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"MEASURING AND REMOTE SENSING OF BURN SEVERITY"

Carl H. Key, USGS Northern Rocky Mountain Science Center [1]
Nate C. Benson, USNPS Glacier National Park [2]

[1] USGS Glacier Field Station
c/o Glacier National Park
West Glacier, MT 59936
carl_key@usgs.gov

[2] *Present Address:*
Everglades National Park
Fire Management Office
40001 State Rd 9336
Homestead, FL 33034-6733
nate_benson@nps.gov

THE COMPOSITE BURN INDEX (CBI): FIELD RATING OF BURN SEVERITY

ABSTRACT

The Composite Burn Index (CBI): Objectives to correlate remote sensing data with observed fire effects require definition of burn severity, and a sampling strategy that matches recorded field characteristics to sensor capabilities. The Composite Burn Index (CBI) is designed to define burn severity ecologically, and measure ground effects which collectively provide a signal detected at moderate resolution by the Landsat Thematic Mapper. Average conditions of the community are evaluated ocularly by vegetative strata within relatively large heterogeneous plots. Attributes are rated by criteria which correspond to identified burn levels along a gradient from unburned to extremely burned conditions. The criteria scale considers not only specific physical properties, but also the distribution of traits within plots. Attribute scores then are segregated hierarchically by strata and averaged into understory, overstory, and overall composite ratings. Sampling confirms variable burn responses by strata consistent with observations over the range of severity, suggesting the criteria and rating scale are appropriate. Ratings which incorporate all strata seem to improve the overall measure of severity, and emphasize the importance of considering a broad range of factors when summarizing burns. We suggest the CBI is transferrable and a basis for studying or comparing burns across broad geographic regions. The strategy facilitates direct correlation of burn severity to radiometric response variables and may be used in modeling other environmental factors, such as fuel loading or erosion potential. At the same time, the methodology could be used in the absence of remote sensing data to describe and evaluate localized burn sites for a variety of purposes.

The Normalized Burn Ratio (NBR): We used the CBI (above) to test performance of radiometric measures as estimators of burn severity. Two 1994 fires occurring at Glacier National Park, Montana, were investigated. Indices incorporated band ratios and multi-temporal differencing derived from the Landsat Thematic Mapper, including: 1) post-fire band 7 reflectance; 2) pre- and post-fire differenced band 7 reflectance; 3) differenced Normalized Difference Vegetation Index (NDVI), and 4) differenced Normalized Burn Ratio (NBR), a new index formulated from TM band 7 and band 4 reflectance. Seasonal effects also were tested, with indices obtained from spring and late summer data, for a total of eight models. Evaluation of performance considered amplitude of index response, direct correlation to field-rated burn severity, and visual characteristics of derived images. NBR differenced from early in the growing season was judged the most effective measure of burn severity. Greater amplitude of response and correlation to field-rated burn severity led to better contrast, broader range of severity levels, and sharper delineation of burn perimeters. NDVI differenced late in the growing season exhibited the poorest resolution of burn severity overall. In general, results were improved for all indices when derived early in the growing season. Seasonal differences, however, were influenced by phenology and not strictly by date. Spring scenes performed best at low elevations, while late summer results were stronger at high elevations, where snow melt and plant growth was delayed by at least two months. To facilitate assessment of burn conditions through mapping and summary tabulation, differenced NBR was partitioned into 7 ordinal levels (including meadow, forest, and unburned classes) which exhibited strong relationships to burn severity rated on field plots. Advantages differenced NBR include: 1) a standard, transferable measure with reduced influence from image- or observer-dependent qualities; 2) utility on large, remote burns and potential to compare multiple burns regionally or nationally; 3) direct correlation to field-estimated fire effects and other quantitative environmental variables; and 4) flexibility to apply the measure as a continuous or discrete variable in modeling, research and management.

BURN SEVERITY RATING MATRIX

PLOT #: ☐ **PLOT SIZE:** ☐ **DATE:** ☐ **FIRE:** ☐ **UTM E:** ☐ **UTM N:**
Observer: ☐ **Time Since Fire:** ☐ **GPS Parameters:**

SCORE POST-FIRE EFFECTS

CRITERIA
STRATA
ATTRIBUTES

STRATA / ATTRIBUTES	NO EFFECT 0.0	0.5	LOW 1.0	1.5	MODERATE 2.0	2.5	HIGH 3.0
Substrate:							
litter	unchanged		50% loss		80% loss		consumed
duff	unchanged		light char		50% loss, deep char		consumed
fuels <7.6 cm	unchanged		50% loss		80% loss		consumed
fuels >7.6 cm	unchanged		5% loss, blackened		15% loss, deep char		>30% loss, deep char
a. Δ soil, color/cover	unchanged		10% change		40% change		>80% change
Herb/Low Shrub:							
Fire Moss, cover	none		trace, spotty		moderate	high	low
b. regeneration	100%		90%		50%	<20%	none
c. new serals (herbs)	none		low	moderate	high		low to none
d. Δ richness/cover	unchanged		little change		moderate change		high change
Tall Shrub/Sapling: *1-5 m high*							
% consumed	none		10%		50%		>90%
b. re-gen shrub/trees	100%		80%		30%	<10%	none
c. new serals (pico)	none		low		moderate	high	low to none
d. Δ richness/cover	unchanged		little change		moderate change		high change
e. **Intermediate Trees:** *approximately 10-20 cm diameter and 5-20 m high*							
% green	100%		80%		40%	<10%	none
% brown (scorch)	none		5-20%, or <10'		40-80%, or >50'	<20%	none
% black (torch)	none		5-20%		60%	>85%	branching consumed
char height	none		1.5 m		2.75 m		>5 m
Optional, other mortality indicators							
f. % girdled (bole/root)	none		10%		50%		>75%
e. **Big Trees:** *trees larger than intermediate trees*							
% green	100%		95%		50%	<10%	none
% brown (scorch)	none		5-10%, or <15'		30-70%, or >80'	<15%	none
% black (torch)	none		5-10%		50%	>85%	branching consumed
char height	none		1.75'		4 m		>7 m
Optional, other mortality indicators							
f. % girdled (bole/root)	none		10%		50%		>75%

UNDERSTORY
OVERSTORY
TOTAL PLOT

PLANT COMMUNITY / NOTES:

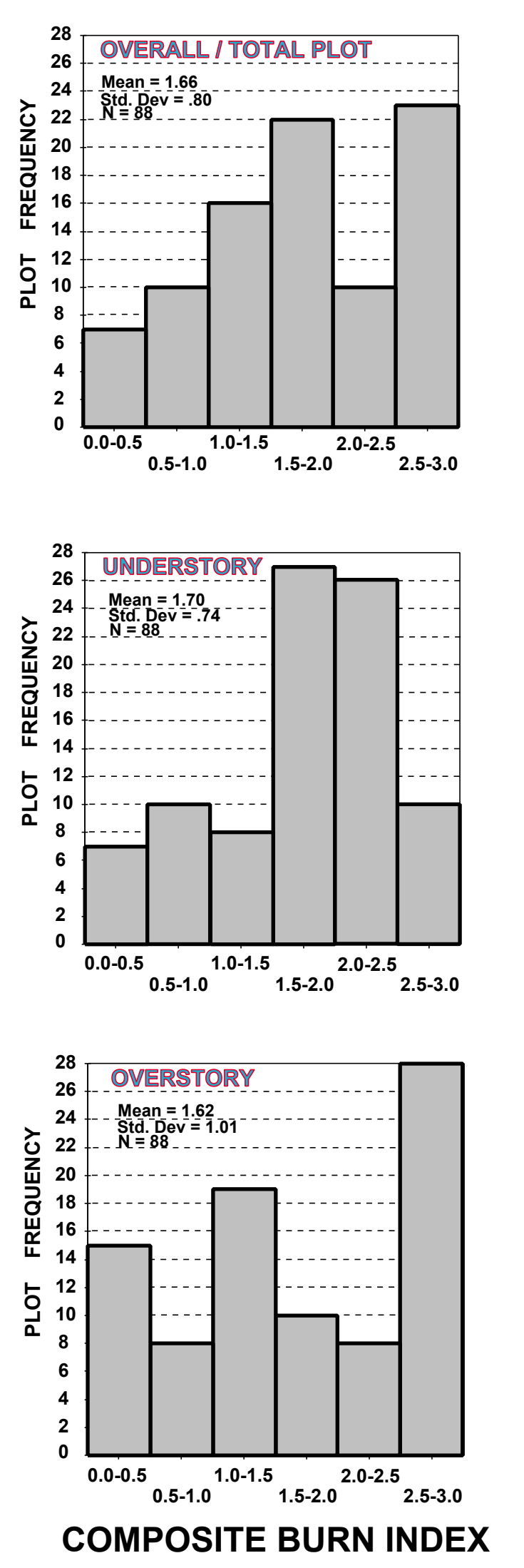
Time-dependent tree factors:
% felled (downed)
Total % mortality

