



Comparison of Forest Disturbance Detection Results Obtained at Different Scales

Case Study: Mountain Pine Beetle Damage and Mortality in the Colorado Rocky Mountains

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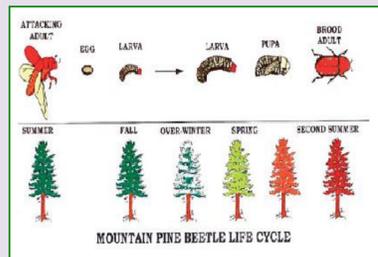


Abstract

To assist in flight mission planning within the sketch-mapping community, information on the timing, location, and spatial extent of forest disturbances is being derived from MODIS satellite image data. A digital change detection methodology has been developed to discern forest disturbances within a rapidly-updated framework using MODIS data, with the aim of delivering weekly change detection results within 2-4 weeks of the acquisition date of the imagery from which it is based. Verification of these change detection results is difficult due to a lack of timely and spatially extensive ground-based measurements that might be used as ground truth for standard statistical validation methods. An alternative approach is described here, wherein information derived from progressively finer scale image data (i.e., Landsat, Quickbird, and aerial imagery) is applied to substantiate change detection results obtained using MODIS.

Study Area and Data

Almost 2 million acres of lodgepole pine forest in the Colorado Rockies have undergone forest mortality due to an infestation of mountain pine beetle (MPB), *Dendroctonus ponderosae*, that began in 1996. Lodgepole pine needles turn progressively redder for successive growing seasons during the red attack phase of a MPB infestation, and tree mortality follows. Trees in red-attack phase are often referred to as “faders”, and the timing of red-attack and tree mortality follows the MPB life cycle.



MODIS image data has been applied to detect and track the spread of the MPB infestation in this region, as well as other forest disturbances nationwide. MODIS data has a 250-meter spatial resolution, and daily repeat coverage for any given location. MODIS data is collected in visible, NIR, and MIR wavelengths, permitting the calculation of indices of vegetation health (e.g., NDVI, NDMI, etc). Multispectral Landsat data contains similar suite of spectral information to that of MODIS, and is collected in 30-meter resolution, thus permitting a much finer-scale detection of forest disturbances compared to MODIS. Landsat can therefore act as a bridge towards ‘ground truth’ in analyzing the validity of MODIS change detection results.

In this study, cloud-free Landsat image data acquired on September 2003, August 2006, and August 2009 were obtained to facilitate change detection analysis between 2003-2009 and 2006-2009. These change detection results were compared to results obtained using 8-day composite MODIS data. QuickBird data (2.5 meter) acquired in September 2007 were obtained for portions of this area to serve as high-resolution visual verification of the Landsat change detection results. Additionally, a raster GIS layer of fader tree crown density was produced using Feature Analyst and ArcMap Spatial Analyst from high-resolution (1-foot) aerial photo imagery collected in July 2008, to act as a fine-scale check on the Landsat results.

MODIS and Landsat Change Detection Approaches

The MODIS change detection approach being applied to detect and track forest disturbances uses a baseline created from a dense time series of 8-day composite MODIS (Aqua and Terra) growing season images (25 composites from April 15 through October 31) covering the conterminous 48 U.S. states. The MODIS image baselines are produced using the per-band median value from 8-day composites from a data stack spanning 2003 to 2007, and serve as robust, cloud-free ‘pre-disturbance’ images to which can be compared to anniversary 8-day composites of incoming MODIS data from the current growing season. To control for forest cover differences and bidirectional reflectance distribution function (BRDF), analysis classes are created by combining static forest group classes and classes created from the dynamic scattering angles of incoming MODIS data. Resistant z-scores (RZ) are then computed on a per-band, class-wise basis, the ΔRZ value is calculated as the difference between the baseline and current-year RZ scores, and a Normalized Difference Forest Index (NDFI; average of NDVI and NDMI indices) is then calculated from the ΔRZ 's of the red, NIR, and MIR bands.

Landsat imagery from 2003, 2006, and 2009 were processed according to MRLC standards, 16-bit NDMI values were calculated for the three individual years, and a change detection analysis was performed using the individual year NDMI values.

Substantiation of Coarse Scale Change Detection Results Through Comparison with Finer-Scale Results

A central question for validating change detection results obtained using MODIS is whether there exists a reliable data source to act as ground truth for the results of the analysis performed using MODIS image data. Because performing timely field work to validate change detection analysis at the scale of multiple states is infeasible, remotely sensed image data collected at a finer scale than 250-meter MODIS data represents probably the best source of information to confer information useful for corroborating MODIS change detection results. In this study, Landsat change detection results are used as a check on MODIS change detection results, and data localized within the Frasier Experimental Forest (FEF) in Colorado relating lodgepole pine fader crown density obtained from high resolution aerial photo imagery is used to act as a check on the Landsat change detection results.

