Abstract

The processing and evaluation of digital airborne imagery for detection, monitoring and modeling of mountain pine beetle (MPB) infestations is evaluated.

The most efficient and reliable remote sensing strategy for identification and mapping of infestation stages (“current” to “red” to “grey” attack) of MPB in lodgepole pine forests is determined for the most practical and cost effective procedures.

This research was planned to specifically enhance knowledge by determining the remote sensing imaging systems and analytical procedures that optimize resource management for this critical forest health problem. Within the context of this study, airborne remote sensing of forest environments for forest health determinations (MPB) is most suitably undertaken using multispectral digitally converted imagery (aerial photography) at scales of 1:8000 for early detection of current MPB attack and 1:16000 for mapping and sequential monitoring of red and grey attack. Digital conversion should be undertaken at 10 to 16 microns for B&W multispectral imagery and 16 to 24 microns for colour and colour infrared imagery.

From an “operational” perspective, the use of twin mapping-cameras with colour and B&W or colour infrared film will provide the best approximation of multispectral digital imagery with near comparable performance in a competitive private sector context (open bidding).

Keywords: aerial photography, multispectral digital imagery, mountain pine beetle, forestry

1. Introduction

1.1 Previous Research

Over the past two decades the British Columbia Ministry of Forests (MOF) has engaged in a series of research projects to evaluate the potential for orbital and airborne electronic sensor systems to contribute to forest health resource management. Although substantial financial and personnel resources have been committed to these projects. The results have been generally inconclusive at best and often clearly disappointing (1-16).

Satellite imagery suffers from: (1) availability problems due to cloud cover and orbital periodicity, and (2) inadequate spatial resolution for forest health issues that require a suitable spectral image for individual tree crowns.

The use of airborne imaging spectrometers (e.g. CASI) and multispectral scanners (e.g. GERS) has proved disappointing. There have been no satisfactory results for reliable early (current attack) detection of MPB and other forest pests. Secondly these airborne line-imaging systems are not good mapping instruments in comparison with aerial photography. This inevitably drives up the costs for any operational project.
An obvious gap in remote sensing research, related to these forest health problems, has been the almost complete lack of experimentation (and comparison) with digitally converted colour, colour infrared and multispectral aerial photography. In particular it is recommended that all experimental studies be evaluated against this standard in terms of: (i) mapping accuracy, (ii) potential for automated spectral interpretations and (iii) cost effectiveness. Aerial photography is the “gold standard” in terms of mapping.

1.2 Strategic Plan

The current MPB infestation has provided an urgent incentive to address a strategic plan for remote sensing of forest health in British Columbia. Although such a proposed plan must directly addresses the present MPB problem, most aspects should also relate to other forest health problems. It should be a template for future investigations into the suitability of using remote sensing for a specific problem (e.g. MPB), a general plan for forest health remote sensing and the development of cost effective operational procedures.

Three important criteria must be met in order for this plan to be effective:

1. Under all circumstances the suitability for knowledge transfer from research studies to operational conditions must be considered.
2. Of equal importance is the cost effectiveness of the procedure and the degree that it can be implemented in a business environment involving private competition.
3. Finally, of paramount importance is the need for a “patent” (open) treatment of all investigative research.

2. REMOTE SENSING EVALUATIONS

Mountain pine beetle (Dendroctonus ponderosae Hopkins) is one of the most serious forest insect pests native to British Columbia. In British Columbia this beetle attacks and kills standing, large diameter lodgepole pine (Pinus contorta var. Latifolia) trees and is now moving into smaller diameter trees. Lodgepole pine forests make up 35% of British Columbia's forested land base and now account for over 50% of the total timber volumes harvested in British Columbia. MPB attacks were common due to large areas of mature or over-mature lodgepole pine stands which are a result of successful forest fire suppression. Recent epidemic outbreaks have, on average, resulted in the death of over 30 million mature pine trees per year. Currently a state of emergency exists in BC as a result of the increasing spread of MPB in BC's forests.

Even though there has been an intensive interest and considerable funds have been spent in research, there have been no studies prior to our research that have been able to reliably detect current attack from mountain pine beetle in lodgepole pine. The few previous current attack studies undertaken often have conflicting “promising” results that subsequently are not confirmed by further research (3-7). Many studies have not provided adequate information to permit scientific validation of their results and, on a number of occasions, have provided inadequate information regarding basic procedures and spectral data.

