CHARACTERIZING ASPEN DIEBACK SEVERITY USING MULTIDATE LANDSAT DATA IN WESTERN CANADIAN FORESTS

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ABSTRACT
Dieback and mortality of Trembling aspen (*Populus tremloides Michx*.) stands, often referred to as aspen decline, appears to be increasing in Western Canada and in many other areas within the range of this species. This study was done within the aspen parkland and the boreal transition ecoregions where aspen dieback has been attributed to severe drought events in combination with repeat insect defoliation. A particular challenge has been the creation of a ground-based index to represent vegetation damage that could be linked to satellite-based observations. Health assessments from field surveys were used to relate the severity of aspen dieback to the relative difference in the infrared simple ratio (ISR) from multidate Landsat imagery. Aspen dieback damage ranged from 23% for light to 58% for moderate and 80% for severe. The variability in aspen dieback increased with severity class. Research results to date demonstrate a linear relationship between aspen dieback and the relative change in infrared simple ratio (R^2 = 0.7). Work is continuing to further develop these relationships and to apply these methods for mapping the severity of aspen dieback over larger geographic regions in Western Canada.

INTRODUCTION

Trembling aspen (*Populus tremloides Michx*.) is the most widely distributed North American tree species (Perala, 1990) and from ecological and commercial perspectives, is the most important deciduous tree species in the North American boreal forest (Peterson and Peterson, 1992; Hogg *et al*., 2002). Repeat defoliation by insects, in combination with drought, severe early spring freeze-thaw events, and fungal pathogens have caused reduced growth and dieback of aspen in different parts of North America (Hogg *et al.*, 2002; Brandt *et al*., 2003). With defoliation and dieback impacts currently estimated at over 10 million ha and 4 million m³ per year in Canada (Hall *et al*., 1998; Simpson and Coy 1999; Canadian Forest Service 2005), the ability to assess and monitor the status and health of trembling aspen is increasingly necessary for reporting on the status and health of Canada's forests. It is also becoming increasingly important with the amount of forest area that is expected to be potentially impacted over a region that is exhibiting symptoms of a changing climate (Hogg *et al.*, 2005)

The spatial distribution and severity of aspen dieback and mortality is not routinely captured through Canadian federal and provincial reporting agencies. Unlike defoliation where provincial agencies assess to some degree, the extent of damage using aerial survey methods, the spatial distribution and magnitude of the area affected by dieback often goes unreported, or will sometimes be incorporated into mapping of aspen defoliation during annual forest health surveys. Defoliation and dieback are disturbance factors that resemble each other visually, but it may have different magnitudes of impact over a long time frame. A problem is that there is a scarcity of information on the impacts of defoliation and dieback in trembling aspen stands of varying structure and composition across the boreal landscape (Brandt *et al*., 2003). To address this problem, a regional scale study, CIPHA, was established in 2000 that has included regional monitoring of field plots located in 75 aspen stands distributed across the western

Canadian interior (Hogg *et al*,. 2005). Linkage to remote sensing is considered the only feasible means by which to scale these field plots to the landscape across the Prairie Provinces.

Satellite remote sensing using sensors such as those from the Landsat Thematic Mapper (Landsat TM) allows for relatively efficient mapping of disturbances over large geographical areas, and offers the possibility of time-series analysis given the large quantity of archived data spanning many years (Lillesand and Kiefer 1994). Using this archive, there has been success in relating the relative changes in Landsat spectral response to the severity of aspen defoliation (Hall et al. 2003). Of interest was to extend use of this remote sensing work toward the detection and assessment of aspen dieback severity as measured from field data. The objective of this study was to assess if the severity of aspen dieback could be characterized from Landsat TM imagery by comparing and relating values obtained from the relative difference in infrared simple ratio (ISR) to field observations.

METHODS

Study Area

The area of interest for this study (Figure 1) covers part of the aspen parkland ecoregion within the Prairies ecozone and the boreal transition ecoregion within the Boreal Plains ecozone (Ecological Stratification Working Group, 1995). This region has experienced severe droughts over the 2001-2003 period which was thought be the major underlying factor behind increases in aspen dieback and mortality (Figure 2) in this part of Canada (Hogg *et al.*, 2006).

