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Using Landsat images to determine burn severity in western Canadian landscapes

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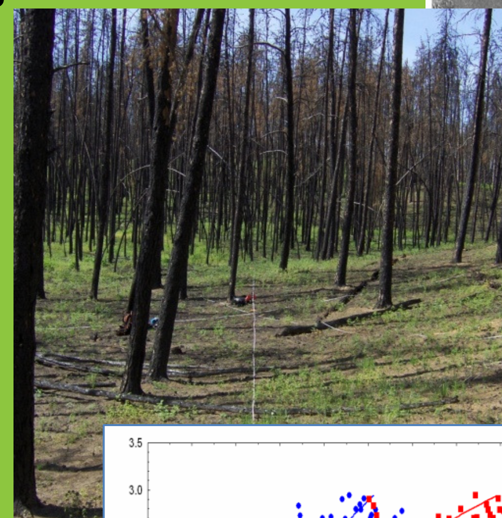
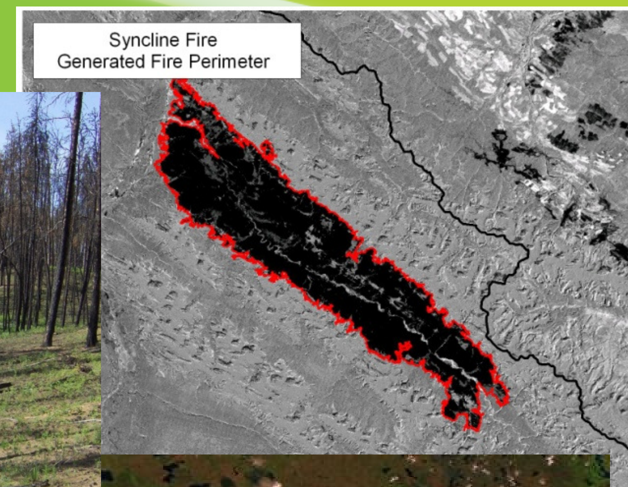
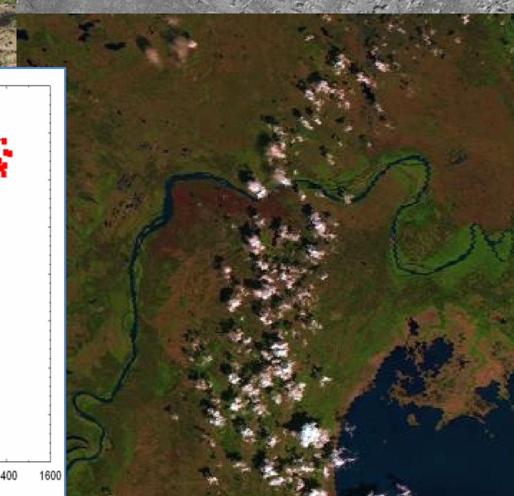
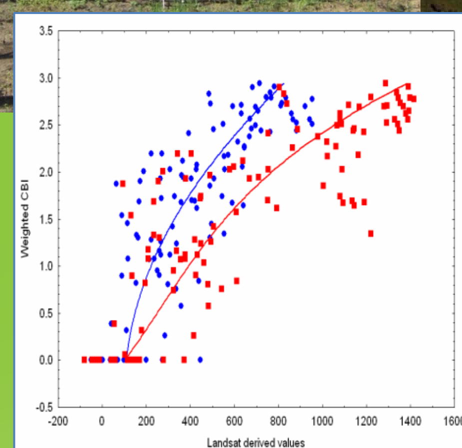
Overview

- Parks Canada fire monitoring
- Intro to burn severity monitoring
  - –Remote sensing: dNBR
  - –Ground truth: CBI
- Research project with UBC
  - —Methods and Results
- Benefits and implications
- Limitations
- Future direction









Parks Canada Fire Management

- Dual mandate:
  - — Safety and protection of lives, structures, and other values
  - — Maintenance and restoration of ecological integrity (EI)

Parks Canada Fire Monitoring

Fire Management Directive (2005):

- Monitor prescribed fire for achievement of objectives
- Monitor all fires for fire behaviour, impacts and effects
- Achieve consistent monitoring across all National Parks