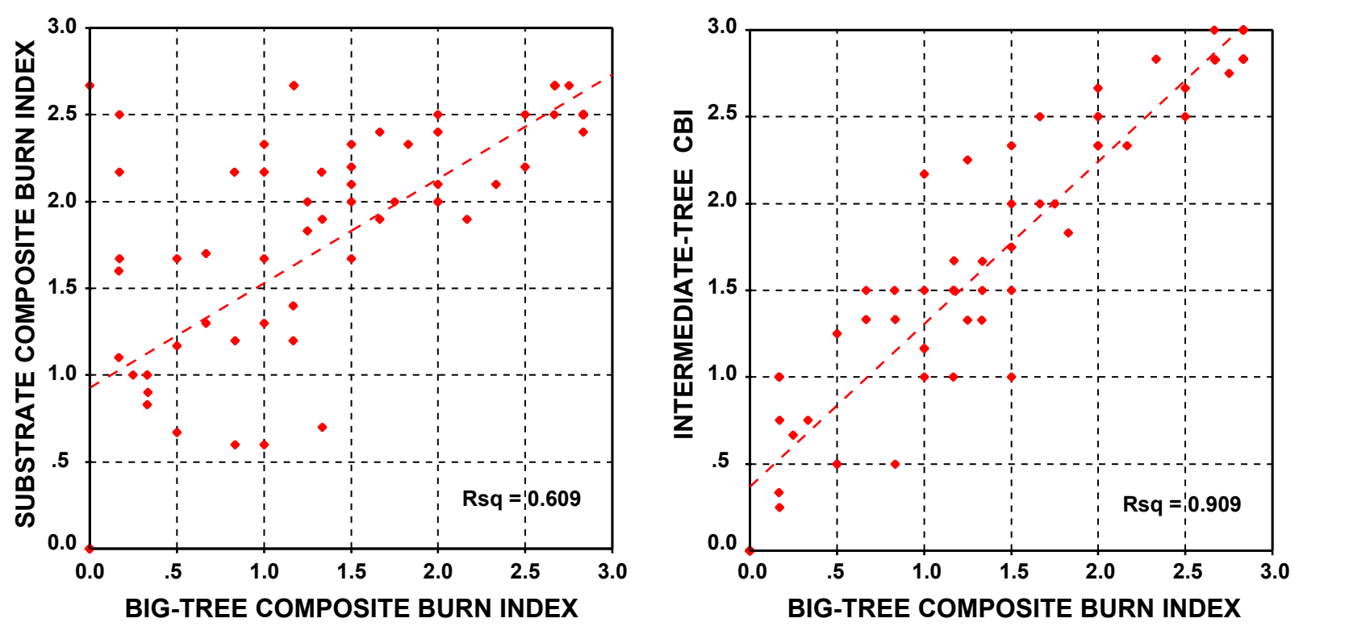
Count Rated Criteria Only:

STRATA	Score Sum	N Criteria	COMPOSITE BURN INDEX Average
Substrate			
Low Shrub/Herb			
Tall Shrub/Sapling			
Intermediate Trees			
Big Trees			
UNDERSTORY			
OVERSTORY			
TOTAL PLOT			

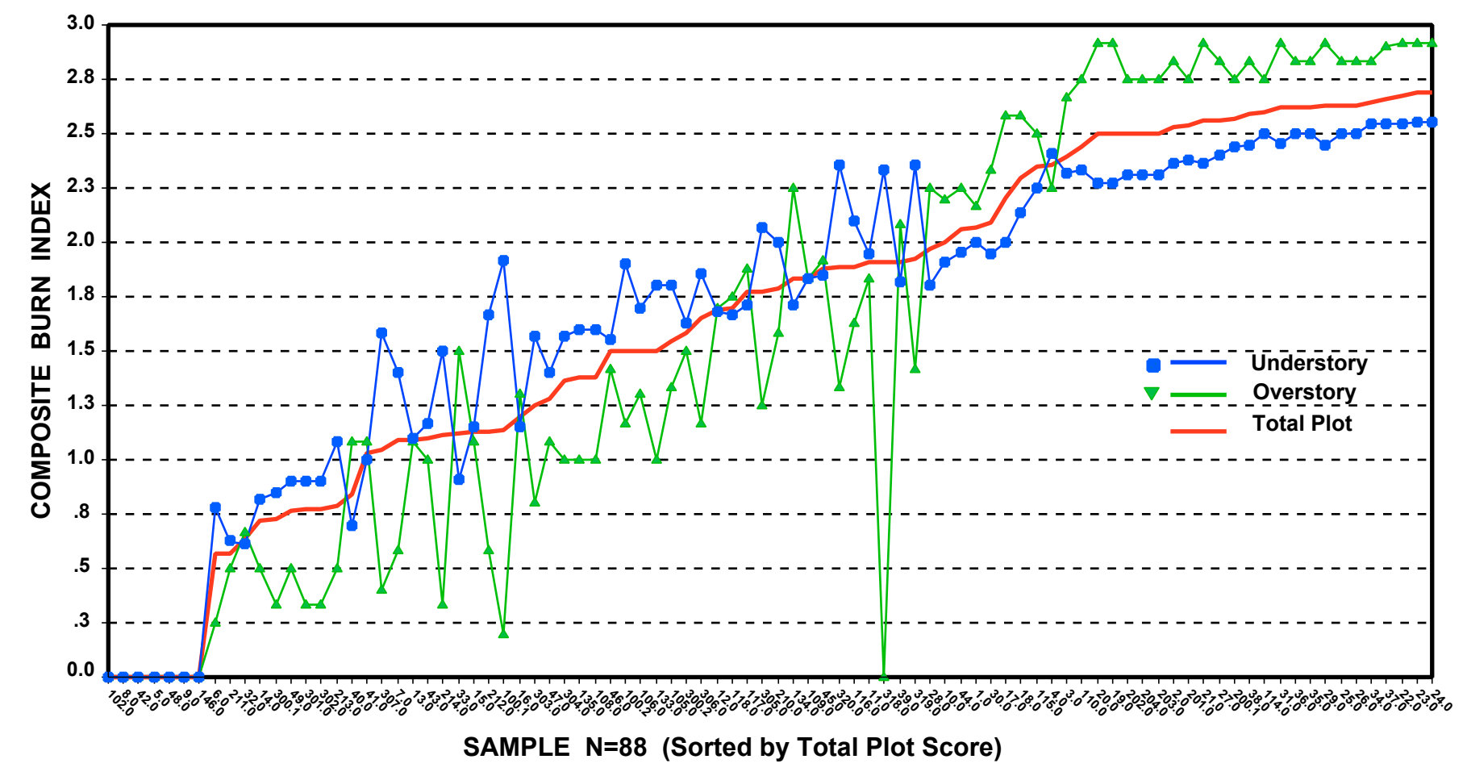
a. Increase cover of exposed mineral soil, and change from native color, general lightening with loss of organics. At high end up to 10-15% reddish.
b. Amount of regrowth from plants that burned but survive from living roots and stems, relative to estimated pre-fire vegetation plot-wide.
c. Potential dominance within a 4-year time span, averaged for plot. Frequency may be more recognizable at first with cover increasing over time.
d. Total change in composition and relative densities of species anticipated within a 4-year time span, relative to estimated pre-fire vegetation on plot.
e. Crown foliage condition of whole plot, relative to estimated pre-fire crown volume. Except, char height is the average median height on tree boles.
f. Percent of trees on plot burned through the bark to a degree of 50% or more around circumference of lower boles or buttress roots.