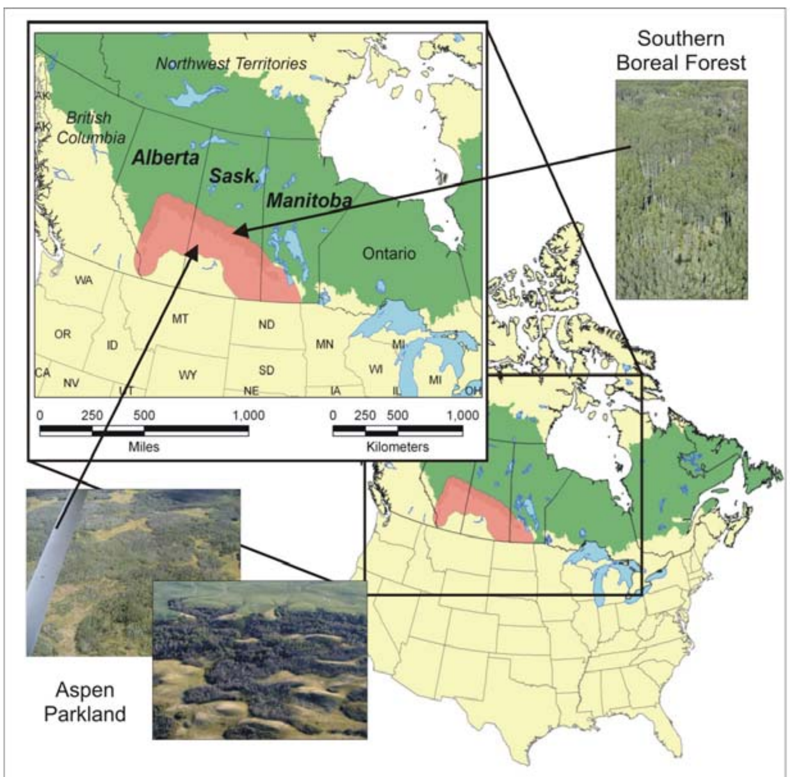

Figure 1. General area of interest

Figure 2. Examples of dieback in aspen parkland region of Saskatchewan

A smaller area measuring 625 km^2 and located within the Landsat TM WRS-2 frame corresponding to path 39, row 23, north of the town of Biggar, Saskatchewan was chosen for establishing control plots for this study (Figure 3). It was selected because a wide range of aspen dieback severity could be sampled over the area allowing the establishment of a network of plots that could be related to the satellite image.

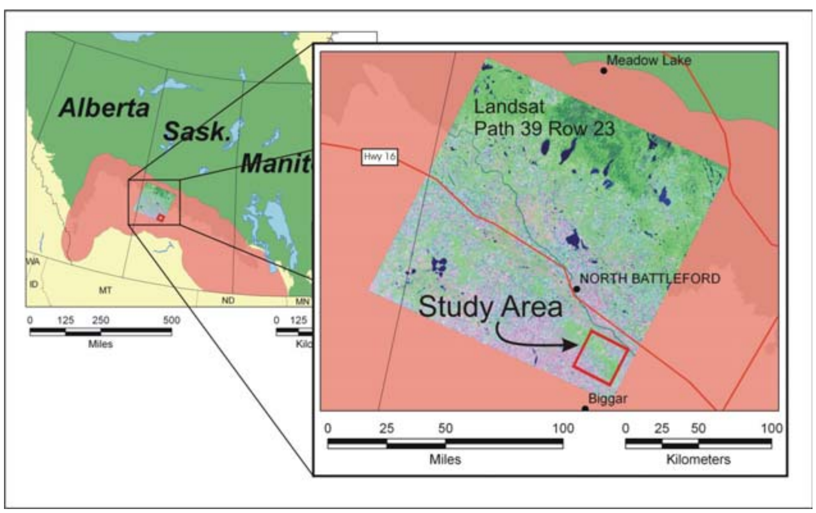

Figure 3. Study area in Biggar, Saskatchewan, Canada

Collection of Ground Data

A field data collection campaign was held August 8-12, 2005 near Biggar Saskatchewan (Figure 3) of which 21 plots were established in aspen stands exhibiting a range of dieback severity.

Plots were established using a prism sweep technique using a basal area factor of 2 m^2 ha^{-1}. At each plot, the plot center location was recorded with a Trimble Pro XR global positioning system and then later, differentially corrected using post-processing techniques to attain sub-meter accuracy. The plots were also documented using digital photos taken at horizontal, oblique and vertical look directions facing North and South, and with general descriptors of the surrounding stand, such as average stand height, crown closure, species composition and understory vegetation.

At the tree level, each tree included in the prism sweep was rated by a forest health technician with regards to dieback severity in percent of branch foliage affected using a continuous scale from 0 to 100% where 100% was considered to be a dead tree. Species and stem diameter (1.3-m height) were also recorded for every tree, and total tree height, and height of highest and lowest living foliage were measured using a laser vertex instrument.

Satellite Remote Sensing Data

Landsat-5 TM satellite data (WRS-2: Path 39 and Row 23) were acquired for two dates: an August 10, 1998 image used as a baseline where dieback was negligible and a post-dieback image from July 25, 2004. For this type of analysis, it is critical that the imagery be acquired outside of the defoliation period so as not to confuse dieback with defoliation. These images were orthorectified and georeferenced to a UTM Zone 13 projection based on the NAD83 datum. A Top-of-Atmosphere Reflectance (TOAR) correction procedure, based upon Markham and Barker (1986) was then applied to the near (TM4) and shortwave near infrared (TM5) Landsat TM bands of the August 10, 1998 image. The corresponding spectral bands of the post-dieback image were calibrated to the pre-dieback baseline image using a linear regression between reflectance values of pseudo-invariant targets common to both images.

