Using MERIS to Assess Insect Defoliation in Canadian Aspen Forests

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Abstract—**This paper describes the preliminary results of a study into the potential of images from the Medium Resolution Imaging Spectrometer (MERIS) for the mapping and monitoring of aspen defoliation in Canada. Information relating to aspen defoliation supports environmental and sustainable development initiatives. More specifically, the information needs relate to the location, extent and severity of defoliation events. Our results indicate that with the help of MERIS images, the assessment of location and extent of defoliation is straightforward but the assessment of defoliation severity is challenging. MERIS derived defoliation information products offer advantages over conventional defoliation maps that are produced on the basis of aerial surveys.**

Keywords-MERIS, insect defoliation, boreal forest, trembling aspen

I. Introduction

Within Canada and abroad there is growing acceptance of the link between environmental health and human wellbeing. This is evidenced by initiatives such as the introduction of sustainable development strategies, carbon accounting procedures and national reporting obligations (e.g. arising from the Kyoto protocol). These initiatives create a growing demand for consistent and timely information on the status of and trends in environmental and sustainable development indicators. Natural Resources Canada (NRCan), through its Sustainable Development Strategy (SDS), has federal responsibility to ensure sustainable development of Canada's forests. NRCan's Earth Sciences Sector and Canadian Forest Service support the SDS for forests by research to increase Canada's forest knowledge and by developing geo-spatial tools to improve information on forest cover. Forest cover is among the variables adopted by the Government of Canada as indicators of environmental health and sustainable development.

In this paper we will address the use of the Medium Resolution Imaging Spectrometer (MERIS) as a tool for collecting information on aspen forest cover disturbance in the form of insect defoliation. More specifically, the information requirement relates to the location, extent and severity of the forest cover disturbance / insect defoliation. Our study into the potential of MERIS in support of aspen defoliation mapping and monitoring is ongoing.

II. Aspen Defoliation

Trembling aspen (*Populus tremuloides* Michx.) is the principal deciduous tree species in Canada's boreal forest region. In most years, insects defoliate several million hectares of aspen dominated boreal forest in Canada. The principal aspen defoliators are the forest tent caterpillar (*Malacosoma disstria* Hübner) and the large aspen tortrix (*Choristoneura conflictana* Walker). Typically, the majority of trees will refoliate within 4-6 weeks after the caterpillars complete feeding. The effects of severe defoliation include twig mortality, smaller leaf size, reduced radial stem growth and increased susceptibility to other stress factors such as drought, pests and diseases. Occasionally, several years of severe defoliation in combination with other stress factors (e.g. drought) can result in tree mortality.

The conventional means of assessing the location, extent and severity of aspen forest cover disturbance from insect defoliators is based on visual observation and sketch-mapping (typically at 1:250.000 scale) in the course of aerial surveys. The severity of the infestation is expressed in terms of level of defoliation and commonly rated as nil, light, moderate or severe. The corresponding defoliation levels are 0%, <35%, 35-70%, and >70%, respectively. However, these surveys are largely confined to managed forest areas and result in information of limited spatial detail and precision. In particular, the severity rating is highly dependent on the perception of the surveyor. Thanks to a systematic, synoptic and repetitive imaging capability, satellite remote sensing holds good promise as an alternative means for the mapping and monitoring of aspen defoliation.

III. Study Area

The study area is centered at about 57°40'N, 118°00'W and roughly corresponds to the Northwest forest region of the province of Alberta (Fig.1). Topographically the study area can be characterized as nearly level to gently undulating. According to the Canadian system of ecological land

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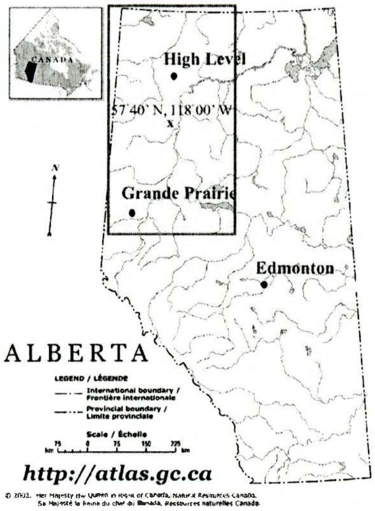

Figure 1. Location of study area.

classification, the study area is part of the Boreal Plains ecozone (http://www.ccea.org/ecozones/terr.html). Circa 95% of the study area is covered by forests that comprise a mixture of deciduous, mixed and coniferous stands. The dominant tree species in the deciduous and mixed forest stands is trembling aspen. Commonly found complementary tree species include: balsam poplar (*Populus balsamifera* L.), white birch (*Betula papyrifera* Marsh) and white spruce (*Picea glauca* (Moench) Voss).