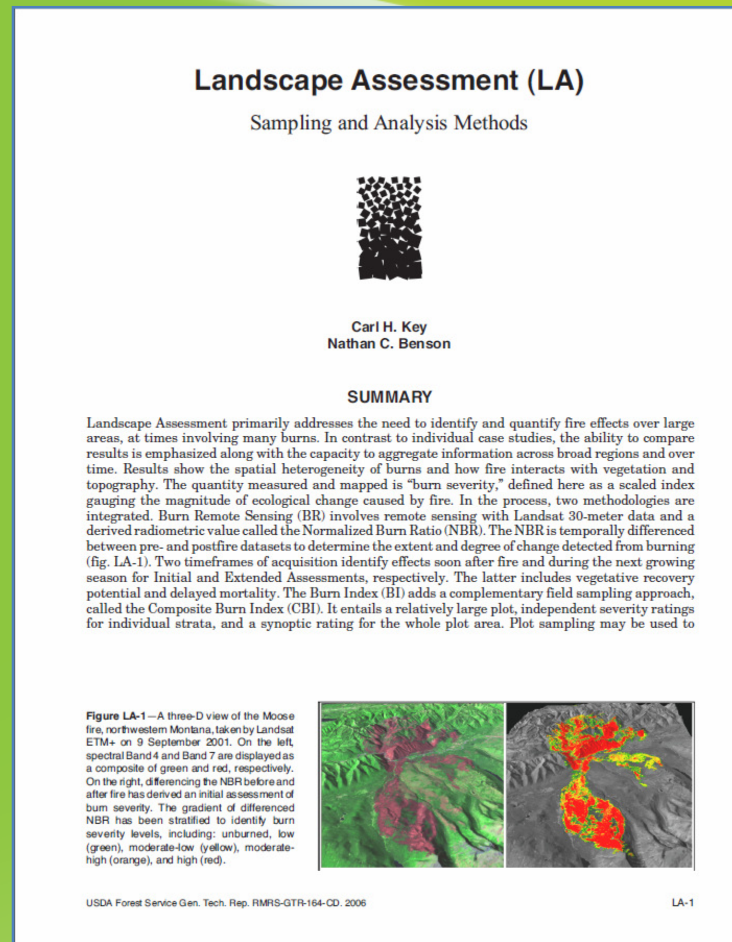
Fire Monitoring, Sugar Creek Prescribed Fire, PANP

Monitoring at a Landscape Scale

- Required monitoring that was:
  - Cost effective
  - Applicable across Canada
  - Easy to apply in remote areas

- Remote sensing methodology originally developed by USGS researchers in 1990s (C. Key and others) – Burn Severity
- Recent version in US interagency FIREMON manual (2005)

- Four key parts:
  1. Remote Sensing
  2. Ground truth
  3. Analysis (correlation)
  4. Integration into policy



Landscape Assessment (LA)

Sampling and Analysis Methods

Carl H. Key
Nathan C. Benson

SUMMARY

Landscape Assessment primarily addresses the need to identify and quantify fire effects over large areas, at times involving many burns. In contrast to individual case studies, the ability to compare results is emphasized along with the capacity to aggregate information across broad regions and over time. Results show the spatial heterogeneity of burns and how fire interacts with vegetation and topography. The quantity measured and mapped is "burn severity," defined here as a scaled index gauging the magnitude of ecological change caused by fire. In the process, two methodologies are integrated. Burn Remote Sensing (BR) involves remote sensing with Landsat 30-meter data and a derived radiometric value called the Normalized Burn Ratio (NBR). The NBR is temporally differenced between pre- and postfire datasets to determine the extent and degree of change detected from burning (fig. LA-1). Two timeframes of acquisition identify effects soon after fire and during the next growing season for Initial and Extended Assessments, respectively. The latter includes vegetative recovery potential and delayed mortality. The Burn Index (BI) adds a complementary field sampling approach, called the Composite Burn Index (CBI). It entails a relatively large plot, independent severity ratings for individual strata, and a synoptic rating for the whole plot area. Plot sampling may be used to

Figure LA-1—A three-D view of the Moose fire, northwestern Montana, taken by Landsat ETM+ on 9 September 2001. On the left, spectral Band 4 and Band 7 are displayed as a composite of green and red, respectively. On the right, differencing the NBR before and after fire has derived an initial assessment of burn severity. The gradient of differenced NBR has been stratified to identify burn severity levels, including: unburned, low (green), moderate-low (yellow), moderate-high (orange), and high (red).

USDA Forest Service Gen. Tech. Rep. RMRS-GTR-164-CD. 2006 LA-1

• *Key, C. H., and N. C. Benson. 2005. Landscape assessment - sampling and analysis methods. Pp. LA1-LA51 in D. Lutes (ed.), FIREMON: Fire Effects and Inventory Monitoring System. Gen. Tech. Rep. RMRS-GTR-164-CD, USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.*

