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Using a Canopy Reflectance Model for the Detection of Aspen Dieback from Multi-temporal Landsat Thematic Mapper Data

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ABSTRACT

Trembling aspen (*Populus tremuloides Michx*.) is the predominant tree species in the aspen parkland and boreal transition ecoregions located within the Canadian Prairie provinces. Recent severe drought in this region has led to extensive dieback, mortality and reduced growth of trembling aspen trees but its precise spatial extent and occurrence is unknown. Tree level estimates of percent dieback were used to create an index of crown biomass loss at the plot level that could be related to the change values derived from satellite imagery. Multitemporal Landsat Thematic Mapper data representing pre-dieback (1999) and progressive stages of dieback conditions observed in 2001, 2003 and 2006 were analysed. Results suggest that image estimates of differences in crown closure derived from the inversion of the Li-Strahler canopy geometric-optical model were sensitive to canopy structure and the loss of crown biomass caused by dieback. Future work will focus on translating the loss in crown biomass to stand-level impact assessments on aspen forest productivity and biomass.

Keywords: Aspen dieback severity, change detection, infrared simple ratio, geometric-optical model, Landsat

1 INTRODUCTION

Trembling aspen (*Populus tremloides Michx*.) is the most widely distributed North American tree species (Perala, 1990). It is also considered the most important deciduous tree species in the boreal from ecological and commercial perspectives (Peterson and Peterson, 1992; Hogg *et al*., 2002). The ability to assess and monitor the status and health of the trembling aspen resource is of increasing importance for reporting on the state of Canada's forests. In particular, the aspen parkland and southern boreal regions of west-central Canada is an area that is expected to be particularly sensitive to differences in moisture and temperature as a result of a changing climate (Hogg *et al.*, 2005). Symptoms of aspen dieback and mortality have already been documented and observed within this region, and attributed to climatic conditions that followed the severe droughts that occurred during 2001-2002 (Hogg *et al.*, 2008).

Satellite remote sensing using optical sensors such as 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 that span back to 1972 (Lillesand and Kiefer 1994). Using this archive, there has been success in relating the relative changes in leaf area index from 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, defined as the proportion of foliage and branch mortality (i.e. including twigs) occurring in the crown portion of the forest stand. This undertaking is challenging due to the heterogeneous nature of the forest stands on the landscape and its open canopy structure that result in strong contributions from understory reflectance. Previous work focused on a vegetation index based on the Infrared Simple Ratio (ISR) was able to detect dieback to some degree, but certain issues emerged such as the influence of spectral noise from understory vegetation (Arsenault *et al*., 2007). To help address this problem, a method based on the inversion of a canopy reflectance model to estimate crown closure was applied along with a relative differencing technique of two-date imagery to relate spectral responses to ground measures of crown biomass loss resulting from dieback. This canopy modeling approach was conducive towards handling the influence of the understory on the signal compared to previous approaches based on vegetation indices alone such as the ISR. The objective of this study was to address these research questions in the application of remote sensing to the detection and mapping of aspen dieback:

1. To what extent can the severity of aspen dieback be detected from satellite imagery?
2. How is the ground measure of dieback severity related to differences in canopy reflectance derived from pre and post-disturbance images?

2 METHODS

2.1 Study Area

The area of interest for this study (Figure 1) covers part of the Aspen Parkland Eoregion 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 in this part of Canada (Hogg *et al.*, 2006).