Fig.2 shows the estimated extent of aspen defoliation in Alberta from 1999 to 2005. The estimates shown were recorded by the province on the basis of information collected during aerial surveys. Complementary provincial information obtained through ground surveys shows that the large aspen tortrix was the primary defoliator prior to 2005. In 2005, the large aspen tortrix population collapsed and the forest tent caterpillar became dominant. The period of infestation or defoliation

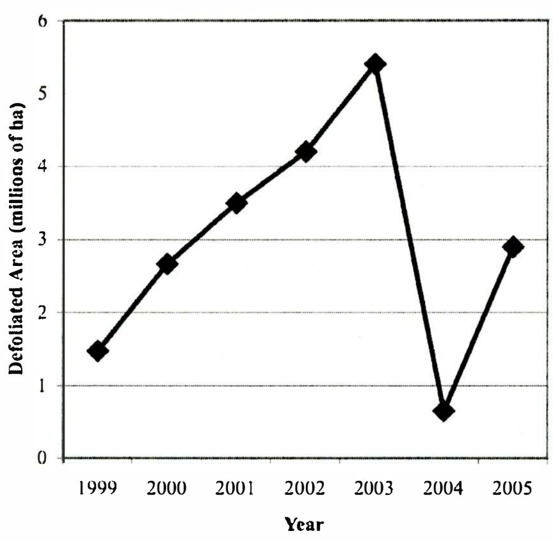

Figure 2. Extent of insect defoliation recorded by the province of Alberta.

season varies as a function of environmental conditions but typically runs from mid-June to mid-July.

The research team traveled to the study area to collect ground data in June 2005. Our fieldwork focused on aspen stands in the vicinity of the towns of Grande-Prairie and High Level (see Fig.1). The data collected related to variables such as tree species composition, defoliation level, tree height, tree diameter, basal area, coverage and composition of the understory.

IV. MERIS Data

The MERIS data set available to the study is largely comprised of large scene (575 km by 575 km), full resolution (260 m by 290 m), level 2 (geophysical) image products for the 2003, 2004 and 2005 defoliation seasons. For certain acquisition dates the corresponding level 1 image products are also on hand. All images were provided to the team by the European Space Agency (ESA) in the framework of an Envisat AO project. The 2003 data were retrieved from the image archive whereas the data for 2004 and 2005 were acquired on our request. Unfortunately, many of images relating to the 2005 defoliation season show extensive cloud coverage.

It may be noted that MERIS images lack the mid-infrared waveband which commonly used for land and vegetation observation. This absence of a mid-infrared imaging capability on MERIS can be explained form the fact that this sensor was developed primarily for use in support of ocean applications. The primary strengths of MERIS in the context of this study are its two to three day repeat cycle and its ability to image large areas at a medium spatial resolution. The high revisit frequency is beneficial considering both the limited duration of the defoliation season and the chances of cloud cover. The coverage and spatial resolution provided by the images agrees well with the scale at which aspen defoliation occurs and is assessed through conventional sketch-mapping.

V. Analysis Approach

The available MERIS data were analyzed using two complementary approaches. A region based approach was used to extract and evaluate the MERIS signatures of classes of interest on specific dates and over time. In addition, a pixel-by-pixel processing approach was used to generate image products that visualize the effects of defoliation for the study area. The three classes considered in the region based approach were healthy, moderately defoliated and severely defoliated aspen forest. A series of regions representing each of these classes was defined with the help of ground reference data through visual interpretation and on-screen digitalization of polygons. Both of the analysis approaches described were preceded by the orthorectification of all MERIS images of acceptable cloudiness to the UTM WGS84 coordinate system. The software used in the orthorectification process was the freely available Basic ENVISAT Toolbox for (A)ATSR and MERIS (BEAM).

Stratification of the land cover in the study area in terms of aspen forest versus non aspen forest was achieved with the help of land cover products created by the Canadian Forest Service in the framework of the Earth Observation for Sustainable Development of Forest (EOSD) project. Information with respect to the location, extent and level of defoliation was obtained from aerial sketch-maps and, in the case of the 2005 defoliation season, through dedicated fieldwork.