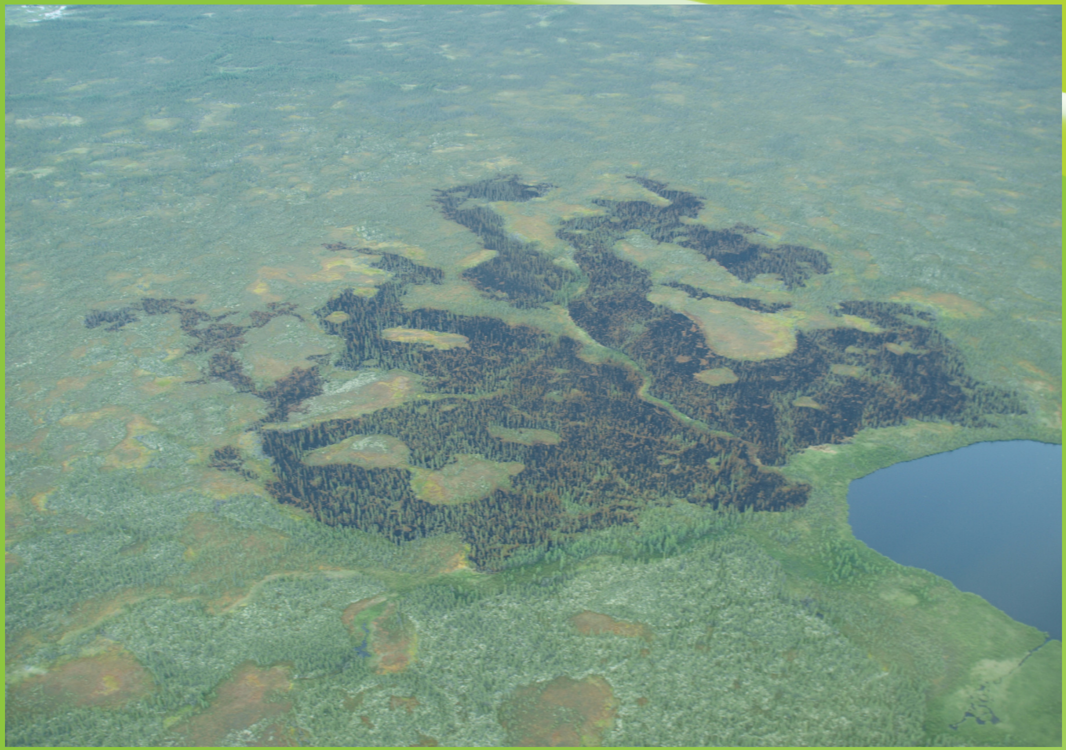
Monitoring for Burn Severity

• Landsat imagery provided for the monitoring of Burn Severity

•What is Burn Severity?

Magnitude of ecological change due to fire or,

The effect of fire on an ecosystem

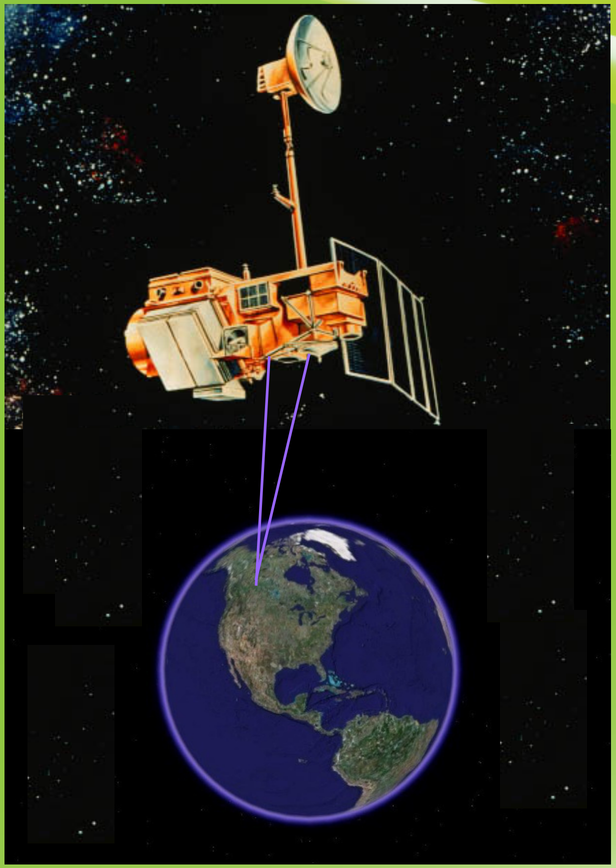


•Distinct from *fire size*, *fire intensity*, *fire severity*

Burn Severity & Remote Sensing

- Based on Landsat 5 satellite constellation (some Landsat 7)
- Non-tasked satellite, 16 day repeat cycle (overlap in high latitudes)
- Scale of interest is 30 m Landsat TM pixel size