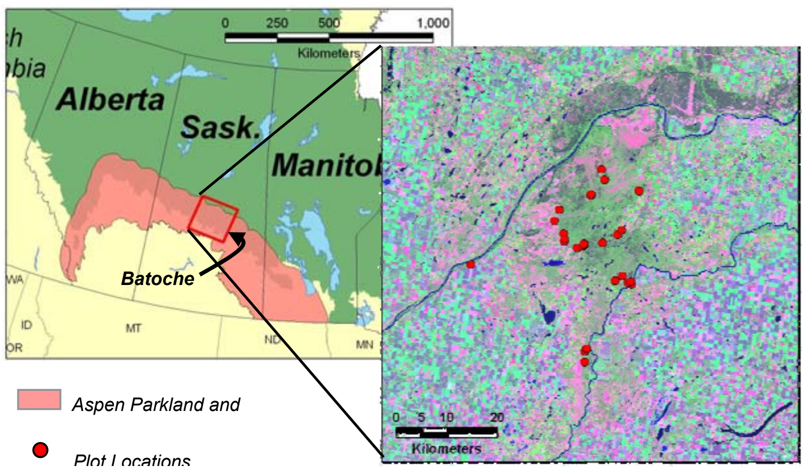


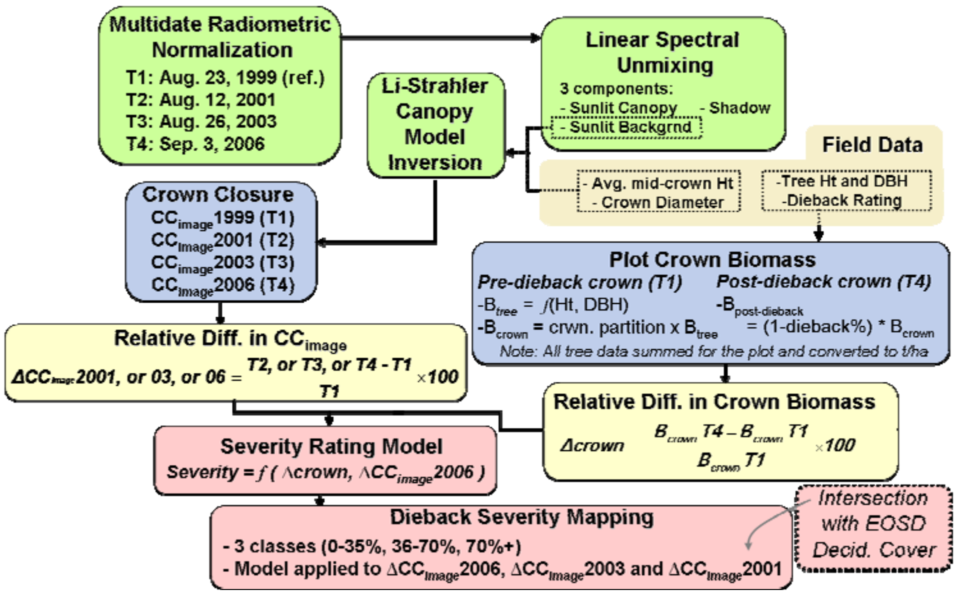
Figure 1. Study area located in Batoche, SK.

2.2 Data

Field campaigns to collect ground data were held in the summers of 2006 and 2007. The plot distribution is shown in Figure 1 and the attributes collected consisted of plot level measurements (i.e.: GPS position, inventory stand call, and digital photos) and tree mensuration data (i.e. species, diameter at breast height (dbh), height) along with health rating data (i.e.: percent dieback, percent defoliation and mortality). A time series of Landsat-5 TM and Landsat-7 ETM+ imagery (Frame 37-23) was also collected over the study site at different stages of the aspen dieback progression with the first image in the time series acquired on Aug. 23, 1999 (Landsat-7), which is considered to be the pre-dieback image and subsequent images acquired Aug. 13, 2001 (Landsat-7), Aug. 26, 2003 (Landsat-5), and Sep. 3, 2006 (Landsat-5). The analysis was focused on a 525,000 ha area that comprised the deciduous land cover within the Landsat scene.

2.3 Methods of analysis

A method flowchart was created to describe how dieback severity was determined from the multitemporal Landsat TM data (Figure 2). The Landsat images consisted of orthorectified and top-of-atmosphere corrected data from 1999 (T1), 2001 (T2), 2003 (T3) and 2006 (T4). The images in the time series were normalized, using the T1 image as the reference, by developing a linear regression model between pseudo-invariant features common to all images. The imagery was then processed to obtain crown closure estimates based on an approach combining the use of spectral unmixing and the inversion of a canopy reflectance model as described in Zeng et al. (2007, 2008). The reference and normalized images were unmixed to extract the following components: sunlit canopy, sunlit background and shadow. The spectral signatures used as endmembers for the unmixing were sampled over the six Landsat spectral bands using training sites on the T4 image identified through visual interpretation and *a priori* knowledge of the land features observed during field data collection.



igure 2. Flowchart of methods applied to model and map aspen dieback.

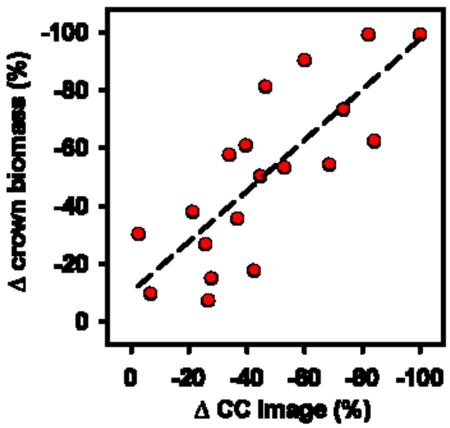
Attributes to describe the tree crowns were derived from the data collected in the field. These consisted of height from the base of the tree at ground level to the mid-point of the crown, horizontal length as measured by crown radius and the half of the vertical length of the crown. The sunlit background component from the spectral unmixing and the crown attributes were then used as inputs into the Li-Strahler canopy reflectance model (Li and Strahler, 1992) from which crown closure was derived through a model inversion process.