VI. Results and Discussion

Fig. 3 shows the spectral signatures for healthy, moderately defoliated and severely defoliated aspen forest. The MERIS image from which these signatures were extracted was acquired on June 26, 2004. The locations of the widely applied Landsat TM spectral bands 1 through 4 have been marked as points of reference. In 11 out of 13 spectral bands shown, the reflectances for severely defoliated aspen can be seen to differ considerably from those for healthy aspen and moderately defoliated aspen. This indicates that MERIS has potential as a tool in support of the mapping of high levels of aspen defoliation. The signatures for healthy and moderately defoliated aspen are very similar and seem to indicate that MERIS images may not support the mapping of lower levels of aspen defoliation. Moderately defoliated stands differ from severely defoliated stands in more than one way. Firstly, the overall percentage of defoliation is lower 35-70% versus > 70%. Secondly, moderate defoliation is concentrated in the top two thirds of the crown layer whereas severe defoliation occurs throughout the crown layer and often affects other forest layers such as tree understories and shrub layers. Naturally, the remaining foliage in moderately defoliated forest will compromise the detection capabilities of remote sensing systems. However, it should be pointed out that the on-screen digitalization of moderately defoliated aspen image regions was based on sketch-map information. This implies that the corresponding level of defoliation was somewhere in the range from 35% to 70%. If the level of defoliation observed was close to the lower end of this range, then this could well explain why the signature for moderately defoliated forest as shown in Fig.3 resembles the signature for healthy forest much more closely than the signature for severely defoliated forest.

Fig.4 shows the so-called MERIS Global Vegetation Index

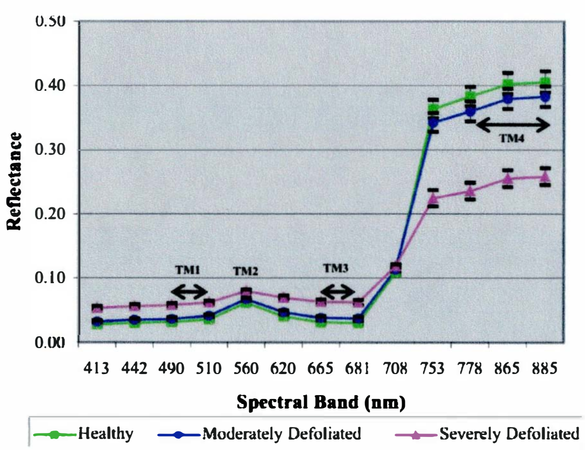

Figure 3. Aspen signatures extracted from MERIS image acquired on June 26, 2004.

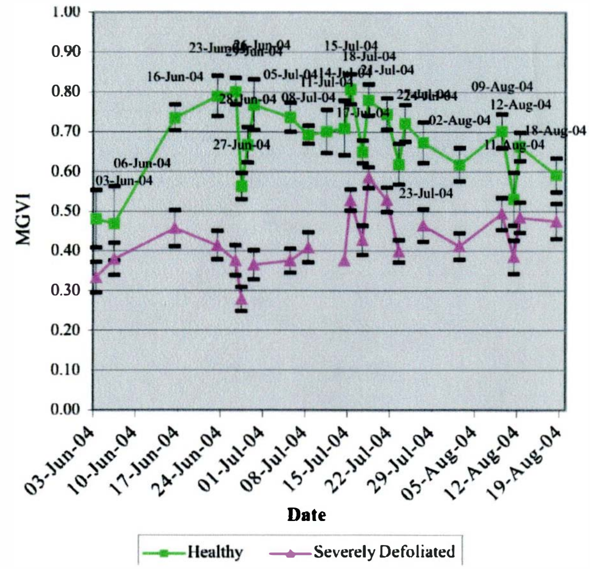

Figure 4. MERIS Global Vegetation Index (MGVI) as function of time for healthy and severely defoliated aspen stands.

(MGVI) as a function of time for healthy and severely defoliated aspen forest. The time period shown includes the defoliation season which typically runs from about mid-June to mid-July. The MGVI is one of the biophysical products that are included as image channels in level 2 MERIS data sets. The index developed by Gobron et al. [1] represents the fraction of absorbed photosynthetically active radiation (FAPAR) and as such relates to the state and productivity of the observed vegetation. According to Gobron et al. the MGVI is insensitive to atmospheric and angular effects. The measure is computed using the information contained in the 681 nm (red) and 865 nm (near-infrared) MERIS spectral bands.

Throughout the period of observation, the MGVI values for healthy forest can be seen to exceed those for severely defoliated forest. The relatively low MGVI values for the defoliated forest class are expected for the period from mid-June to mid-July (typical defoliation season) but not for the preceding and subsequent periods of time. The lower MGVI values for the defoliated forest class at the beginning of the growing season points to a lower vitality of the stands comprised in this class. This lower vitality may well be the result of defoliation events that occurred in previous years. This explanation seems to agree with low MGVI values observed for the defoliated forest class in the period following the season of defoliation. These relative low MGVI values indicate that the forests involved are unable to completely refoliate which degrade both their immediate and long-term vitality.