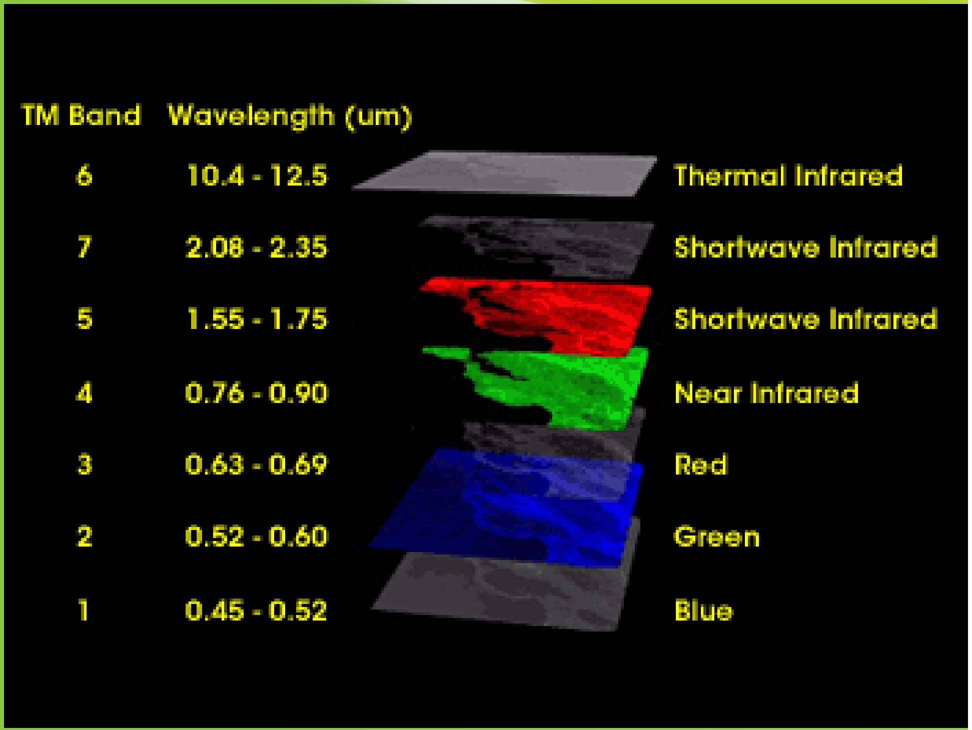
- Burn Severity measured immediately after fire (Initial Assessment) or 1 year after (Extended Assessment)



Normalized Burn Ratio

- Metric of interest: Normalized Burn Ratio (NBR)
- NBR is the normalized ratio of near infrared and shortwave infrared spectral bands
- A ratio of Band 4 (R4) to Band 7 (R7)
- With fire, R4 will decrease while R7 increase

- Change is detected using a Differential NBR (dNBR)



$$dNBR = NBR(\text{Pre}) - NBR(\text{Post})$$

Normalized Burn Ratio

- In general, for Extended Assessment
  - **dNBR ~ 0**: unburned or very low severity effects
  - **dNBR ~ 600+**: complete crown consumption, very high severity understory effects
  - **dNBR < 0**: "negative severity" – enhanced understory regrowth after fire
  - **dNBR ~100-500**: various levels of low to high severity effects

•Miller, J. D., and A. E. Thode. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment 109:66-80.

• Miller, J. D., E. E. Knapp, C. H. Key, C. N. Skinner, C. J. Isbell, R. M. Creasy, and J. W. Sherlock. 2009. Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three measures of fire severity in the Sierra Nevada and Klamath mountains, California, USA. Remote Sensing of Environment **113:645-656.**

Ground Truth – Burn Severity

- Define meaning of dNBR values
- Done using Composite Burn Index (CBI) form
  - 30 m diameter plots paired with individual pixels
- Rapid plot assessment based on visual estimates
  - No true measurements
- Method is strong when many plots are assessed

Ground Truth – Burn Severity

- CBI form separates forest stand into 5 vertical layers – strata
    - Substrates (fuels, litter, etc.)
    - Understory (< 1 m height)
    - Shrubs/small trees (1-5 m)
    - Subcanopy trees
    - Main canopy trees
- Assessments yield BI value 0.0 to 3.0
- CBI is a weighted average of stratum values

FIREMON LA Form

BURN SEVERITY -- COMPOSITE BURN INDEX (BI)

PD - Abridged	Examiners:			Fire Name:	
Registration Code		Project Code		Plot Number	
Field Date mmddyyyy	/ /	Fire Date mmyyyy	/		
Plot Aspect		Plot % Slope		UTM Zone	
Plot Diameter Overstory		UTM E plot center		GPS Datum	
Plot Diameter Understory		UTM N plot center		GPS Error (m)	
Number of Plot Photos		Plot Photo IDs			