This form identifies criteria used to rate attributes in the northern U.S. Rocky Mountains. Though intended to be generic, attributes and criteria may differ slightly in other regions. Scores reference average conditions within relatively large plots (20-30 m diameter). Scores are summed and averaged by strata, understory/overstory, and overall to yield composite indices, lower right.





We evaluated the rating system on 88 field plots, representing a broad range of fire effects. The CBI quantified severity independently in 5 strata, and at aggregate levels of understory, overstory, and total plot. CBI captured properties expected from fire behavior, as observed in the field. Strata scores were all significantly correlated, but those in close spatial proximity had highest associations (top right). Strata farthest apart were most variant (top center). Where dissimilarities occurred, they were greatest at lower burn severities. Differential effects in under- and over-story (left and below) reflected heating thresholds, e.g. overstory moved quickly to high severity once fire reached the canopy. Total plot scores (top left) integrated variations among strata and seemed best suited for remote sensing applications. Rating criteria can be tailored to any ecosystem, to compare fires at multiple levels in a standard way for broad-scale monitoring.



PLOT PHOTOS -- SEVERITY SCORES

Understory - 1.00
Overstory - 1.08
Total Plot - 1.03

Light charring, up to moderate consumption of downed fuels. Regenerated forbs and grass dominate understory. Shrubs and saplings show little mortality. Overstory not scorched or blackened, and tree charring remains < 2 m.

Understory - 1.95
Overstory - 2.25
Total Plot - 2.06

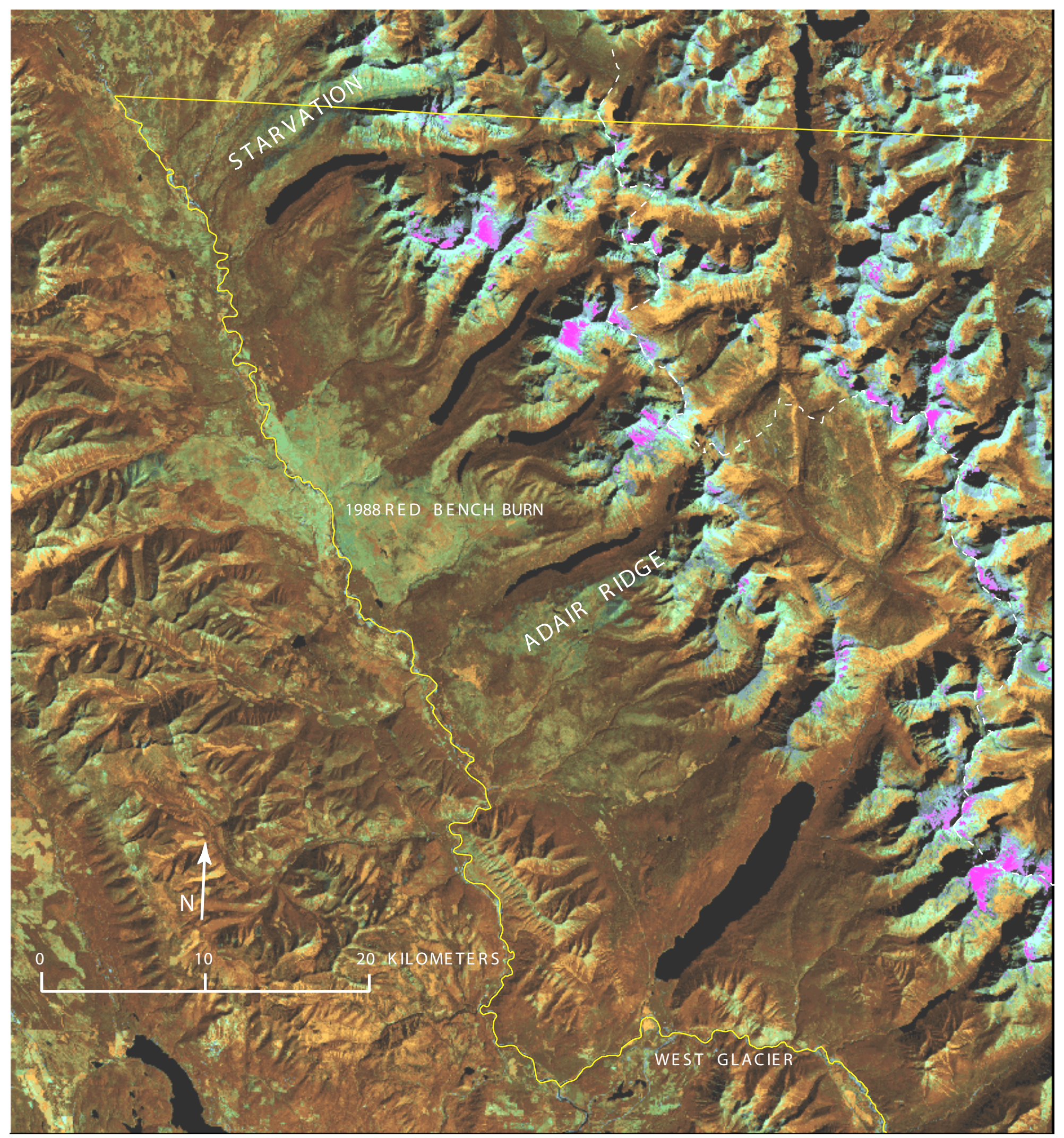
Deep char, largely consumed small fuels. Increased densities of new serals (fireweed, lodgepole pine), but some pre-fire herbs and shrubs persist. Most tree crowns blackened or largely scorched, a few green crowns remain.

Understory - 2.45
Overstory - 2.92
Total Plot - 2.63

Major portions of large downed fuels consumed, substantial amounts of exposed mineral soil. Pre-fire herbs and shrubs essentially absent, low-density patches of seral species occupy understory. Overstory consumed including most branching in crowns.

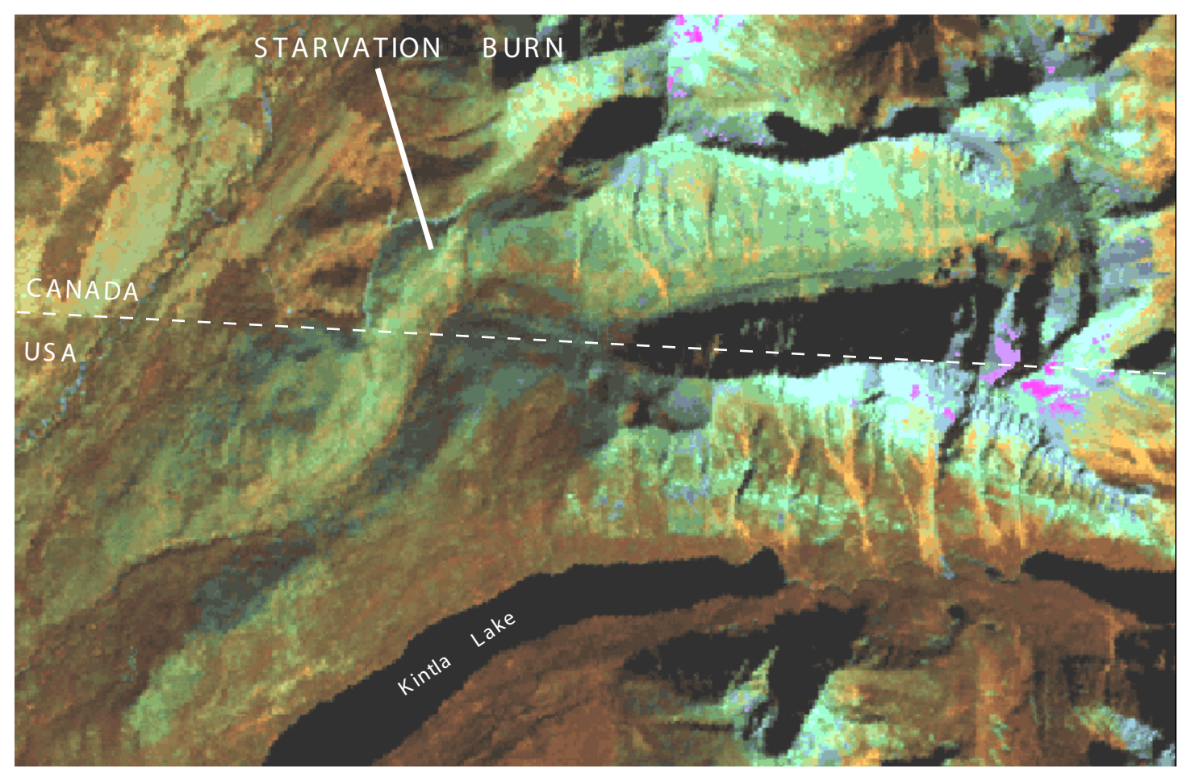
THE NORMALIZED BURN RATIO (NBR): A LANDSAT TM RADIOMETRIC MEASURE OF BURN SEVERITY