Generally speaking, the curves shown in Fig.4 confirm the potential of the MGVI measure, and as such MERIS, for the mapping and monitoring of aspen defoliation. However, the curves reveal peculiar drops that result from low MGVI values for June 27, July 17, July 23, and August 11. The exact cause of these unnaturally low MGVI values is unknown at present but it seems plausible that there is a problem with either the MERIS data or the MGVI algorithm.

Fig.5 presents a result of our pixel-by-pixel processing approach. Fig.5a shows a subset of a composite MERIS image that covers a region just North of Grande Prairie, Alberta. The image composite comprises the MERIS channels 14 (in red), 8 (in green), and 3 (in blue). Fig.5b shows a corresponding defoliation product which has been superimposed with a vector (shown in gray) resulting from the 2003 provincial aerial survey. According to the survey the vector marks an area of moderately defoliated forest. Land areas not covered by broadleaf forest, water bodies, clouds as well as cloud shadows are masked out. The defoliation product was obtained by subtracting the MGVI channel for July 11, 2003 from the MGVI channel for August 11, 2005. Being short of images acquired prior to 2003, the August 2005 image was chosen to represent the healthy/foliated condition. The absence of defoliation in 2005 was ascertained using aerial sketch-maps and fieldwork data.

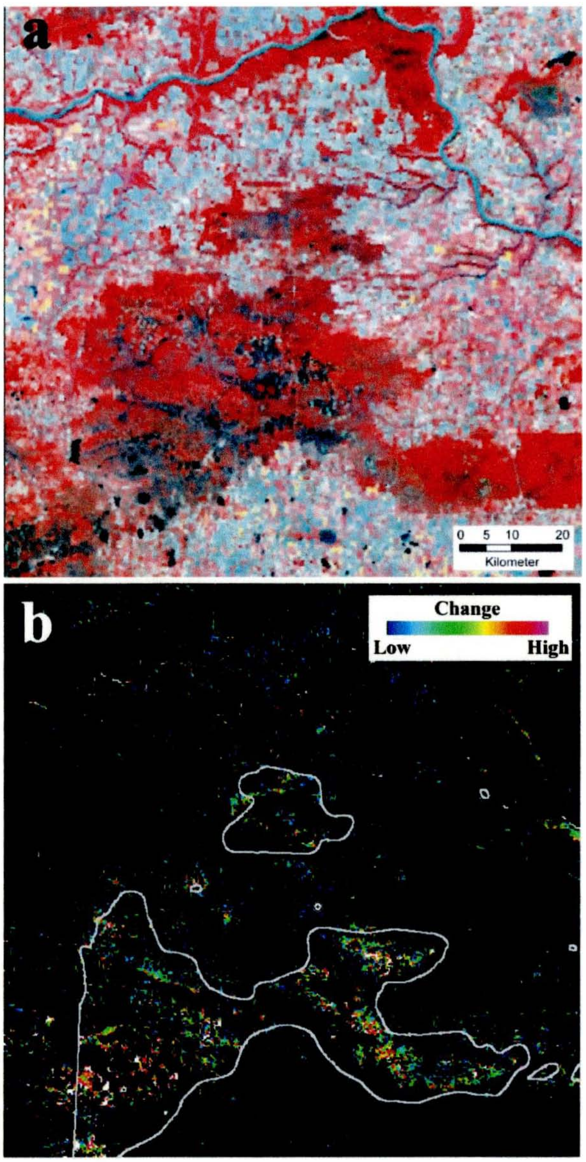

Figure 5. (a) Subset of MERIS image (R=14, G=8, B=3) acquired on 11 July 2003; (b) Matching defoliation product, overlayed with provincial sketch-map vector .

Generally speaking, the image patterns in the defoliation product agree with the shape of the sketch-map vector. However, the image pattern offers much more spatial detail and, unlike the sketch-map vector, reveals spatial variability in the level of defoliation. Light defoliation is shown in blue/green while severe defoliation is shown in red/white. Cloud permitting, repeat imaging would enable the seasonal monitoring of the defoliation process. This is not feasible with sketch-mapping since this is a one time activity that is executed close to the peak of the defoliation season.

VII. Preliminary Conclusions

The results of this study show that MERIS images, despite the absence of mid-infrared channels, can be used in the mapping and monitoring of aspen forest cover disturbance from insect defoliators. Assessment of the location and extent of the defoliation is straightforward but reliable assessment of defoliation severity will be challenging. Plots showing the evolution of the MERIS Global Vegetation Index (MGVI) over time appear to have anomalies that require further investigation. MERIS based defoliation image products show patterns that are overall comparable to the shape of defoliation vectors available from aerial sketch-maps. However, the image products present more spatial detail and in addition show spatial variability in defoliation severity. The coverage and spatial detail provided by MERIS agree well with the geographic extent of aspen defoliation and the 1:250.000 scale used in conventional aerial sketch-mapping.

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