BI – Long Form	% Burned 100 feet (30 m) diameter from center of plot =					Fuel Photo Series =			
STRATA RATING FACTORS	**BURN SEVERITY SCALE**							**FACTOR SCORES**	
	No Effect	**Low**		**Moderate**		**High**			
	0.0	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**		
A. SUBSTRATES									
% Pre-Fire Cover: Litter =	**Duff =**		**Soil/Rock =**		**Pre-Fire Depth (inches): Litter =**	**Duff =**	**Fuel Bed =**		∑ =
Litter/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel		
Duff	Unchanged	--	Light char	--	50% loss deep char	--	Consumed		N =
Medium Fuel, 3-8 in.	Unchanged	--	20% consumed	--	40% consumed	--	>60% loss, deep ch		
Heavy Fuel, > 8 in.	Unchanged	--	10% loss	--	25% loss, deep char	--	>40% loss, deep ch		$\bar{X}$ =
Soil & Rock Cover/Color	Unchanged	--	10% change	--	40% change	--	>80% change		
B. HERBS, LOW SHRUBS AND TREES LESS THAN 3 FEET (1 METER):									
Pre-Fire Cover =		**% Enhanced Growth =**							∑ =
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss		
Frequency % Living	100%	--	90%	--	50%	< 20%	None		N =
Colonizers	Unchanged	--	Low	--	Moderate	High-Low	Low to None		
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change		$\bar{X}$ =
C. TALL SHRUBS AND TREES 3 to 16 FEET (1 TO 5 METERS):									
Pre-Fire Cover =		**% Enhanced Growth =**							∑ =
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss		
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%		N =
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%		
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change		$\bar{X}$ =
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)									
Pre-Fire % Cover =		**Pre-Fire Number Living =**			**Pre-Fire Number Dead =**				∑ =
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None		
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss		N =
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch		
% Canopy Mortality	None	--	15%	--	60%	80%	%100		$\bar{X}$ =
Char Height	None	--	1.5 m	--	2.8 m	--	> 5 m		
Post Fire: %Girdled =		**%Felled =**		**%Tree Mortality =**					
E. BIG TREES (UPPER CANOPY, DOMINANT, CODOMNANT TREES)									
Pre-Fire % Cover =		**Pre-Fire Number Living =**			**Pre-Fire Number Dead =**				∑ =
% Green (Unaltered)	100%	--	95%	--	50%	< 10%	None		
% Black (Torch)	None	--	5-10%	--	50%	> 80%	100% + branch loss		N =
% Brown (Scorch/Girdle)	None	--	5-10%	--	30-70%	< 30 or > 70%	None due to torch		
% Canopy Mortality	None	--	10%	--	50%	70%	%100		$\bar{X}$ =
Char Height	None	--	1.8 m	--	4 m	--	> 7 m		
Post Fire: %Girdled =		**%Felled =**		**%Tree Mortality =**					

Community Notes/Comments:	**CBI = Sum of Scores / N Rated:**	**Sum of Scores**	**N Rated**	**CBI**
	Understory (A+B+C)			
	Overstory (D+E)			
	Total Plot (A+B+C+D+E)			

The Composite Burn Index (CBI)

BI – Long Form	% Burned 100 feet (30 m) diameter from center of plot =					Fuel Photo Series =		
STRATA RATING FACTORS	BURN SEVERITY SCALE							FACTOR SCORES
	No Effect	Low		Moderate		High		
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
A. SUBSTRATES								
% Pre-Fire Cover: Litter =	**Duff =**		**Soil/Rock =**		**Pre-Fire Depth (inches): Litter =**	**Duff =**	**Fuel Bed =**	
Litter/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel	
Duff	Unchanged	--	Light char	--	50% loss deep char	--	Consumed	2.0
Medium Fuel, 3-8 in.	Unchanged	--	20% consumed	--	40% consumed	--	>60% loss, deep ch	
Heavy Fuel, > 8 in.	Unchanged	--	10% loss	--	25% loss, deep char	--	>40% loss, deep ch	$\bar{X}$ =
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B. HERBS, LOW SHRUBS AND TREES LESS THAN 3 FEET (1 METER):								
Pre-Fire Cover =		**% Enhanced Growth =**						
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss	2.2
Frequency % Living	100%	--	90%	--	50%	< 20%	None	
Colonizers	Unchanged	--	Low	--	Moderate	High-Low	Low to None	$\bar{X}$ =
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change	
C. TALL SHRUBS AND TREES 3 to 16 FEET (1 TO 5 METERS):								
Pre-Fire Cover =		**% Enhanced Growth =**						
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss	2.2
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%	
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%	$\bar{X}$ =
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change	
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)								
Pre-Fire % Cover =		**Pre-Fire Number Living =**			**Pre-Fire Number Dead =**			
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None	
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss	2.6
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch	
% Canopy Mortality	None	--	15%	--	60%	80%	%100	$\bar{X}$ =
Char Height	None	--	1.5 m	--	2.8 m	--	> 5 m	
Post Fire: %Girdled =		**%Felled =**		**%Tree Mortality =**				
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Pre-Fire % Cover =		**Pre-Fire Number Living =**			**Pre-Fire Number Dead =**			
% Green (Unaltered)	100%	--	95%	--	50%	< 10%	None	
% Black (Torch)	None	--	5-10%	--	50%	> 80%	100% + branch loss	2.9
% Brown (Scorch/Girdle)	None	--	5-10%	--	30-70%	< 30 or > 70%	None due to torch	
% Canopy Mortality	None	--	10%	--	50%	70%	%100	$\bar{X}$ =
Char Height	None	--	1.8 m	--	4 m	--	> 7 m	
Post Fire: %Girdled =		**%Felled =**		**%T[illegible]ortality =**				