Relating Ground Observations of Dieback to the Imagery

The approach used for this work was adapted from previous work reported for aspen defoliation where the infrared simple ratio was applied toward characterizing defoliation damage (Hall *et al*., 2003). The infrared simple ratio was first computed as Landsat TM band 4/Landsat TM band 5 for each date followed by the calculation of the relative change in ISR from the baseline image using equation 1:

$$\Delta ISR = \frac{(ISRpost - ISRpre)}{ISRpre} * 100 \quad (1)$$

where ΔISR is the relative change in ISR in percent, ISRpost is the ISR value of the post-dieback image and ISRpre is the pre-dieback ISR value.

The image was then stratified by pure deciduous land cover types using the classified land cover from the Earth Observation for Sustainable Development (EOSD) of forests project in order to exclude any pixels of different land cover types such as conifer (Wulder *et al*., 2003).

The ΔISR value at each plot was obtained by averaging the pixel value at plot centre along with its eight adjacent neighbors therefore creating an average value for an area of 90m x 90m to compensate for any spatial mis-registration errors between the imagery and GPS plot locations. These average ΔISR values at each plot were then compared against the average dieback severity rating of the plot. Adjusted R^2 and root mean square error (RMSE) were used to assess the strength of the relationship between the two variables.

RESULTS

Of the twenty-one (21) plots measured, seven (7) were located in light dieback damage (< 35%), five (5) in moderate dieback (35-70%) and nine (9) in severe (>70%) (Table 1). The magnitude of aspen dieback increased according to severity of damage with values of 23%, 58% and 80% in light, moderate and severe classes, respectively. The degree of severity did not vary with tree size as characterized by tree height and diameter (unpublished data). The variability in aspen dieback also increased with degree of severity suggesting that the variability in spectral response might also increase as dieback severity increases.

The average rating of dieback for each plot was linearly related to the relative change in ISR (adjusted R^2 = 0.7, root mean square error = 13.7%, Figure 4). Of the field data available, some were rejected on the basis of proximity to other land features such as roads, which introduced noise in the averaging of the ISR values of the pixels over the 3x3 window, thus leaving fourteen (14) plots available for the comparison. A decrease in ISR was consistent with increasing dieback but the change from the baseline date was very subtle, generally less than twenty (20) percent. A possible explanation for this was the large amount of understory shrub vegetation present in the plots, most often beaked hazelnut (*Corylus cornuta* Marsch.), which could have added some "healthy vegetation" noise to the spectral reflectance measured by the sensor, thus making the change between two dates less dramatic.

Table 1. Plot summary of aspen dieback by damage class

Number of plots	Aspen dieback class	Average aspen dieback (%)	Standard deviation aspen dieback (%)
7	Light	23.4	6.8
5	Moderate	58.0	8.4
9	Severe	80.3	9.5

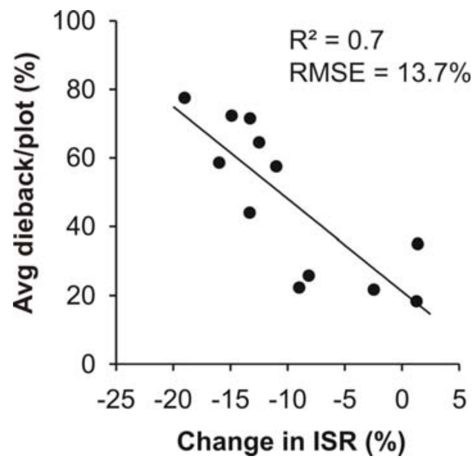

Figure 4. Relationship between average aspen dieback and the percent change in infrared simple ratio (ISR)

SUMMARY AND FUTURE WORK

Aspen dieback and mortality has become increasingly evident in Western Canada and in other regions within the range of trembling aspen in North America. A field-based regional study, CIPHA, was established to assess and monitor the state of forest health and productivity, but a means to scale from field to landscape is necessary. This remote sensing study documents our initial results at relating our field measures of aspen dieback to its spectral response on two-date satellite images. Field measurements of the severity of aspen dieback were positively related to the relative change in infrared simple ratio as characterized by the Landsat Thematic Mapper. While future work will further develop field-based severity measures of aspen dieback, the positive relationship between dieback severity and relative change in ISR was encouraging and consistent with the objectives of this study. Future work will attempt to quantify and project the degree of growth loss and mortality impacts associated with the severity of aspen dieback.

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