Remote Sensing Technologies For Mountain Pine Beetle Surveys

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Abstract

Surveys for mountain pine beetle are undertaken across a range of scales to provide forest managers with up-to-date information regarding the location, extent, and numbers of infested trees. Remote sensing provides new opportunities to detect and map mountain pine beetle damage to inform management and mitigation decisions. The key to using remotely sensed data is to identify how this new information can be integrated with traditional datasets. In this communication, we present the survey information needs for mountain pine beetle management, then match those needs with the potential and limits of remote sensing. Some examples of how remotely sensed data have been used for mapping mountain pine beetle impact are then presented.

Introduction

Management information needs associated with a mountain pine beetle infestation, and the potential of remote sensing to address these information needs were summarized during a stakeholder workshop in June, 2003 (Wiart 2003).

The goals of the workshop, supported by the Mountain Pine Beetle Initiative, were stated as:

- To provide a forum for discussion on the detection and mapping of mountain pine beetle;
- To aid in the reviewing of mountain pine beetle survey and mapping with remotely sensed data;
- To assist in providing direction to Canadian Forest Service (CFS) and British Columbia (BC) Ministry of Forests research managers regarding mountain pine beetle survey and mapping with remotely sensed data.

To meet these goals, there were talks presented by federal and provincial program managers, scientists (federal, provincial, and academic), and industry. The industrial participants represented both the forest management and consulting sectors. The workshop presentations enabled a clear description of the magnitude of the mountain pine beetle outbreak in BC and current management and mitigation activities. The information needs of the provincial and industrial management agencies were discussed and refined into clear business drivers. The key business drivers for mountain pine beetle detection and mapping were identified as:

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- Detection and mapping of provincial level red attack;
- Operational mapping of red attack for layout and sanitation;
- Green attack detection for sanitation; and
- Technology transfer.

The scientists and consultants presented research and operational survey activities. Potential gaps between user needs and research activities were then identified.

Each business driver was evaluated against current remote sensing technologies and relevancy for funding from the CFS Mountain Pine Beetle Initiative. Detection and mapping of provincial level red attack was generally considered to be an issue of provincial concern. Additionally, since there exists no identifiable remote sensing approach that is capable of replicating the cost and utility of the existing provincial aerial overview survey information, this business driver was given a low priority. Operational mapping of red attack for layout and sanitation was identified as a research area that has potential for short- and long-term research, with focus on operational techniques. Operational applications include strategic planning for one party (i.e., province) and tactical planning for others (i.e., timber manager). The priority for research and development for red attack mapping was high, with a recommended focus on incipient level of mountain pine beetles. Green attack detection for sanitation at incipient levels was important, but considered a low priority for federal research funding. Green attack detection at endemic or epidemic attack levels was also considered low priority for remote sensing research. A range of issues regarding timing of beetle impacts, data collection, processing, image extent, costs, and required turn-around time were issues identified that limited potential application of green-attack detection. Technology transfer, while not an information need per se, was identified as a desired outcome of research programs, to ensure that agencies involved with mountain pine beetle management have the required information to make informed decisions on detection and mapping activities. Both written documentation and workshops were seen as important forums for communicating methods and results.

Based upon the results of this workshop and the identified operational information needs, our research has focused upon red attack mapping:

- Testing existing red attack mapping techniques at the incipient and endemic level of mountain pine beetle;
- Developing new methods for red attack detection at the stand and landscape scales;
- Improving estimates of the magnitude of forest damage at the landscape scale; and
- Technology transfer.

With remotely sensed data, red attack mapping has been demonstrated with a range of techniques, including with single date imagery (Franklin et al. 2003), multi date imagery (Skakun et al. 2003), and through data integration (Wulder et al. *in press*). Further investigation of models, data integration procedures, high spatial resolution, and high spectral resolution imagery show potential. Long term goals of a remote sensing program in support of red attack mapping would be to develop low-cost techniques for integrating stand and landscape scale information. The transfer of technology from research to operational management communities is also an important objective of current and future research activities.

Background

Mountain Pine Beetle

In BC, an outbreak of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has reached epidemic proportions. The primary host, lodgepole pine (*Pinus contorta*), experiences extensive mortality when susceptibility to attack is high, particularly during sustained periods of warm, dry weather over several years, and when abundant reserves of host trees are accessible (Carroll and Safranyik 2004; Safranyik 2004). Symptoms of mountain pine beetle attack are evident by the colouration of crown foliage. The first change in foliage colour occurs during the fall or early winter of the year following an attack when foliage of infested trees gradually changes from bright to dull green, referred to as green attack. By the spring, damage is visually apparent, as foliage becomes yellow (i.e., chlorotic), then bright red. Trees that have been dead for more than a year and have lost most or all of their foliage are referred to as grey-attack (Unger 1993).