Community Notes/Comments:	CBI = Sum of Scores / N Rated:	Sum of Scores	N Rated
	Understory (A+B+C)		
	Overstory (D+E)		
	Total Plot (A+B+C+D+E)		

2.55

dNBR and CBI - Correlation

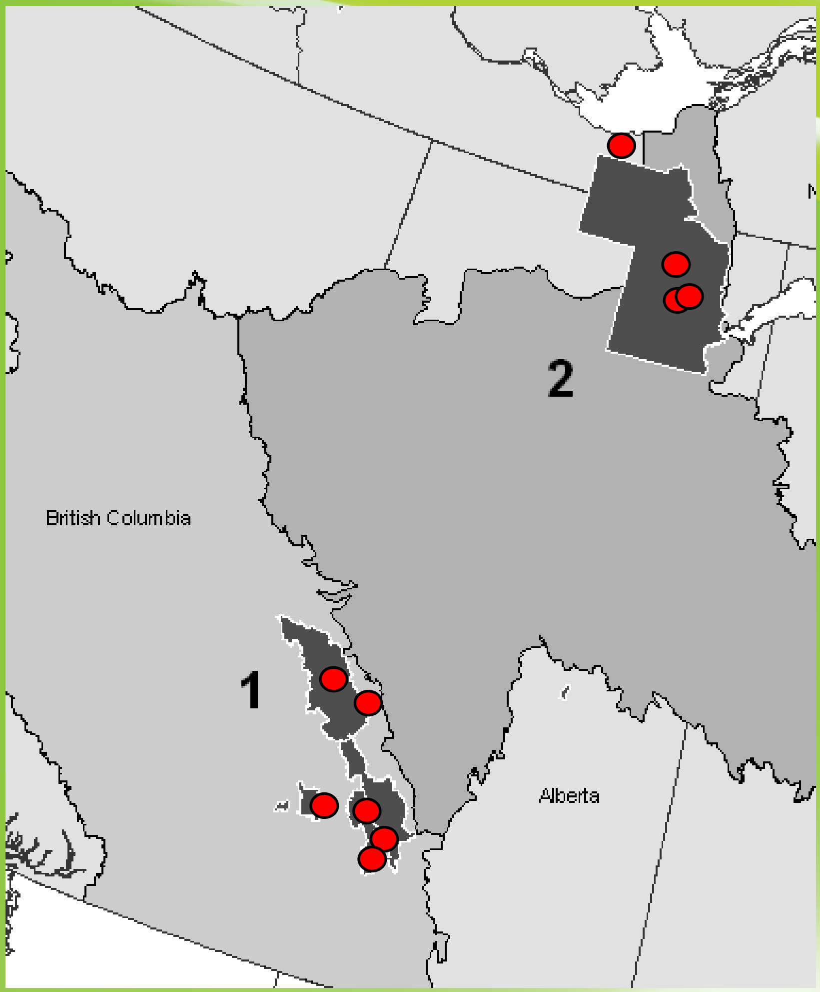
- Simple regression models
- Linear, quadratic, cubic models fitting dNBR to CBI (or vice versa)
- Done on per-fire basis, or pooled data from several fires
- Reported coefficient of determination (R^2) mostly
    - 0.6 – 0.85 in forests
    - 0.3 – 0.6 in grass/shrublands

Partnership with UBC

- Study of wildfires and prescribed fires in western Canadian Nat. Parks
- Evaluate use for correlation models on landscape fire effects monitoring

- Analysis of 10 fires (2005-2008) in western cordilleran, boreal, and taiga forests
- Fire size ranging from 125,000ha to 140ha

- 475 CBI plots



Results

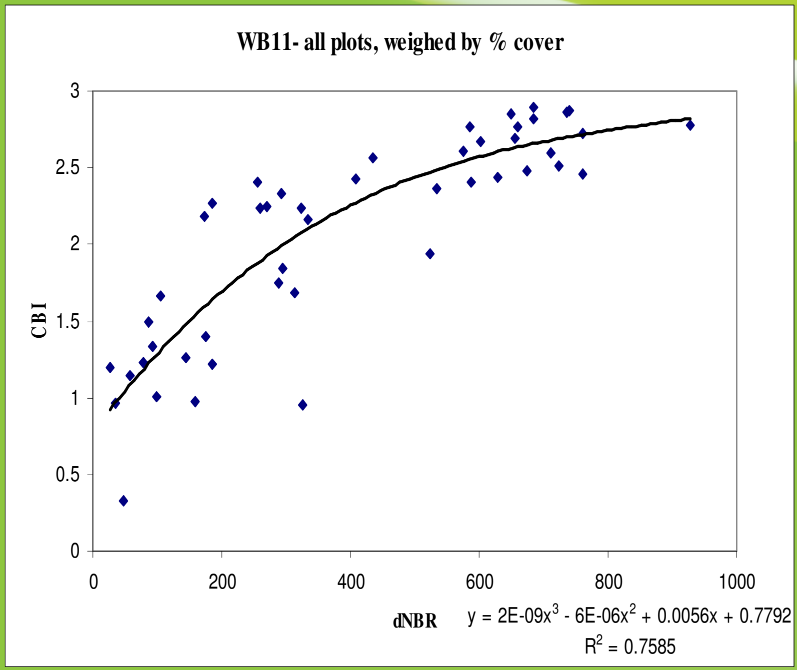
•Determination of coefficient (R^2) ranging from 0.40 to 0.89