For the ground measurements collected in 2006 and 2007, the foliar and branch biomass for each tree in a field plot was computed as a function of tree diameter (i.e. dbh) and tree height using the national tree-level biomass functions developed by Lambert et *al.* (2005). The sum of the foliar and branch biomass was an estimate of crown biomass for each tree that was subsequently totaled for the plot. Dieback was considered a composite of foliage loss and the degree to which the twigs and branches in the crown were dead. Each tree was given a subjective rating regarding the amount of dieback using 10% interval classes by an experienced forest health technician. The dieback rating for each tree was multiplied by the total crown biomass to compute the amount of crown biomass lost from dieback. This amount was subtracted from the total crown biomass to estimate the remaining live crown biomass for each tree. The individual live tree crown biomass was then summed to derive plot level estimates.

The change in crown closure derived from the canopy reflectance model was used as a proxy for the change in crown biomass caused by dieback. The relative change in crown closure between the 1999 and 2006 image dates from the Li-Strahler canopy reflectance model was regressed against the relative difference in live crown biomass computed from the field data. This model of dieback severity was subsequently applied to the 2001, 2003 and 2006 images. The image maps were subsequently generalized to three classes of severity: light (10 to 34%); moderate (35 to 70%) and severe (>70%) based on the percentage of crown biomass loss. A modal-filter was applied to the final thematic output maps in order to merge pixels to their neighbour in cases where they were inconsistent with the majority value within a 5 x 5 pixel window.

3 RESULTS AND DISCUSSION

There was a positive slope in the linear relationship between the relative change in crown biomass and the change in crown closure computed from the imagery (Figure 3). A linear regression analysis was used to produce the model which generated a coefficient of determination (adjusted R^2) of 0.67 and a Root Mean Square Error (RMSE) of 19% based on a leave-one-out cross validation that resulted from computation of the PRESS (Predicted REsidual Sum of Squares) statistic. The data used to derive the model were also normally distributed for both variables with p-values resulting from the Shapiro-Wilk test for normality of 0.24 and 0.51 for the image computed values and the field-derived values respectively.



Δcrown = 0.88(ΔCC) - 10.03

Adj. R^2: 0.67

Figure 3. Model result obtained by relating the change in crown closure (X-axis) from the imagery to the change in crown biomass (Y-axis). The dashed line is the resulting linear regression line.

The area of dieback mapped by applying the model to the 2006 image resulted in areas of light dieback occurring over much of the deciduous portion of the forested area with moderate and severe dieback detected mostly along river banks and on the perimeter of forest stands adjacent to agricultural fields (Figure 4a).

a)

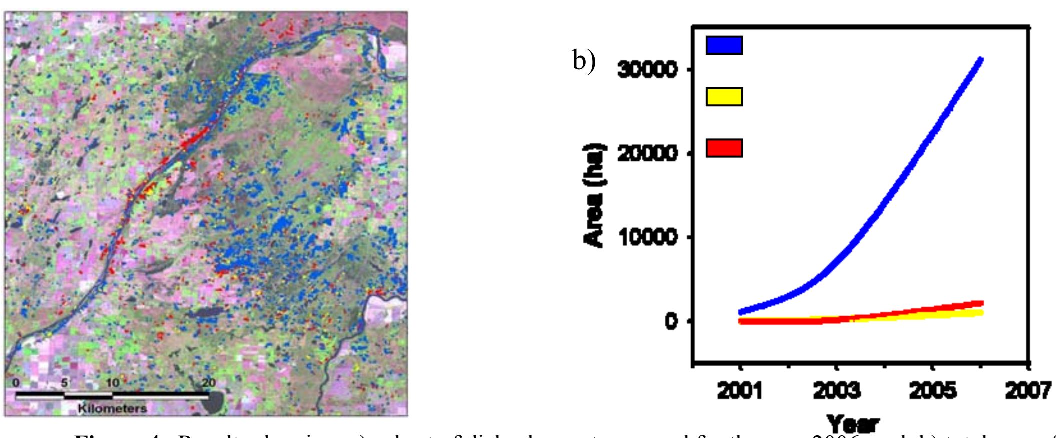


Figure 4. Results showing: a) subset of dieback events mapped for the year 2006, and; b) total area affected by severity class and by year

Of the 525,000 ha deciduous land cover area within the Landsat scene analyzed, the largest increase in dieback area was in the light class rising from 1092 ha in 2001 to 31,165 ha in 2006. There was also an increase in the extent of moderate and severe dieback from levels close to nil in 2001 to amounts reaching 1020 ha and 2174 ha respectively in 2006 (Figures 4b). The areas of moderate and severe dieback are expected to increase as dieback progresses in the areas that were rated as light. If these increasing values for the study area are reflective of the trends within the region, then the area of moderate and severe dieback will continue to increase. Continuing to monitor this area will provide empirical evidence regarding the utility of the canopy reflectance modeling approach to identify and map areas of dieback severity.