The impacts of a severe infestation include economic, environmental and social losses. Economic losses occur primarily through the direct loss of timber volume and through indirect means, including the disruption of forest management plans and tourism. Environmental losses include wildlife habitat and increased fire hazard. Furthermore, social disruption occurs as a consequence of job losses.

Remote Detection and Mapping

Changes in foliage characteristics are detectable with remote sensing instruments. Pigments, the structure of leaf tissues, and leaf moisture content have characteristic patterns of absorption or reflectance of electromagnetic energy (Wiegand et al. 1972). Knowledge of these patterns allows for the development of algorithms to detect changes in foliage characteristics using remotely sensed data. Additional opportunities conferred by remote sensing of forest insect disturbances include efficiency over ground surveys, repeatability, and wide-area coverage.

Users of remotely sensed data must find a match between image information content and the resolution characteristics of available imagery (Lefsky and Cohen 2003). The spatial resolution of the imagery will dictate the information content of a given pixel (e.g., tree or stand level characteristics). The spectral resolution will define the types of characteristics that may be discerned. For instance, changes in leaf vigour are evident earlier in infrared wavelengths than in the visible wavelengths. The discernable forest characteristics may be limited by field conditions including: atmospheric conditions, influence of surrounding objects, angle between the light source and the surface, angle between the surface and the point of observation (Wiegand et al. 1972). Temporal resolution considerations include what time (day, year, etc.) an image is collected. The revisit cycle of a particular sensor also influences the types of analysis options available. Radiometric resolution of a given sensor will influence the precision with which attributes may be defined.

As noted in Lefsky and Cohen (2003) image resolution characteristics combine to result in unique information content (Table 1). For instance, a Landsat pixel will relate a range of characteristics. In a mountain pine beetle context, the digital number of a given Landsat pixel will be based upon factors such as the number of trees, the stand structure (age, stratum, crown closure), species mixture, attack state and understory composition. As a result, the range of spectral characteristics that define a disturbed pixel may overlap with those of a healthy stand. Figure 1 illustrates the relationship between image spatial and spectral resolution and resultant information content.

Table 1. Image data requirements for red attack detection at three levels of mountain pine beetle populations.

Mountain pine beetle population	Forest damage characteristics	Spatial resolution requirements	Spectral resolution requirements
Endemic Level	Single or small groups of trees	High	High
Incipient Level	Small groups of trees	High or medium	High or moderate
Epidemic Level	Large groups of trees over large areas	Medium	Moderate

Figure 1. Illustration of information content of three common image spatial resolutions of 30 x 30 m, 4 x 4 m, and 1 x 1 m. Larger pixels tend to amalgamate a greater variety of stand elements.

The three frames in figure 1 simulate three different pixel sizes, placed upon the digital photo of an area undergoing mountain pine beetle attack. The larger frame represents a 30 x 30 m pixel (e.g., Landsat multispectral), the mid-size frame represents a 4 x 4 m pixel (e.g., IKONOS multispectral) and the smallest frame represents a 1 x 1 m pixel (e.g., IKONOS panchromatic). Within the large frame, red attack trees, faders and green trees can be visually interpreted. Also present are shadows, understory, and other elements of a typical pine stand. The spectral response for that particular pixel is an amalgam of all the elements present. This amalgamation would not result in a effective signal for the mapping of red attack in this particular pixel. Higher spatial resolution multispectral data, in this example illustrated by the mid-sized frame, contains fewer elements, therefore, would be capable of higher accuracy in red attack mapping. The trade-off for the higher resolution is smaller image extent. For example, a Landsat TM image covers 185 x 185 km whereas a IKONOS image has a minimum order size of 10 x 10 km. The high spatial resolution panchromatic example, represented by the smallest frame, begins to capture stand conditions that are not entirely based upon mixtures. The small pixel may capture a single stand element, such as a portion of a sunlit tree crown. For algorithm development it is preferable that groups of pixels capture the distinct signal rather than single pixels. The compromise with the panchromatic data is that the broad spectral range is inferior to detection capabilities of narrower spectral bands captured with multispectral sensors. Research has demonstrated that across this range of spatial resolutions, not withstanding the above limitations, red attack has been successfully mapped using satellite and airborne systems (Franklin et al. 2003; Skakun et al. 2003; Bentz and Endreson, In Press; White et al. In Press). While the pixels are mixtures of various stand elements and characteristics, image-processing techniques can be applied to capitalize upon the image information present.