•For the 10 fires, overall model had a coefficient of $R^2 = 0.69$

•Some variation may be explained by season of burn and speed of green-up post fire

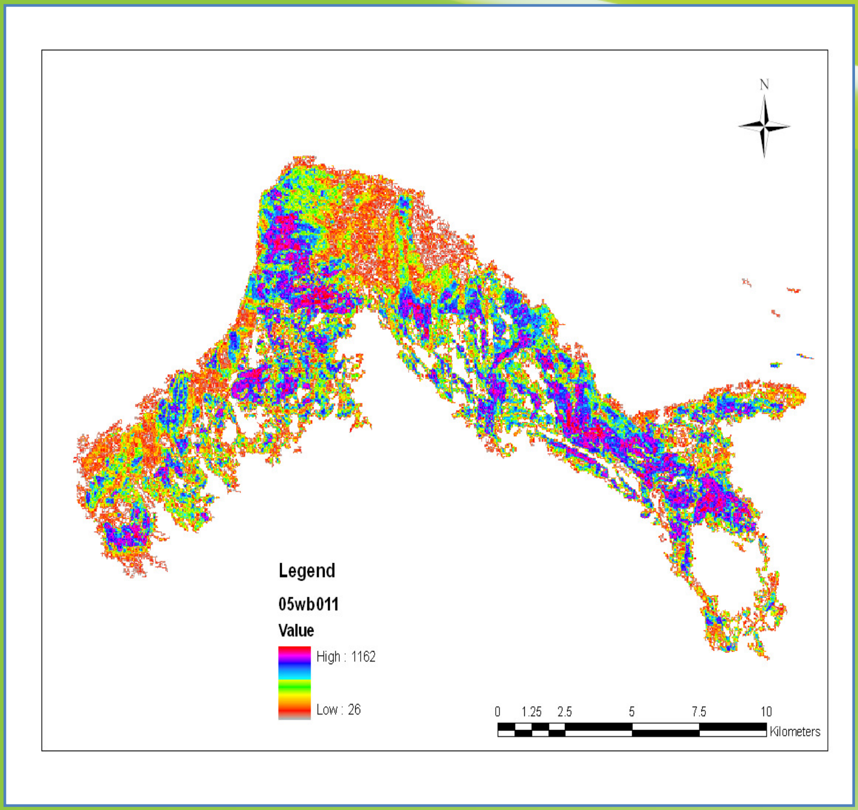
•Difference in post-fire brightness between mountains and boreal