STUDY AREA

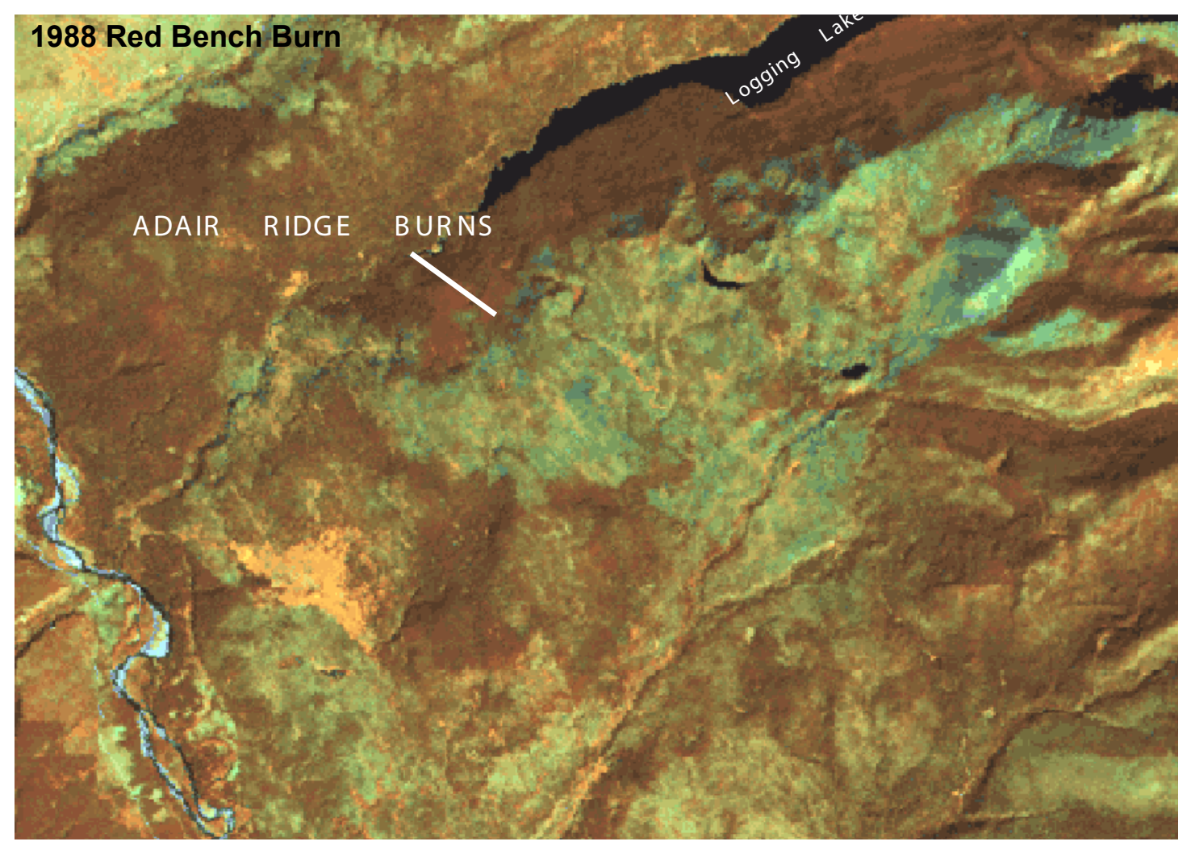


Landscape of northwest Glacier National Park viewed September 1, 1995 approximately one year after the Starvation and Adair Ridge Fires. The 1988 Red Bench Fire also is clearly evident (center). The image is a multi-spectral classification of Landsat TM bands 3, 4, and 5, with classes colored to simulate infrared photography. Increasingly, remote sensing technologies are required by the National Park Service to assess and monitor wildfires, where fire size, remoteness, and rugged terrain make alternative methods impractical.

Where were the fires?



What effect did they have?



Enlargements of the 1995 classification (left) showing Starvation and Adair Ridge Burns of 1994. New satellite remote sensing techniques are needed to consistently distinguish burned from unburned areas, to separate recent from older burns, and to quantify severity of effects within the burns. We developed the Normalized Burn Ratio (NBR) to improve upon previous methods which typically did not fully resolve one or more of those features.

Multi-temporal image differencing provides a general strategy to quantify change from one time to the next. The question is, however, what radiometric value and what time of year offers best discrimination of burn characteristics.

Four Landsat TM scenes were processed representing Spring and Late-Summer dates, before and after fire. This raw dataset was standardized, using a number of transformations to permit direct radiometric comparisons between scenes: 1) radiance; 2) rectification; 3) reflectance; and 4) date-to-date normalization of atmospheric transmittance.

From a random sample of pixels inside the burns, TM bands 4 and 7 exhibited the greatest reflectance change in response to fire. We hypothesized that a ratio of those bands would be most discriminating for burn effects, and constructed the Normalized Burn Ratio from their transformed reflectance (R) values:

$$\text{NBR} = \frac{R4 - R7}{R4 + R7}$$

R7 increased with fire, while R4 decreased, and those trends were accentuated in the normalized ratio. The NBR was calculated for each of the four TM scene dates. Then, for both Spring and Late-Summer pairs, the NBR image after fire was subtracted from the NBR image before fire. This yielded two seasonal models of NBR change, with values increasing positively as burn severity increased.

For comparison, we constructed models of three other radiometric measures of burn severity reported in the literature: 1) post-fire R7; 2) before-and-after fire R7 difference; and 3) the NDVI difference. As above, these were derived independently for both Spring and Late-Summer to evaluate seasonal effects.