Research Summary

In this following section, the results of completed research projects will be summarized, and indications of future research directions will be presented. The research and related discussion is focused on the red attack stage of mountain pine beetle attack from satellite imagery. There are a range of spatial data sources available to aid satellite based red attack mapping, including sketch maps, GPS survey data, forest inventory, and ancillary data sources such as digital elevation data.

Single satellite image mapping

The identification and classification of mountain pine beetle red attack damage patterns was accomplished using 1999 Landsat TM satellite imagery, a 1999 mountain pine beetle field and aerial point dataset, and GIS forest inventory data (Franklin et al. 2003). This study took place in a mature lodgepole pine forest located in the Fort St. James Forest District, BC. Variance in the satellite imagery that was unrelated to mountain pine beetle damage was reduced – primarily by stratifying the image using forest inventory data and removal of other factors uncharacteristic of red attack damage. Locations of known mountain pine beetle infestation were used to train a maximum likelihood algorithm. Overall classification accuracy was 73%, based on an assessment of 360 independent validation points. The classification accuracy achieved in this project was higher than that obtained in earlier research with Landsat data and forest damage classes because spectral differences between non-attacked and red attack areas were enhanced through stratification. The final classification map showed small pockets of infestation – individual pixels within forest stands – which were likely the locations of mountain pine beetle red attack damage.

Multiple satellite image mapping

Forest disturbances, by definition, have a temporal aspect. This characteristic can be capitalized on to detect change. Disturbances can be difficult to find with single date imagery, where analysis is based upon contrast and variation of spectral signal from expected values. The use of multitemporal Landsat-7 Enhanced Thematic Mapper Plus imagery was examined to determine the potential for red attack mapping. The image data were acquired in 1999, 2000, and 2001, and were geometrically and atmospherically corrected and processed using the Tasseled Cap Transformation to obtain wetness indices. These steps were followed by a new enhancement called the enhanced wetness difference index (EWDI). The final processing steps of the EWDI include pixel subtraction, enhancement, and thresholding of the wetness index differences. The EWDI was designed to improve visual identification of canopy changes over time, and was used in this study to help isolate small clusters or pixels that represent groups of red attack tree crowns that were otherwise difficult to discern. A helicopter-based red attack survey dataset was used to identify stands with red attack in 2001. A forest inventory dataset was also used to stratify the image data; visual interpretation and classification results indicated that classes with red attack trees were different from non-attacked forest stands. The resulting EWDI discriminated classes of 10-29 red attack trees, 30-50 red attack trees, and healthy forest. Classification accuracy of red attack damage based on the EWDI ranged from 67% to 78% correct (Skakun et al. 2003).

Polygon Decomposition

Polygon decomposition was developed as a tool to integrate different data layers, such as satellite image classifications, with existing GIS data to provide timely and accurate estimates of forest change (Wulder and Franklin 2001). A forest inventory database requires maintenance over time or the data can become quickly outdated. Polygon decomposition, following an insect infestation, can document the changes which have occurred to polygon attributes which otherwise may not be represented until a complete update procedure has been conducted. Timely observation and mapping of mountain pine beetle red attack stands are important information requirements if infestations are to be understood and managed.

Polygon decomposition may be applied to improve the understanding of the extent and characteristics of mountain pine beetle attack as depicted in maps from a variety of sources. Differing map products, such as sketch maps, attack locations recorded using a Global Positioning System, and EWDI results, may be compared. These differing data sources may be "decomposed" using the existing forest inventory, into estimates of the proportion (in percent) and area (in hectares) of mountain pine beetle red attack damage (Figure 2).

