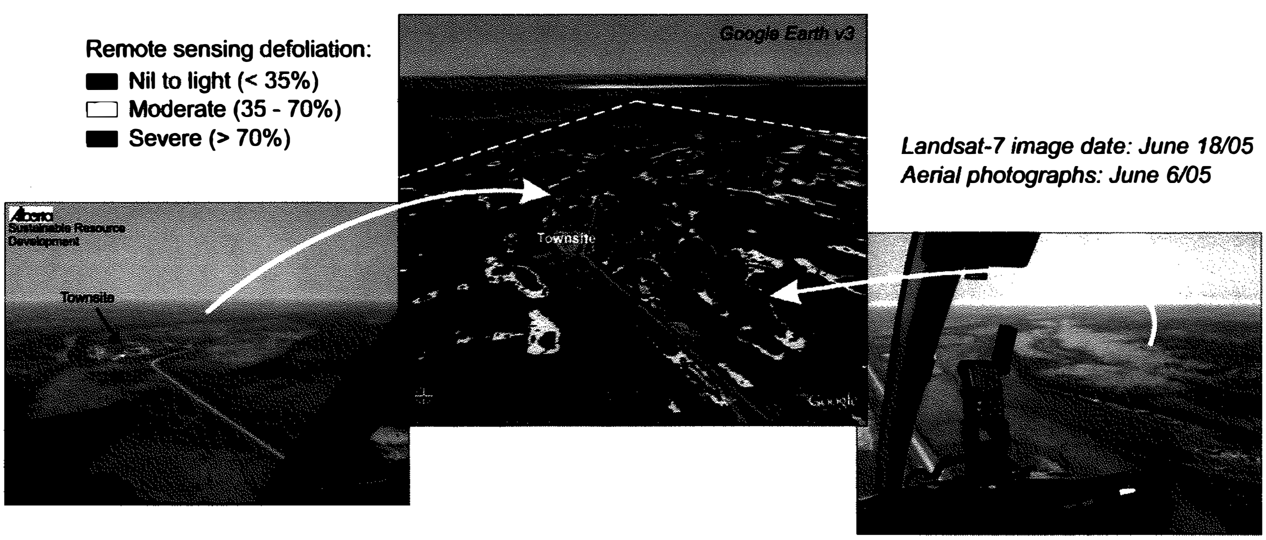

Figure 1. Image map of defoliation severity projected onto Google™ Earth and referenced to aerial survey photographs.

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