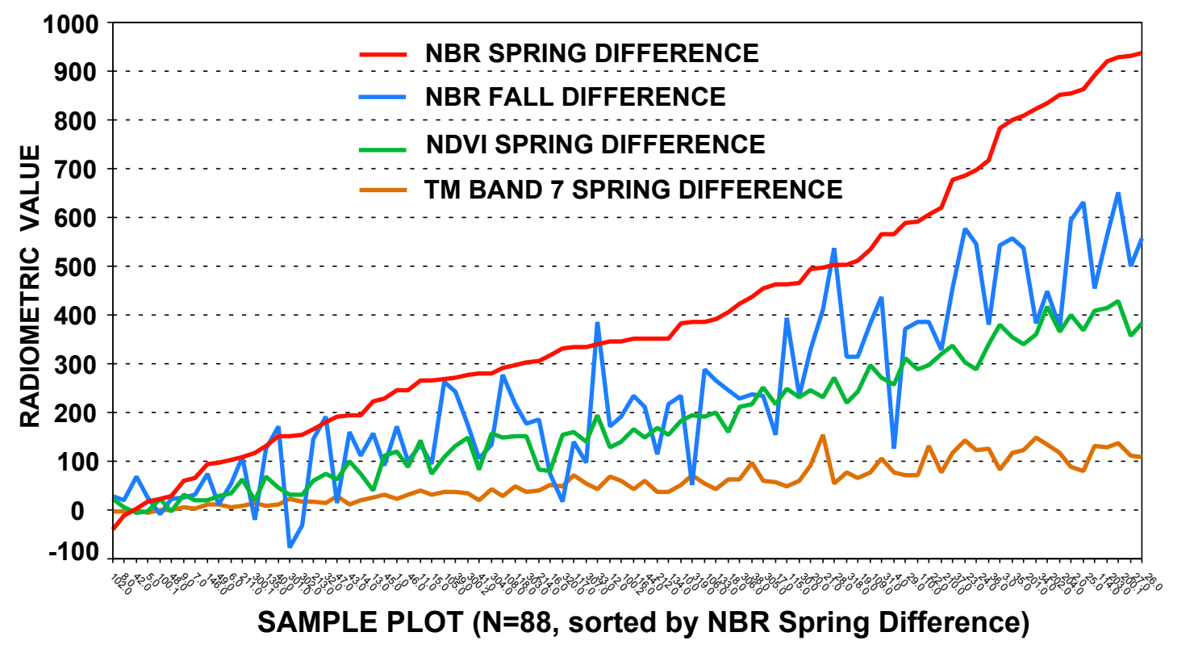
Note: NDVI is the Normalized Difference Vegetation Index similarly constructed as the NBR, but from TM bands 4 and 3. All calculations were done with floating point math, and results were scaled by 1000 to store positive and negative values in 32-bit images, retaining at least 4 significant digits.

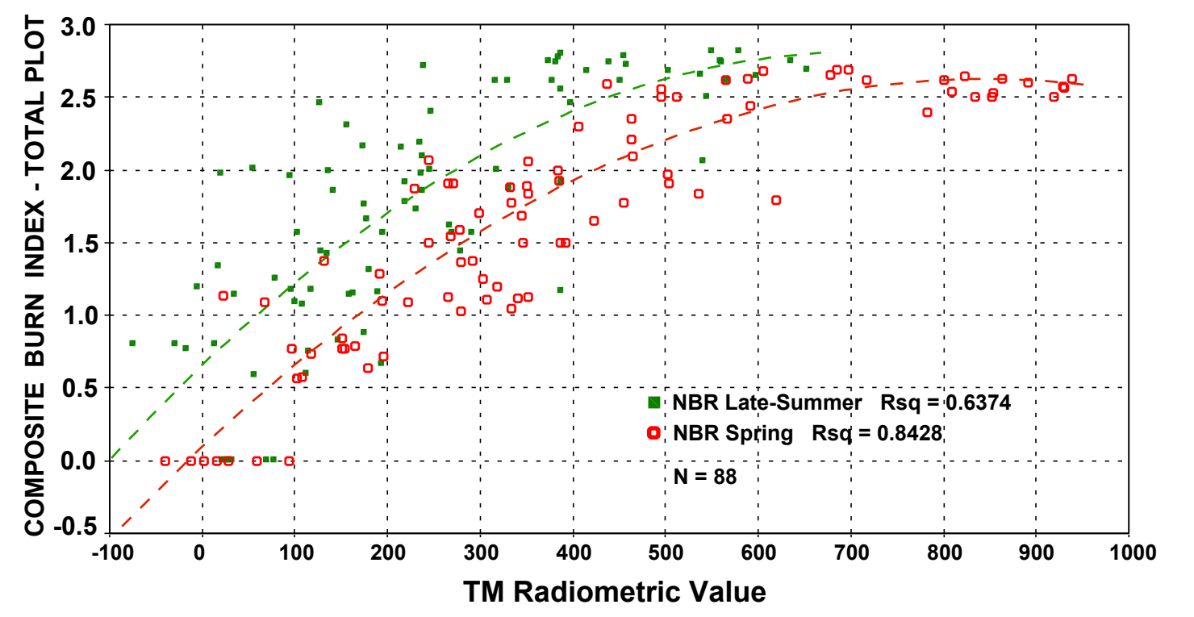
We compared all radiometric and seasonal measures to the Composite Burn Index (CBI) sampled from 88 plots, described above. Since all measures were ratio-level variables, testing was done by regression and direct evaluation of goodness-of-fit. This represented an advantage over other methods that rely on categorical or ordinal data for verification.

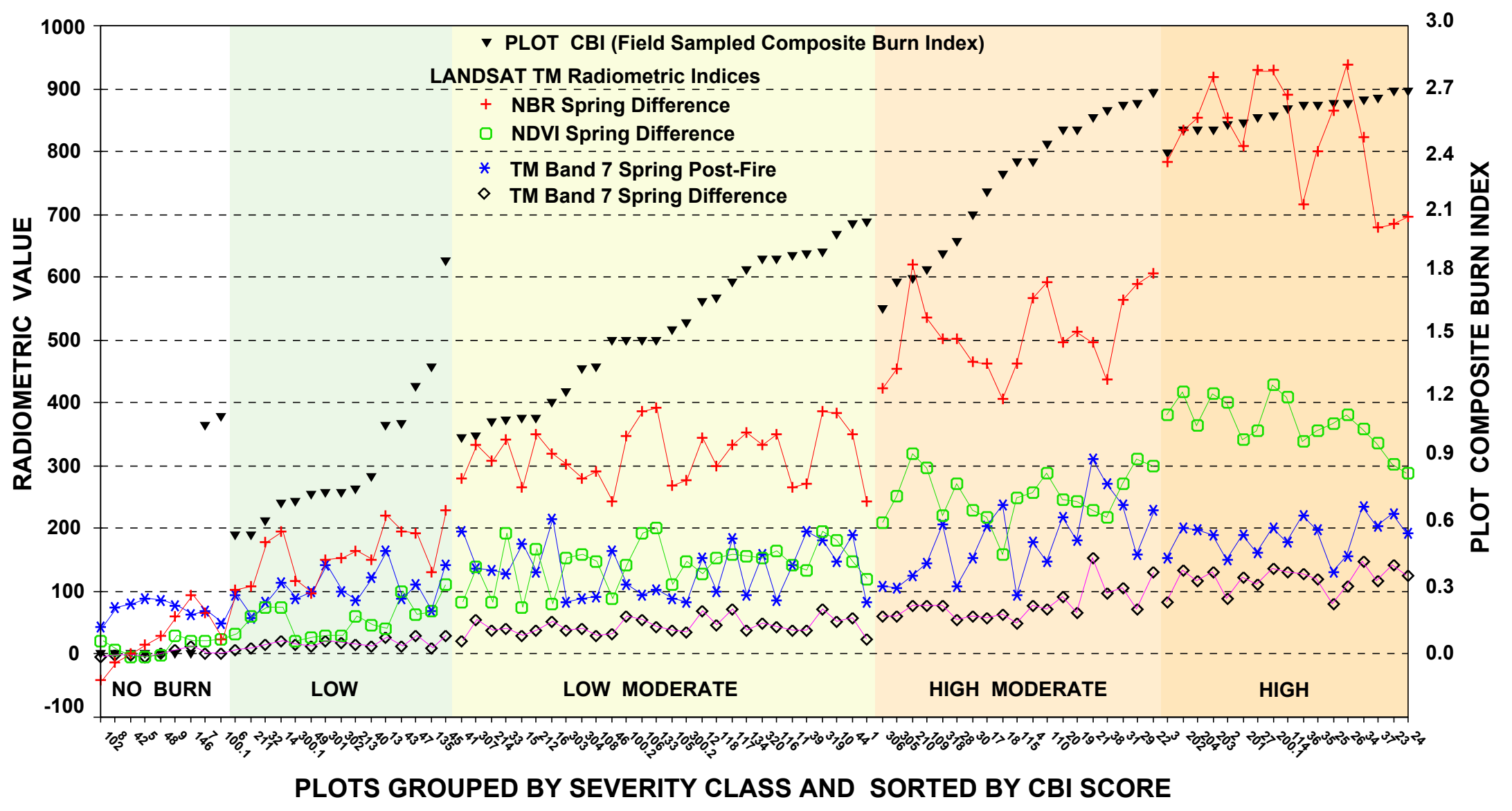
RIGHT -- The NBR Spring difference had greatest dynamic range of values within burns. It thus provided highest contrast between burn severity levels, as well as best distinction between burned and unburned areas, without further scaling of data. For all measures, Spring results performed better than Late-Summer results. Across measures, NBR had greatest correlation to field-rated CBI regardless of season.