•Due likely to the deeper organic soil content found in the boreal



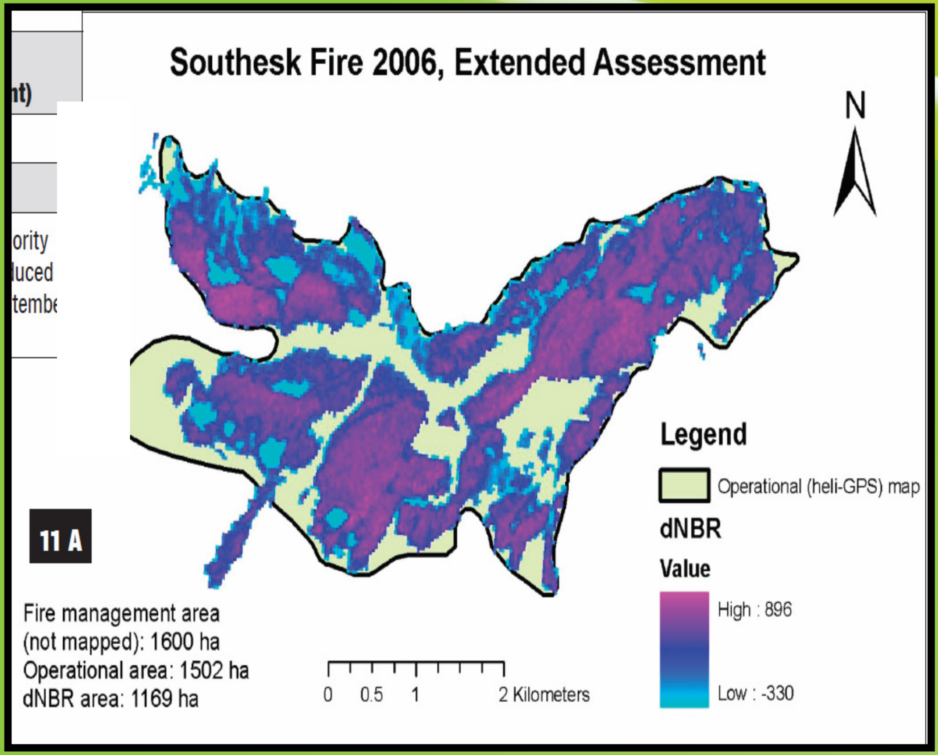
Benefits and Features

- Very good for assessing large fires rapidly
- Good depiction of fire area heterogeneity
- Availability of imagery ("free")
- 30 m pixel size excellent for many ecosystem effects of interest to land managers
- Automatic data collection makes retrospective analysis possible



Limitations

- Landsat 5 not dependable
- 16 day repeat rate – data gaps
- Clouds, smoke, make images unusable
- 'Moderate severity' class – overstory vs. understory?
- Poor for individual veg. species

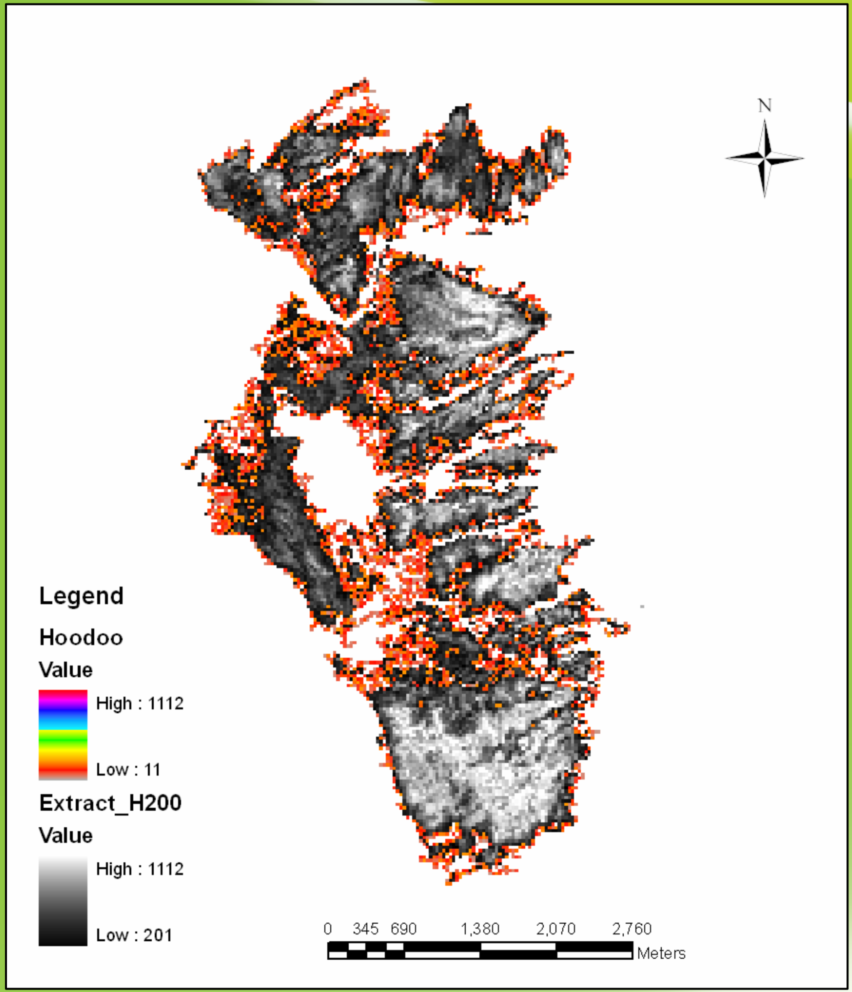


Conclusion

- Works for 10 fires, seems positive to work for others
- Method allows basic monitoring of many fires rapidly

Future Direction

- Work to refine models – reduce variation in regional types
- Will work to build monitoring into burn plans
- i.e. burn severity targets



Acknowledgements

- University of British Columbia
- Nic Soverell – MSc Research

- Dan Perrakis – Western Fire Ecologist

•Soverel, N.O., D.D.B. Perrakis and N.C. Coops. 2010. Estimating burn severity from Landsat dNBR and RdNBR indices across western Canada. Remote Sensing of Environment **114:1896-1909.**

• Soverel, N.O., N.C. Coops, D.D.B. Perrakis, L.D. Daniels, and S.E. Gergel. 2011. The transferability of a dNBR derived model to predict burn severity across ten wildland fires in western Canada. International Journal of Wildland Fire **In press.**