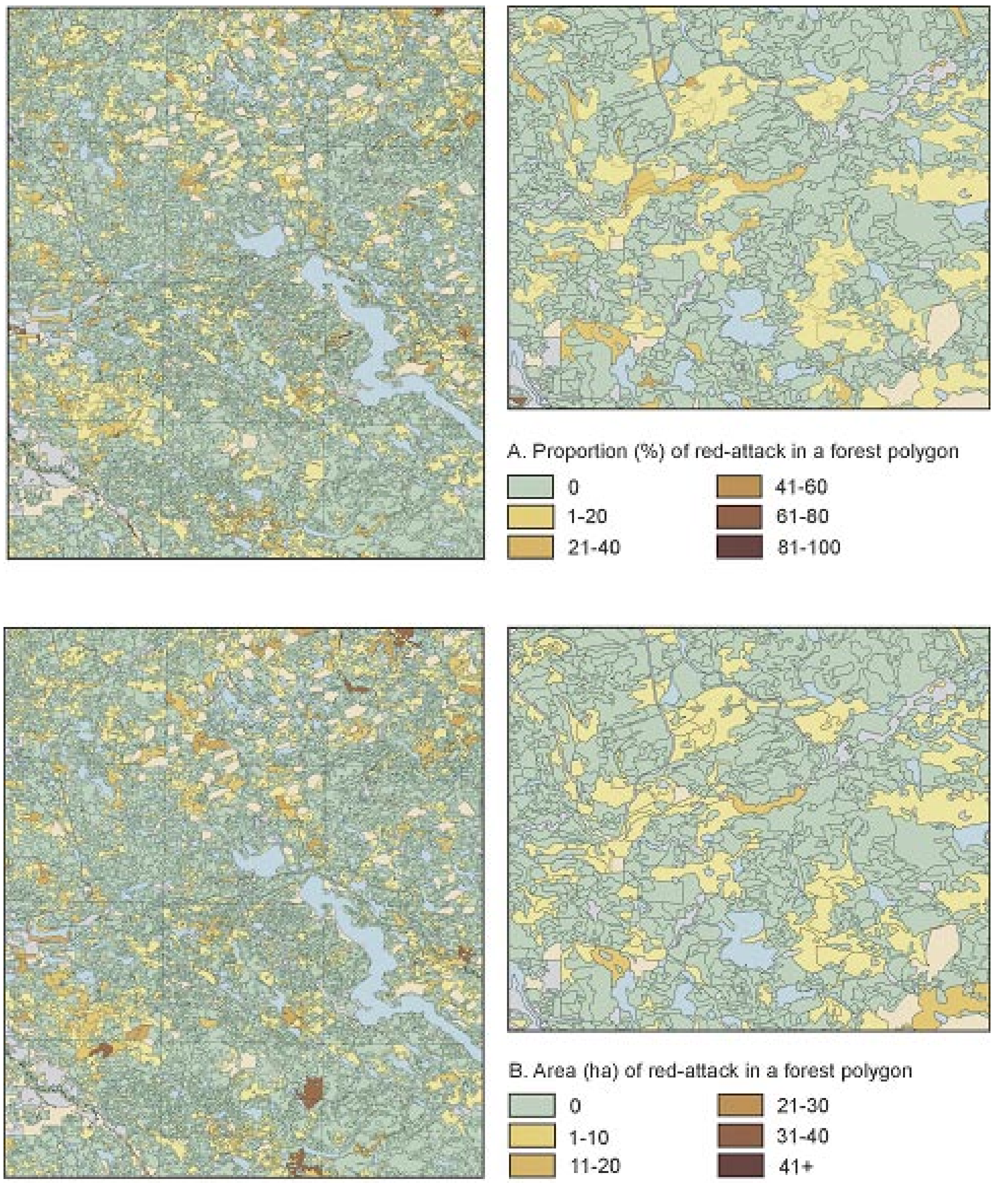

Figure 2. Example 1:20,000 provincial inventory map sheets populated with the results of a change detection procedure applied to Landsat satellite imagery. The pixel based change detection results can be integrated with the forest inventory data following a polygon decomposition approach to create new attributes indicative of mapped mountain pine beetle impacts. In this example, new attributes of proportion and area attacked are shown.

Large differences were observed in the area of the infestations as represented in the three different maps, but the red attack stands had similar forest characteristics. Stands with a high pine component in the age category 121 to 140 years, with diameter breast height over 25 cm and crown closures from 66% to 75% were identified as most susceptible to beetle attack. A stand-by-stand interpretation of red attack developed using polygon decomposition provides more detail than could be obtained by considering each of these data layers seperately. In the future, it is expected that polygon decomposition could be used in assessing non-attacked forest stands for susceptibility or perhaps predicting beetle movement patterns (Wulder et al. in press).

Conclusions

When surveying the red attack stage of a mountain pine beetle infestation, as in all studies using remotely sensed data, the information needs must dictate image data choices. To aid in the image data selection, the information need should also be constrained by area of coverage desired, costs, and timing. Regarding mountain pine beetle disturbances, remotely sensed data may be used to map large areas of forest at the red attack stage, or to detect smaller areas that may have red attacked trees. The methods for these two examples differ, as do the management questions that will be addressed.

Red attack mapping is possible with a range of methods and data sources. The data sources may be considered as an information hierarchy, where small-scale (i.e., Landsat) characterizations may be used to determine where large-scale data are collected (i.e., IKONOS. Spatial data from a variety of sources can improve mapping accuracy from remotely sensed data. Methods for large area characterization of red attack are appropriate for some operational applications. Data integration with forest inventory data, through polygon decomposition, enables forest managers to access required information in a timely and familiar format.

Future research with high spatial and spectral resolution imagery will test if red attack mapping can also be successful under endemic and incipient conditions. Development of models that combine knowledge of mountain pine beetle biology with spatial data characterization of local and current conditions will improve our ability to plan for and mitigate mountain pine beetle impacts.

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