2.1 Imagery

The evaluated remote sensing data in this research study included:
digitally converted multispectral aerial photography providing normal colour, colour infrared and two groups of false colour infrared composite images;
digitally converted colour negative aerial photography;
digitally converted colour infrared aerial photography;
digitally converted black & white infrared aerial photography;
combined 6 band colour and colour infrared imagery, and;
combined 4 band colour and B&W infrared imagery.

2.2 Imagery acquisition

Site-specific MPB infestation imagery was flown monthly from April to October, 2002, May to October, 2003, May, 2005, May to October, 2006 and June to August, 2007. Imagery was acquired at scales of 1:8000 and 1:16000. In addition a series of imaging flights were undertaken to test film exposures, filter combinations and twin camera synchronized colour and near infrared imagery.

Fig. 1. Four band multispectral image of Deerhorn site, August 14, 2002. Image 1: blue; Image 2: green; Image 3: red; Image 4: nir.

2.3 Multispectral Composites

Each 4 band multispectral image (Figure 1) contains four spectral bands (near infrared (NIR), red, green and blue) that were combined digitally into 4 colour composites: (Figure 2) normal colour, colour infrared and two false colour infrared images for visual and computer analysis and classification. The twin camera imagery consisted of two images: (Figure 3) colour with colour infrared (6 band) and colour with B&W infrared (4 band). These data were digitally converted and evaluated to determine varying levels of interpretational utility and spatial resolution performance for forestry health parameters. In addition the colour and false colour digitally converted aerial images were used as a comparative baseline to assist with the performance evaluation of the multispectral imagery.

2.4 Imagery Registration

Both the multispectral and twin camera imagery required registration of each individual image to a single image. For the multispectral imagery the NIR, red and blue images were registered to the green image. With the twin camera imagery the infrared imagery (colour IR and B&W IR) was registered to the normal colour imagery. This cross-image spectral
band registration created sets of 4 band and 6 band multispectral imagery for enhancement, interpretation and classification. In all instances one of the images was left unaltered to permit precision photogrammetric mapping.

Fig. 2a. Four different colour composite images using Figure 2 spectral bands. Top L: RGB; Top R: IRRG; Lower L: IRRB; Lower R: RIRB.

Fig. 2b. An enlarged area from Figure 2a. Red attack trees are red on RGB & RIRB and green on IRRG & IRRB. TL:RGB; TR:IRRG; LL:IRRB; LR:RIRB.
Fig. 3a. Twin camera colour composite multispectral imagery: Deerhorn site, October 16, 2002. TL:RGB; TR:IRRG; LL:IRRB; LR:RIRB.

Fig. 3b. An enlarged area from Figure 3a. Red attack trees are red on RGB & RIRB and green on IRRG & IRRB. TL:RGB; TR:IRRG; LL:IRRB; LR:RIRB.
A second group of images were registered across time (same site from different imaging dates) to permit forward and backward evaluation of colour changes in MPB infested trees. This registration resulted in large "single" image files containing over 100 images in some instances. For example, 33 separate images were registered and evaluated across the period from April to October, 2002.

Imagery registration is a somewhat time consuming activity requiring approximately one hour per image. Cross time images take substantially longer as image rotation and scaling issues complicate the registration: assuming that the multiband (4 and 6 band) images making up these data sets are already registered, a single cross time image will take one to two man weeks. All image registration was undertaken at SFU in the SFU Remote Sensing Laboratory using ER Mapper image processing software.

2.5 Imagery Evaluation

Six areas of mountain pine beetle (MPB) infestation, to the west and southwest of Prince George, were sequentially imaged by the SFU Remote Sensing Laboratory between April 2002 and July, 2007. The extent of MPB current attack was mapped, by field survey at the individual tree level, in the fall and winter of 2001 and the fall of 2002. All indicated trees are numerically keyed to data tables. A total of six sites were ground truthed by MOF and SFU/MOF combined. The total number of trees examined was 2890.

There was an apparent change in most of these currently infested trees at these six sites over the initial 2002 season (a small percentage of these 2001 infested trees had still shown no visible change by November 2002). On our April 3, 2002 imagery, the previous year’s dead trees were clearly visible as red standing dead trees. The 2001 ground truthed current beetle attack was not detectable by visual examination on any of this early April imagery. On the later May 15th and June 3rd, 12th and 13th imagery, the currently infested trees increasingly became visible through colour changes on the various composite multispectral images.

By August 14th most of the 2001 attacked trees had changed from a green to red colour. This continued through the fall such that by October a larger percentage of the previously infested trees had continued changing colour to red. The August (and later) imagery then became another form of “ground truth” (verification data) such that we could trace back to trees that were green in April from trees that had changed to red by August. This colour shift showed these trees had died and we worked back through the June and May imagery to determine the earliest detectible “signal”.