BELOW -- As a continuum, NBR difference was the best predictor of burn severity. However, it can be partitioned into severity levels or classes, on statistical grounds, if desired. Number and range of classes is flexible depending on the application. Here we identify five levels, including unburned, with statistical characteristics shown, below right.

BOTTOM -- Selected imagery compares indices and seasons as continuous measures of burn severity. At bottom right, differenced NBR is partitioned into the 5 severity levels, plus meadow burns. An additional advantage of this method is demonstrated by the ease and reliability of delineating burn perimeters.

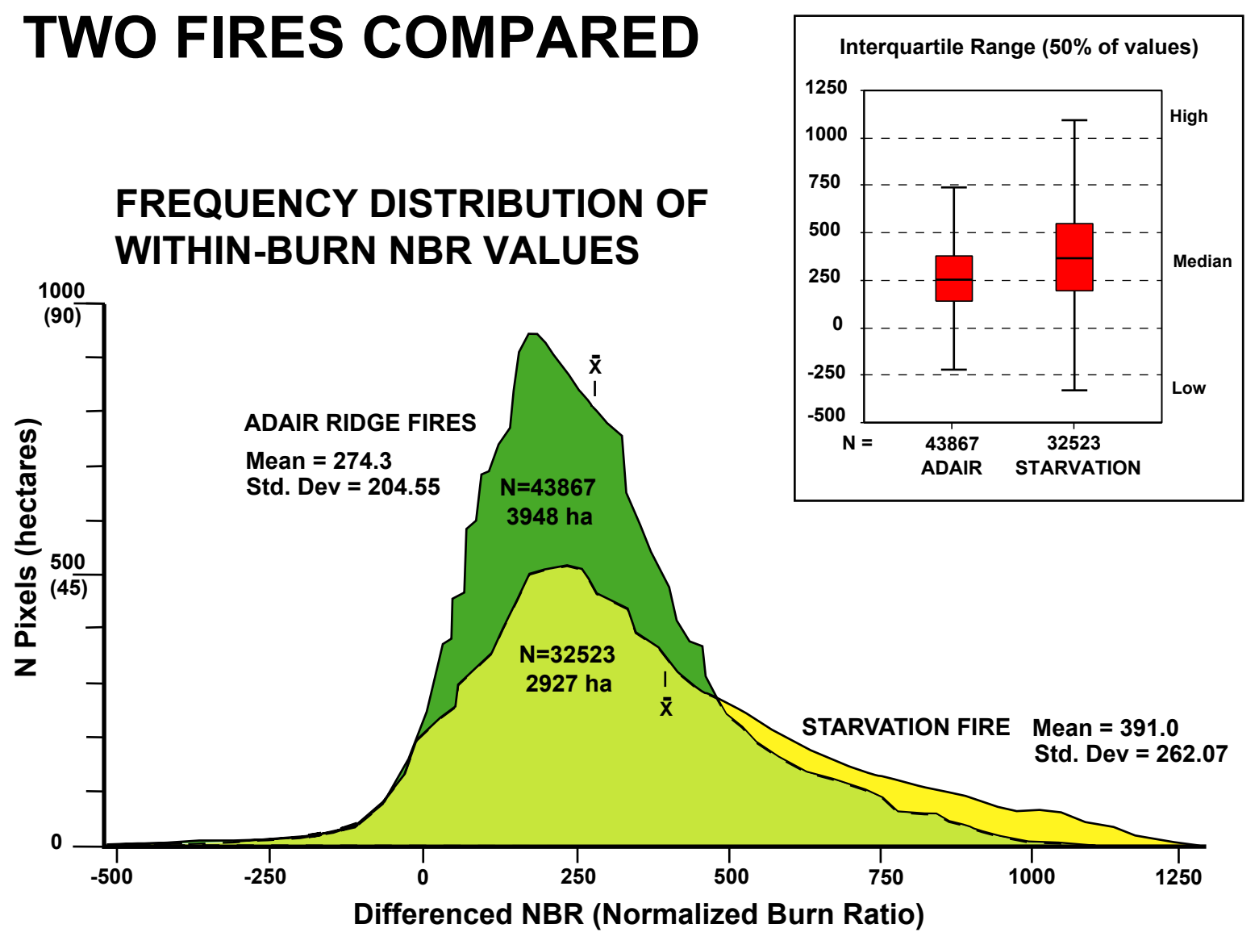






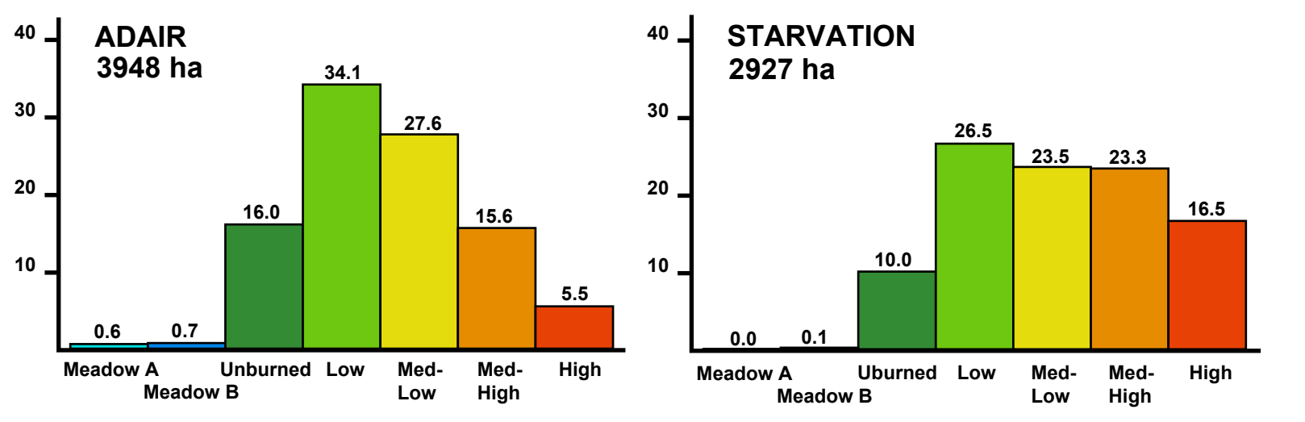
Cross-burn comparison with a standardized measure is a major benefit of this method. Here, Adair Fires burned more area, but generally less severely than the Starvation Fire.