Depictions of a MPB-affected area in the Colorado Rocky Mountains derived from QuickBird, Landsat TM, and MODIS imagery, as well as forest disturbance aerial sketch-mapping data are illustrated in Figure 1. Panel 1a shows the utility of using QuickBird image data to provide a visual verification of forest conditions within this area. However, because spatial coverage of these data is limited and it is often not possible to get multitemporal QuickBird images covering the same spatial extent, this does not represent a practical data source for the substantiation of MODIS results over a regional scale. Panels 1b and 1c illustrate the results of change detection analyses obtained using MODIS and Landsat data, respectively. USFS aerial sketch mapping data that have been combined such that the number of times that damage was observed between 2004 and 2009 is illustrated in Panel 1d, and the cumulative tree-per-acre mortality observed between 2004 and 2009 is portrayed in panel 1e. Combining multiple years of these data can yield a more robust depiction of damage observations compared to singular annual damage observations, but illustrate some of the bias in these data, wherein patterns at times appear to be related to flight lines.

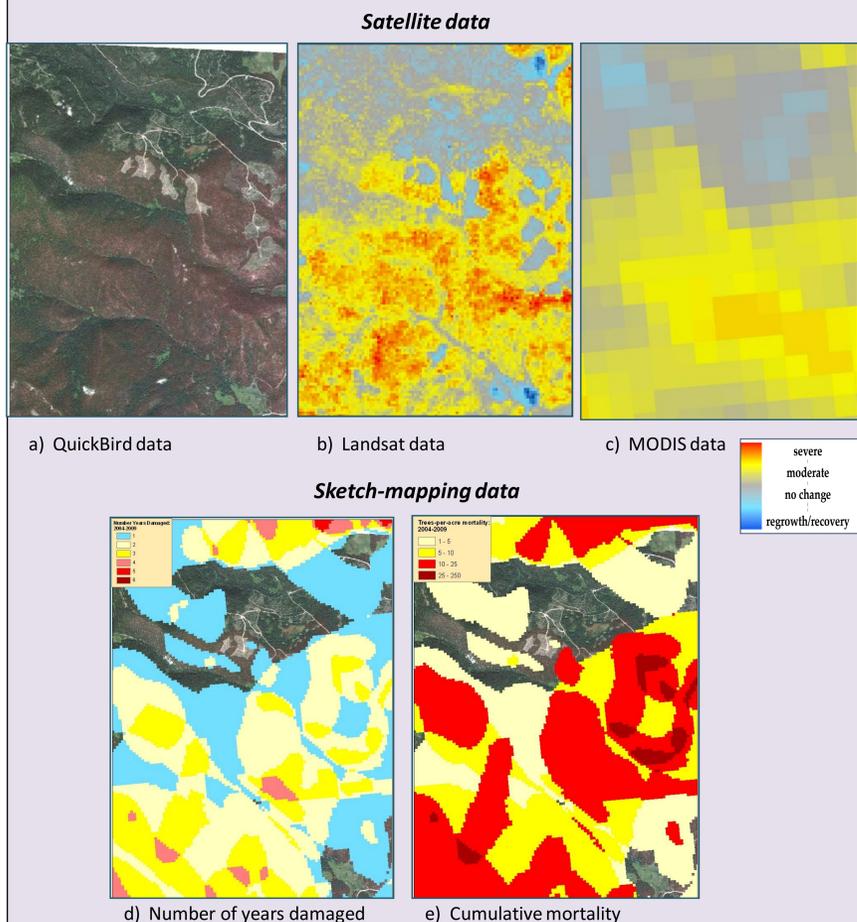


Figure 1: Depictions of MPB-affected area in the Colorado Rockies; a) QuickBird image from Sept 2007, b) Landsat NDMI 2003-2009 change detection, c) MODIS NDFI change detection, d) number of years damaged (2004-2009) from sketch-mapping data, and e) cumulative mortality (2004-2009) from sketch-mapping data.

Application of ANOVA to Quantify Similarity in Change Detection Results

Analysis of variance (ANOVA) represents a useful statistical methodology for comparing separate change detection results. The ANOVA model provides a statistical test of whether the means of several groups are all equal, and therefore generalizes Student's two-sample t-test to more than two groups. The *F*-value statistic is used to determine the statistical significance of an ANOVA model. In this application, the *F*-value serves as a measure of comparability between the results of two change detection analyses. Table 1 show ANOVA results obtained from comparing the 2003-2009 and 2006-2009 Landsat change detections to the tree fader density obtained from very high resolution data collected over the Frasier Experimental Forest (Figure 2, panels a-c). Table 2 shows the ANOVA results obtained from comparing Landsat change detection results (Panels a-c) to that obtained using coarser-scaled MODIS data (Panel 2d). Results from these analyses indicate that the 2003-2009 Landsat change detection results corroborate the information obtained using very high resolution (1-foot) image data. Furthermore, the change detection results obtained using 2003 and 2009 Landsat data corroborate the coarser-scale (250-meter) MODIS change detection results. The Landsat change detection results from the 2003-2009 time frame captured the forest damage in a more similar manner to both the MODIS results and fader density analysis compared to the 2006-2009 time frame.