These visible changes were most pronounced on the infrared false colour composites but were also detectible on the normal colour composites to a lesser degree. The colour changes are the result of reflectance changes on the trees in both the visible and near infrared spectral regions. Our results clearly indicate that early detection of “current” MPB infestations is possible.

3. RESULTS

Aerial imagery was acquired at two different imaging scales (1:8000, and 1:16000) for six different MPB research sites and eight different imagery test sites. The MPB sites were imaged from April 4th 2002 to July 25th, 2007 using 4 and 6 band multispectral imaging systems.

Image Processing: Imagery was developed and scanned throughout the study period with the film being developed as soon as possible following exposure to minimize deterioration. The digital film conversion (scanning) was undertaken in Vancouver by two separate mapping companies and the Simon Fraser University remote sensing laboratory. Scanning resolution varied for test purposes however the B&W imagery was scanned at 12, 16 and 18 microns and the colour imagery was scanned at 16, 18, 20 and 21 microns.
Image quality is generally excellent: this includes film exposure, developing and digital conversion. Colour enhancements and spectral combinations are adjustable and the imagery can be custom enhanced to assist with the interpretation of the different environmental parameters. Although some understory areas could not be imaged in direct sun due to vegetation overhang most of the selected sites have been imaged with good sun illumination.

Specific objectives set for this study indicated that the following needed to be determined more precisely:

### 3.1 Spectral Parameters

The spectral parameters examined were limited by the spectral sensitivity of the films used and the spectral transmission of the various filters. Generally we used “broad band” imaging in the blue, green, red and near infrared.

The B&W film (Agfa 200 PE 1) used with 301a infrared cut-off for the visible bands and specific numbered Kodak Wratten filters produced the following broad spectral bands:

- **blue**: $(47 + 301a: 400nm – 500nm)$
- **green**: $(40 + 301a: 475nm – 580nm)$
- **red**: $(24 + 301a: 580nm – 680nm)$
- **nir**: $(89b: 680nm – 740nm)$.

The colour negative film (Agfa N400) produced the following broad spectral bands:

- **blue**: $(400nm – 475nm)$
- **green**: $(525nm – 580nm)$
- **red**: $(600nm – 660nm)$.

The false colour infrared film (Kodak 2443 & 1443), used with a 520nm yellow filter, produced the following broad spectral bands:

- **green**: $(520nm – 580nm)$
- **red**: $(625nm – 675nm)$
- **nir**: $(620nm – 850nm)$.

![Image of multispectral imagery](image-url)

Fig. 4a. August 14, 2002. Four sub-images from the Blackwater multispectral imagery:

- **Top Left** - IRRB false colour infrared composite with new red attack trees as green, healthy trees as pink and orange and old reds as blue;
- **Top Right** – results from a supervised classification showing new red attack trees as bright red, healthy trees in different shades of green and old reds as dark red;
- **Bottom Left** - normal colour infrared composite with heavily attacked trees ground truthed in 2001 circled & numbered, new red attack trees as red, healthy trees as green and old reds as grey;
- **Bottom Right** - normal colour infrared composite with new red attack trees as red, healthy trees as green and old reds as grey.
Fig. 4b. June 12, 2002 & August 14, 2002. Two sub-images with supervised classifications from the Blackwater multispectral imagery:

Top Left – June 12: IRRB false colour infrared composite with new reds as yellow, healthy trees as pink/orange and old reds as blue; Top Right – June 12: results from a supervised classification showing new red attack trees as bright red, healthy trees in different shades of green and old reds as dark red; Bottom Left – Aug. 14: IRRB false colour infrared composite with new reds as green, healthy trees as pink/orange and old reds as blue; Bottom Right – Aug. 14: results from a supervised classification showing new red attack trees as bright red, healthy trees in different shades of green and old reds as dark red.

The B&W film (Agfa 200 PE 1) used with a 600nm red filter produced the following broad spectral band:

\[
\text{nir} \quad (600\text{nm} - 740\text{nm}).
\]

The colour film was used in conjunction with the two nir sensitive films to produce a 4 or 6 band multispectral image using a twin mapping camera configuration.

Our early results indicate that: (1) the multispectral camera produced more distinct separation of reds and current attack than did the twin camera package; (2) the false colour combination of nir, red and blue provided the best visual separation of trees for mapping both red attack and spring current attack. Both the nir and blue spectral bands improved visual mapping and classification in comparison with the other spectral combinations (rgb & irrg).