TWO FIRES COMPARED



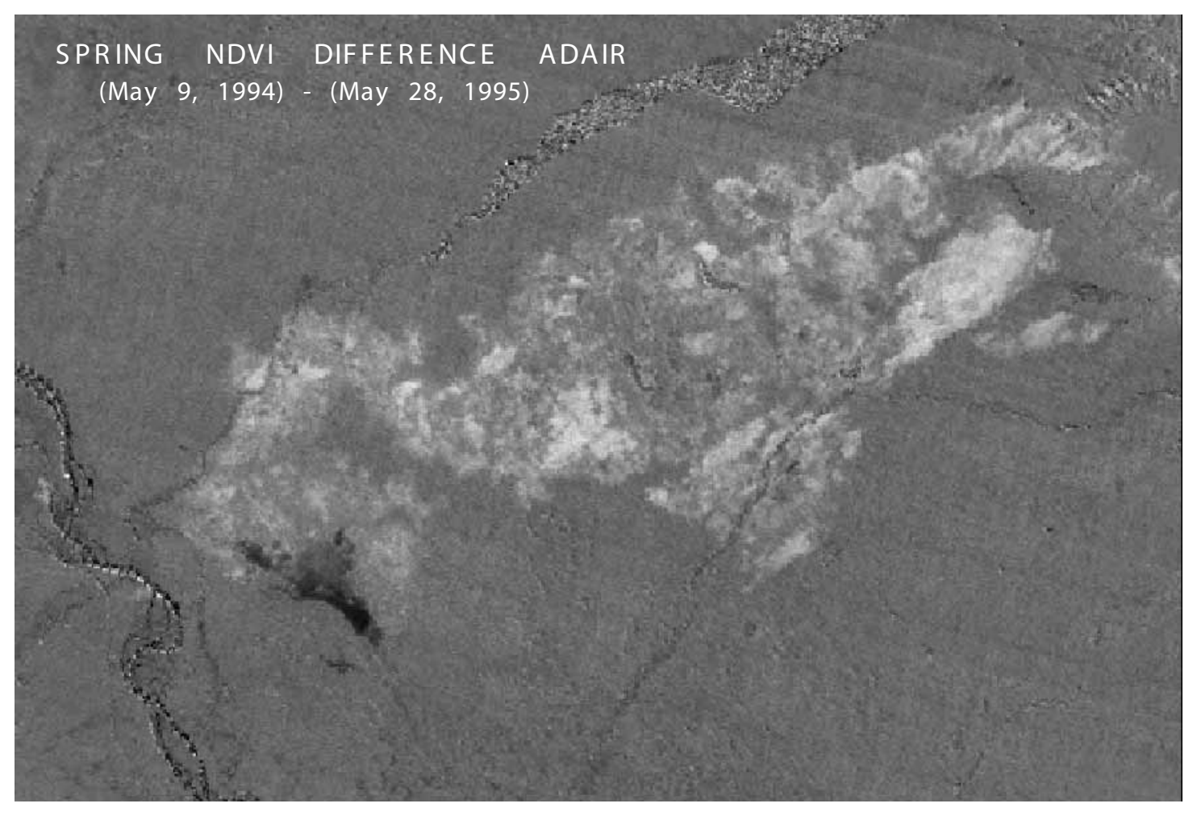
Various statistics, including landscape patch parameters, can be derived from NBR models and used to compare fires, or address ecological hypotheses.

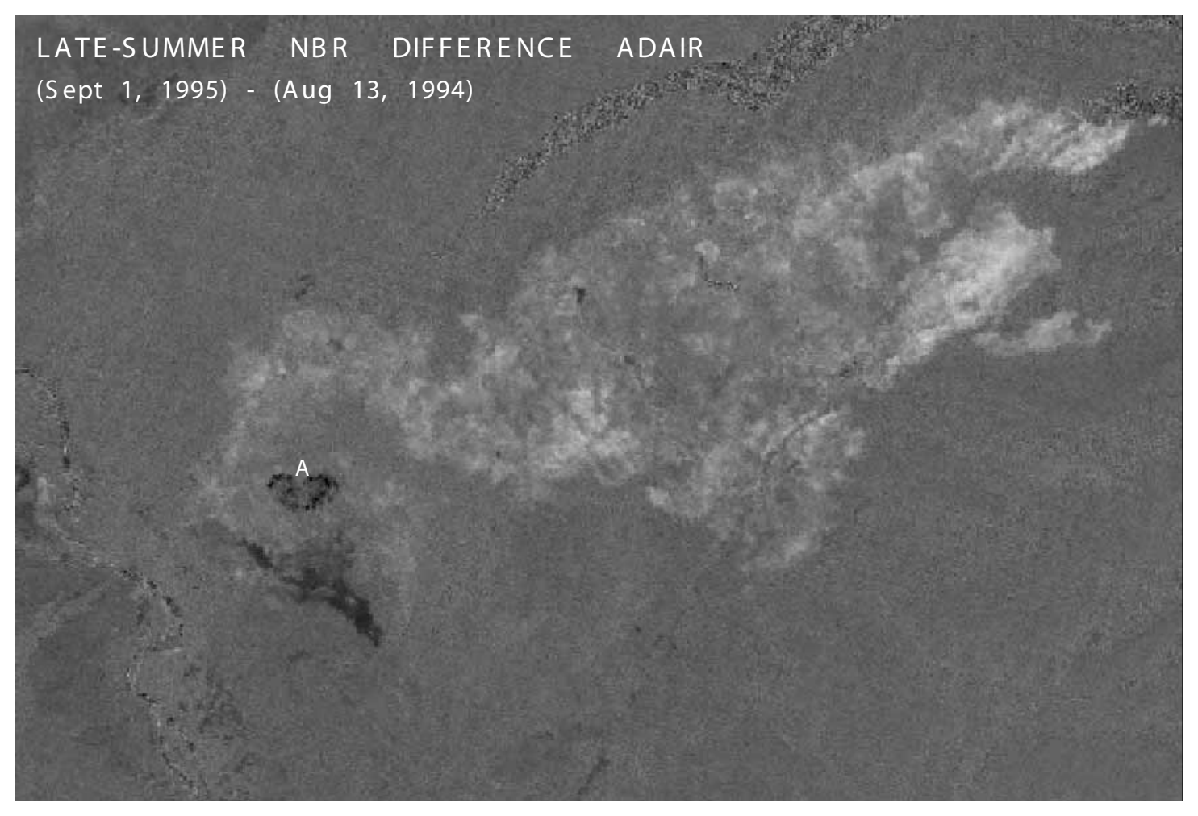
PERCENT COVER OF BURN SEVERITY LEVELS



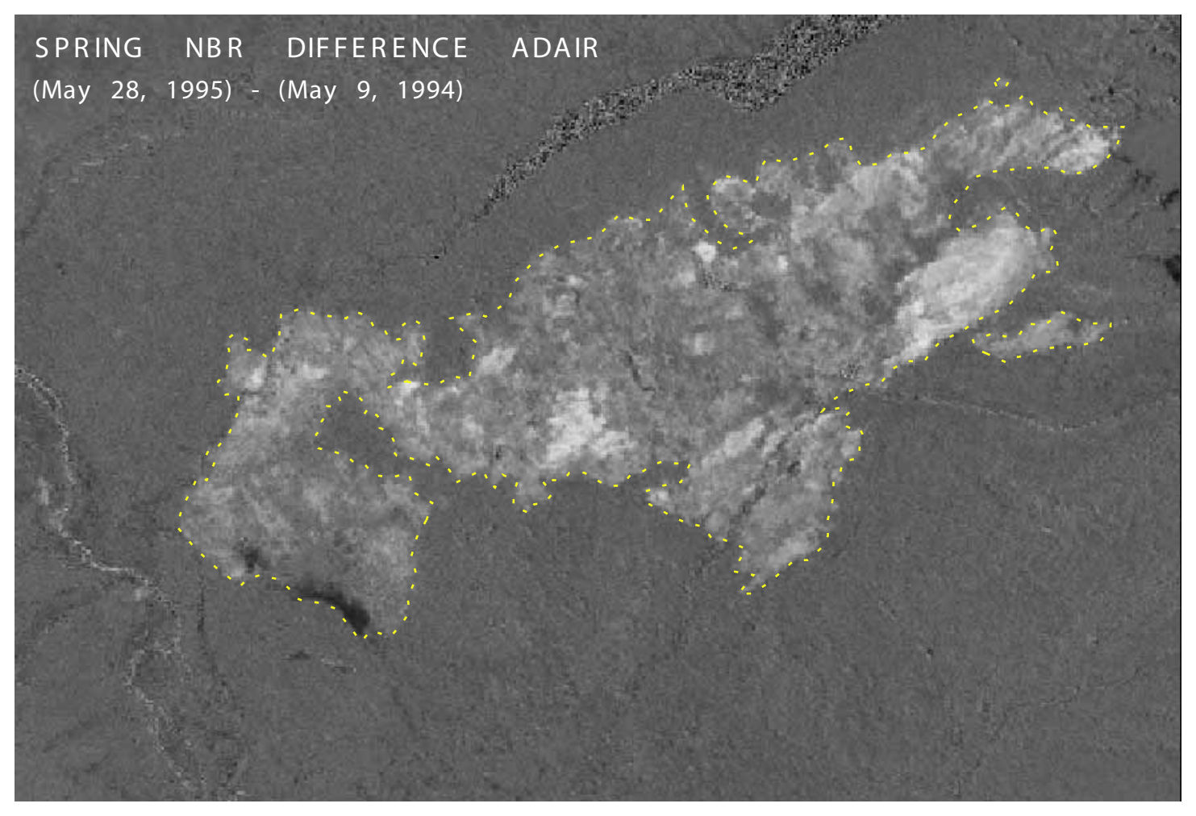
Images of radiometric indices, below, show near-zero values as medium gray (i.e. no change); lighter is increasingly positive, darker is increasingly negative.