4 CONCLUSIONS

An approach based on the inversion of a canopy reflectance model to estimate crown closure from satellite observations was successfully applied along with a two-date relative differencing technique that were related to ground measures of crown biomass loss resulting from dieback. Canopy reflectance modeling accounts for the influence of understory vegetation through the spectral unmixing of the sunlit background component that represents the understory. The resulting dieback maps identified extensive areas affected by light severity that are expected to shift towards moderate and severe classes as time progresses. Continuing the remote sensing time series is recommended to monitor where and how fast dieback occurring in this region of Canada.

5 FUTURE WORK

The current Landsat time series will be extended to 2009 to assess the progression of aspen dieback over the current study site. The canopy reflectance models to detect and map dieback severity will also be applied to data from the SPOT-4 sensor in order to ensure information continuity through other sensors given the unknown life expectancy of the current Landsat-5 sensor and the known data gap issues with Landsat-7 due to the scan-line correction problems. A validation data set is also being created to assess and report on the effectiveness of the canopy reflectance modeling to map and detect dieback severity. A collection of georeferenced frames acquired through airborne video will be used for this purpose. Future work includes extending the mapping of dieback to a larger portion of the prairie parkland and boreal transition ecoregions. This will be undertaken either through the use of a Landsat mosaic or by using coarse resolution mapping as a substitute to generate multi-scale aspen dieback map products over the study area. Linkages between dieback severity and impact on growth and mortality will also be pursued in future work.

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REFERENCES

Arsenault, E., R.J. Hall, R.S. Skakun, E.H. Hogg and M. Michaelian, 2007. Characterizing aspen dieback severity using multidate Landsat data in western Canadian forests, Pages 1-6 in J.D. Greer, editor. *Proceedings of the 11th Forest Service Remote Sensing Applications Conference*, April 24-28, 2006, Salt Lake City, Utah, USA. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, USA.

Ecological Stratification Working Group, 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull. Report and national map at 1:7 500 000 scale.

Hall, R.J., R.A. Fernandes, E.H. Hogg, J.P. Brandt, C. Buston, B.S. Case and S.G. Leblanc, 2003. Relating aspen defoliation to changes in leaf area derived from field and satellite remote sensing data. *Canadian Journal of Remote Sensing*, 29:299-313.

Hogg, E.H., J.P. Brandt and B. Kochtubajda, 2002. Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. *Canadian Journal of Forest Research*, 32:823-832.

Hogg, E.H., J.P. Brandt and B. Kochtubajda, 2005. Factors affecting interannual variation in growth of western Canadian aspen forests during 1951-2000. *Canadian Journal of Forest Research*, 35: 610-622.

Hogg, E.H., J.P. Brandt, B. Kochtubajda, M. Michaelian and B.R. Frey, 2006. Impact of the 2001-2003 drought on productivity and health of western Canadian aspen forests. In: *Proceedings of the 53rd Western International Forest Disease Work Conference*; 2005 September 26-30; Jackson, WY. U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden UT.

Hogg, E.H., J.P. Brandt and M. Michaelian, 2008 Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests. *Canadian Journal of Forest Research*, 38(6): 1373-1384.

Lambert, M.C., C.-H. Ung and F. Raulier, 2005 Canadian national tree aboveground biomass equations, *Canadian Journal of Forest Research* 35: 1996–2018.

Li, X. W and A.H. Strahler, 1992. Geometric-optical Bidirectional Reflectance Modeling of the Discrete Crown Vegetation Canopy: Effect of Crown Shape and Mutual Shadowing. *IEEE Transactions on Geoscience and Remote Sensing*, 30: 276-292.

Lillesand, T.M. and R.W. Kiefer, 1994. Remote sensing and image interpretation. 3rd edition, John Wiley and Sons, Inc., New York, N.Y.

Perala, D.A., 1990. Populus tremuloides Michx. – quaking aspen. In R.M. Burns and B.H. Honkala (Eds.), Silvics of North America. U.S. Department of Agriculture Handbook. Vol. II, pp. 555-569.

Peterson, E.B. and N.M. Peterson, 1992. Ecology, Management, and Use of Aspen and Balsam Poplar in the Prairie Provinces. Special Report 1, Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, AB, Canada.

Zeng, Y., M.E. Schaepman, B. Wu, J.G.P.W. Clevers and A.K. Bregt, 2008. Scaling-based forest structural change detection using an inverted geometric-optical model in the Three Gorges region of China. *Remote Sensing of Environment,* 112(12): 4261-4271.

Zeng, Y., M.E. Schaepman, B. Wu, J.G.P.W. Clevers and A.K. Bregt, 2007. Forest structural variables retrieval using EO-1 Hyperion data in combination with linear spectral unmixing and an inverted geometric-optical model. *Journal of Remote Sensing* (China), 11(5): 648-658.