### 3.2 Timing of Onset

Seasonal “timing” of the onset of visibly detectable current attack (when the first spectral alterations become clearly visible) on this imagery varied between our six sites. At the Blackwater and Marilla sites we had clearly detectible evidence of current attack by May 15th at the Nazko site we did not obtain distinct separation until June 3rd. Taken as a whole it is safe to say that a spreading current attack is clearly visible by late May early June. Further analyses and refinement with more comprehensive imaging, seasonal and environmental data may enable earlier reliable detection (ca. early to mid May). Although some changes in specific trees could be detected on some of the April 3rd imagery there is no indication that this can be considered reliable.
3.3 Image Processing

Analytical procedures to enhance and objectively identify “red attack” and spreading infestations (“current attack”) consist of preprocessing, visual interpretation and classification. Preprocessing is potentially the most complicated as it involves enhancements during image scanning, histogram trimming and viewing enhancements and image modification to improve classifications.

3.4 Reliability

With red attack trees we can clearly detect and map all trees that have changed colour to red. In this sense the reliability (detection accuracy) is close to 100%. With digital image classification this is slightly reduced since some of the reds are shaded and are classified as shade areas. This is very minor and percent success remains around 99%. The issue becomes more complicated when the reliability addresses successful detection of all trees that were attacked in the previous year. Most of the heavily attacked trees (75 – 100% attack in our ground truth classification) can be reliably detected in August at the red attack stage. However many of the less heavily attacked trees (<50% attack in 2001) did not change colour by August and a number had still not changed colour in the fall (November). These trees were not detectible and if included as a statistical component would cause the detection reliability to vary considerably from location to location depending upon degree of attack and other undetermined factors.

For this reason our reliability concerns dealt primarily with attacked trees that died and turned red by August. While we are aware that more trees will have changed in September and October, problems with aspen birch and other deciduous trees undergoing senescence altered clear detection of reds as attacked pine.

Our evaluations of the detection of current attack on our June, May and April imagery were based completely upon heavily (75 – 100%) attacked trees in 2001. As a result we had generally reliable detection of these trees in June and May both visually and through image processing classification procedures (see Figure 4).

3.5 Cost Effectiveness

Evaluation of the cost effective aspects of these procedures is partially constrained by the fact that we did not commercially contract our imagery acquisition, registration and processing. Within the university environment return on capital investment (equipment costs etc.), profit and job security were not a budgetary issue. Our expenses were constrained by the immediate operating and personnel costs. This of course considerably reduces the expense of conducting this type of research and the acquisition and processing costs. However, there is little doubt that aerial photography is substantially less expensive than any other airborne imaging systems. The increased resolution and generally interpretative utility of aerial photography provides data detail, mapping accuracy and imaging flexibility that is not available with orbital sensors.

3.6 Knowledge Transfer

Central to this type of resource management is the determination of an effective and reliable procedure that can be implemented through competitive bidding by private sector companies. There is little applied utility if it is not practical to implement the findings of this research to assist with management of this acute forest health problem. For this reason we have initiated experiments in imaging with a twin mapping camera setup to simulate our multispectral imaging system (see Figure 3). Although this was only undertaken very late in the imaging season we have results that show satisfactory comparative results and reasonable confidence that integrated multispectral RGB & NIR imaging can be undertaken by many photo survey companies. This will permit knowledge and procedural transfer in a competitive context that can be operational more or less immediately.
4. CONCLUSIONS

Within the context of this study, airborne remote sensing of forest environments for forest health determinations (MPB) is most suitably undertaken using multispectral aerial photography at scales of 1:8000 for early detection of current MPB attack and 1:16000 for mapping and sequential monitoring of red and grey attack.

From an “operational” perspective, the use of a twin mapping-camera setup with colour and B&W infrared film will provide the best approximation of the multispectral imagery with near comparable performance in a competitive private sector context (open bidding). The most suitable scales for contracted imagery would be optimized in terms of cost and performance by using 1:10000 imagery for early detection of current attack and 1:20000 for red attack mapping and monitoring.

Digital conversion of aerial photography for MPB detection and monitoring should be undertaken at 10 to 16 microns for B&W imagery and 16 to 24 microns for colour and colour infrared imagery. Image enhancements should not be added to any of this imagery in the scanning process. All enhancements should be undertaken as second-generation imagery such that they can be removed or modified.

5. ACKNOWLEDGEMENT

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6. REFERENCES