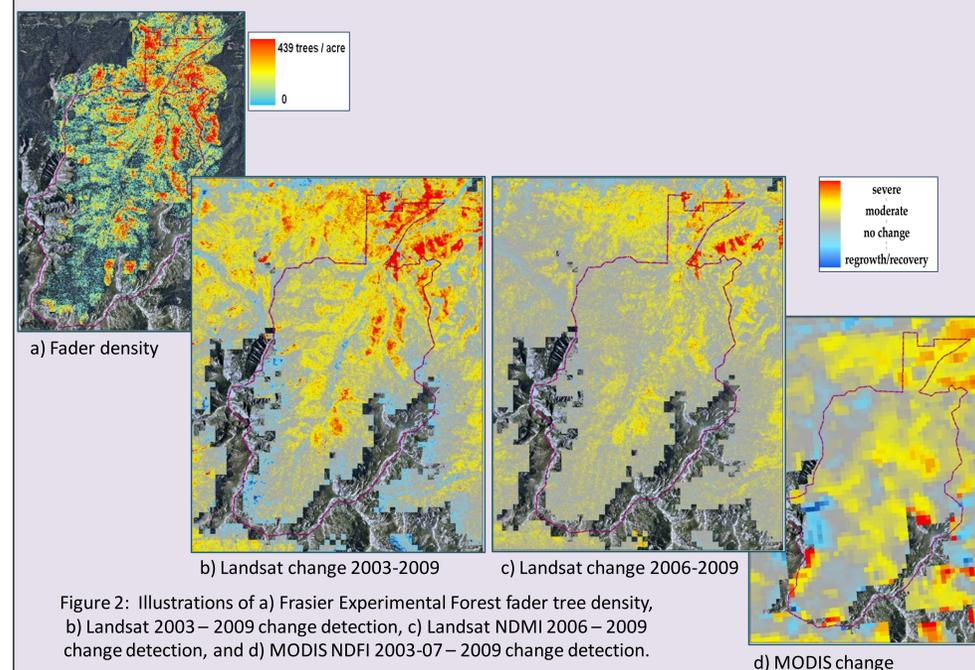


Figure 2: Illustrations of a) Frasier Experimental Forest fader tree density, b) Landsat 2003-2009 change detection, c) Landsat NDMI 2006-2009 change detection, and d) MODIS NDFI 2003-07-2009 change detection.

Table 1: ANOVA results for Landsat and fader density Comparison (sample taken from Frasier Exp. Forest)						
ANOVA: Single Factor		Dependent Variable = Fader Tree Density (trees/ha) Grouping Variable = Landsat Change Detection 2003-2009				
SUMMARY						
Groups	Count	Sum	Average	Variance		
severely damaged	235	28421.54	120.9427	4793.272		
moderately damaged	1124	88094.03	78.37547	3113.711		
not damaged	842	36358.06	43.1806	1457.79		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	1293693	2	646846.7	243.2735	3.62E-96	2.999819
Within Groups	5844324	2198	2658.928			
Total	7138017	2200				
ANOVA: Single Factor						
ANOVA: Single Factor		Dependent Variable = Fader Tree Density (trees/ha) Grouping Variable = Landsat Change Detection 2006-2009				
SUMMARY						
Groups	Count	Sum	Average	Variance		
severely damaged	51	6323.757	123.9952	5280.416		
moderately damaged	781	73847.9	94.55557	3990.723		
not damaged	1369	72701.98	53.1059	2011.361		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	1009691	2	504845.3	181.069	1.61E-73	2.999819
Within Groups	6128327	2198	2788.138			
Total	7138017	2200				
Table 2: ANOVA results for Landsat and MODIS Comparison (sample taken from entire Landsat scene)						
ANOVA: Single Factor		Dependent Variable = RSAC MODIS Terra NDFI Grouping Variable = Landsat Change Detection 2003-2009				
SUMMARY						
Groups	Count	Sum	Average	Variance		
severely damaged	697	22348476	32063.81	440450.9		
moderately damaged	3281	1.06E+08	32375.88	383637.2		
not damaged	8856	2.89E+08	32614.66	443923		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	2.92E+08	2	1.46E+08	341.2996	3.8E-145	2.996432
Within Groups	5.5E+09	12831	428323.8			
Total	5.79E+09	12833				
ANOVA: Single Factor						
ANOVA: Single Factor		Dependent Variable = RSAC MODIS Terra NDFI Grouping Variable = Landsat Change Detection 2006-2009				
SUMMARY						
Groups	Count	Sum	Average	Variance		
severely damaged	248	7932671	31986.58	446969.2		
moderately damaged	2605	84203696	32233.88	364901.9		
not damaged	9819	3.2E+08	32587.36	446212.2		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	2.15E+08	2	1.08E+08	250.6301	1.8E-107	2.996441
Within Groups	5.44E+09	12669	429514.4			
Total	5.66E+09	12671				

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