Spring NDVI difference and Late-Summer NBR difference, below, were close in performance to the NBR Spring difference. Statistically, and by image contrast (i.e. range of values), however, both models were less robust and reliable at distinguishing severity levels. A) small area of burning remains active on 8/13/94.

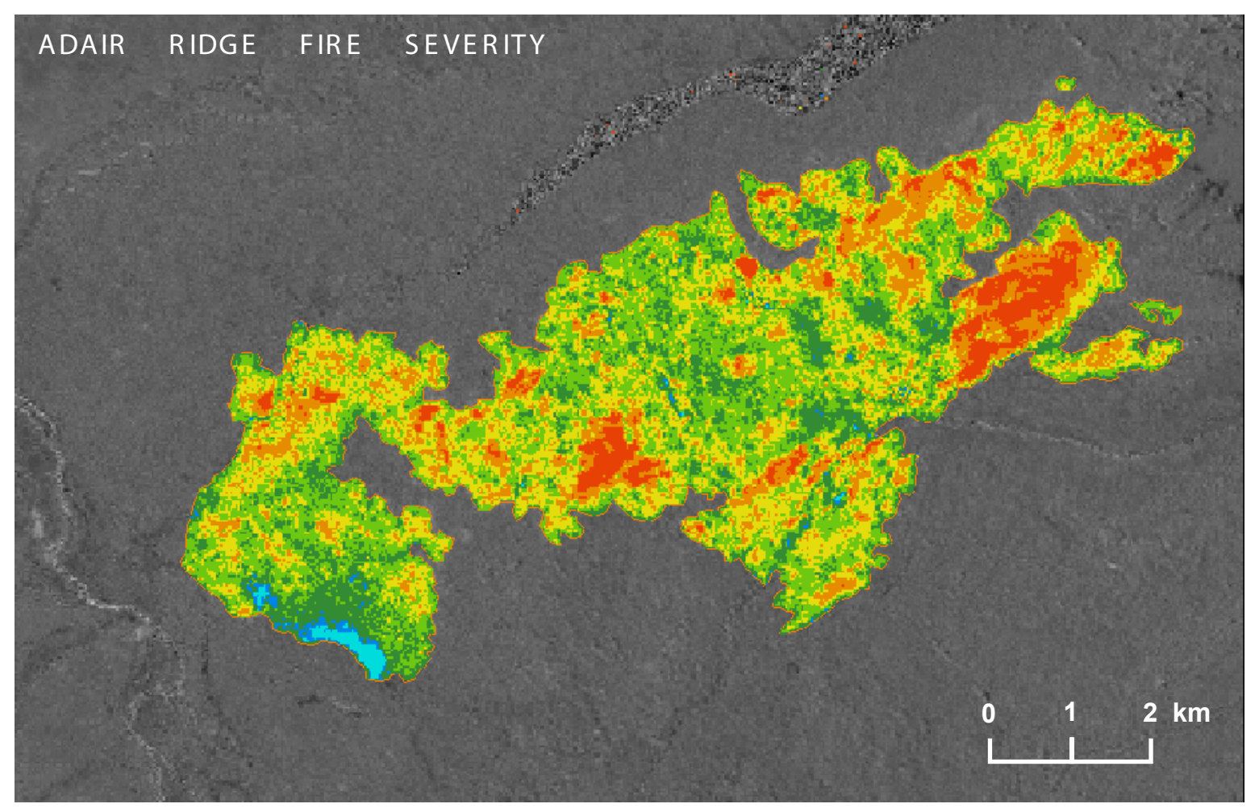




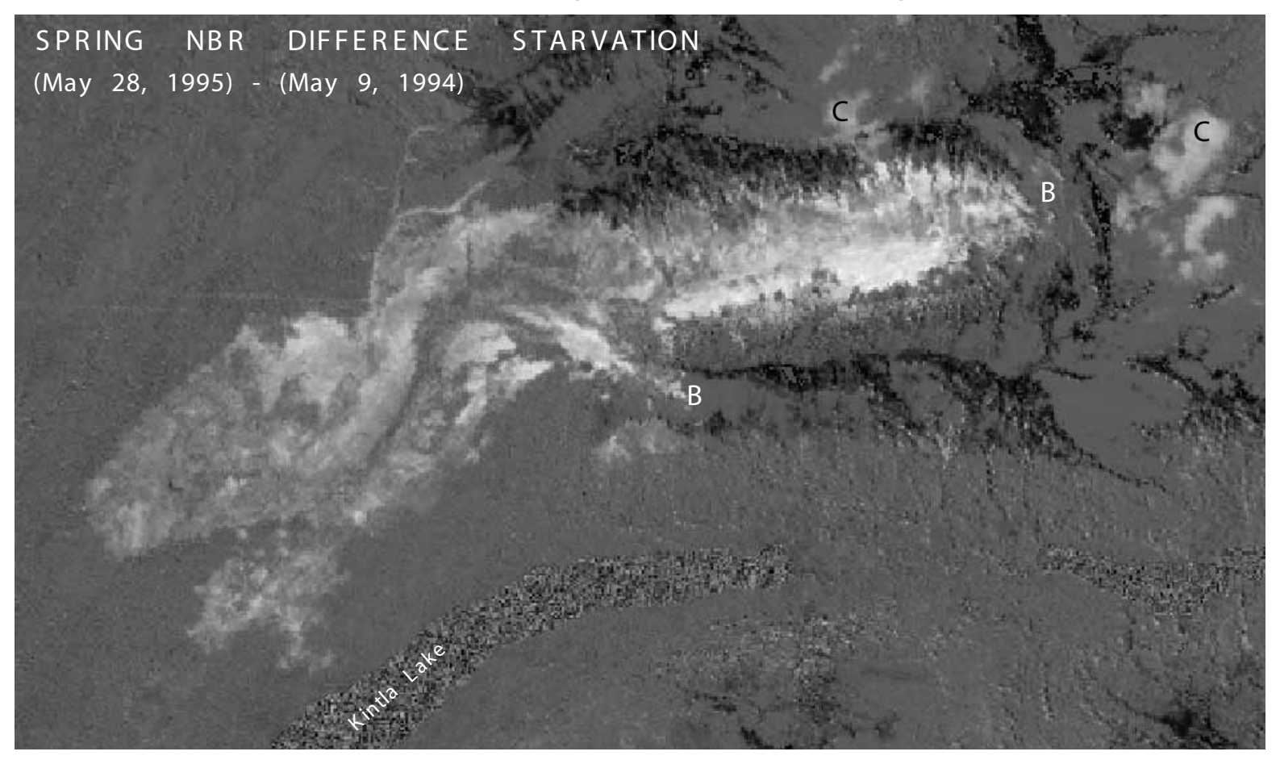
Both models, below, were used to quantify fire effects on the 1994 Glacier Park burns. Perimeters were readily interpreted and digitized "on screen" in a GIS.

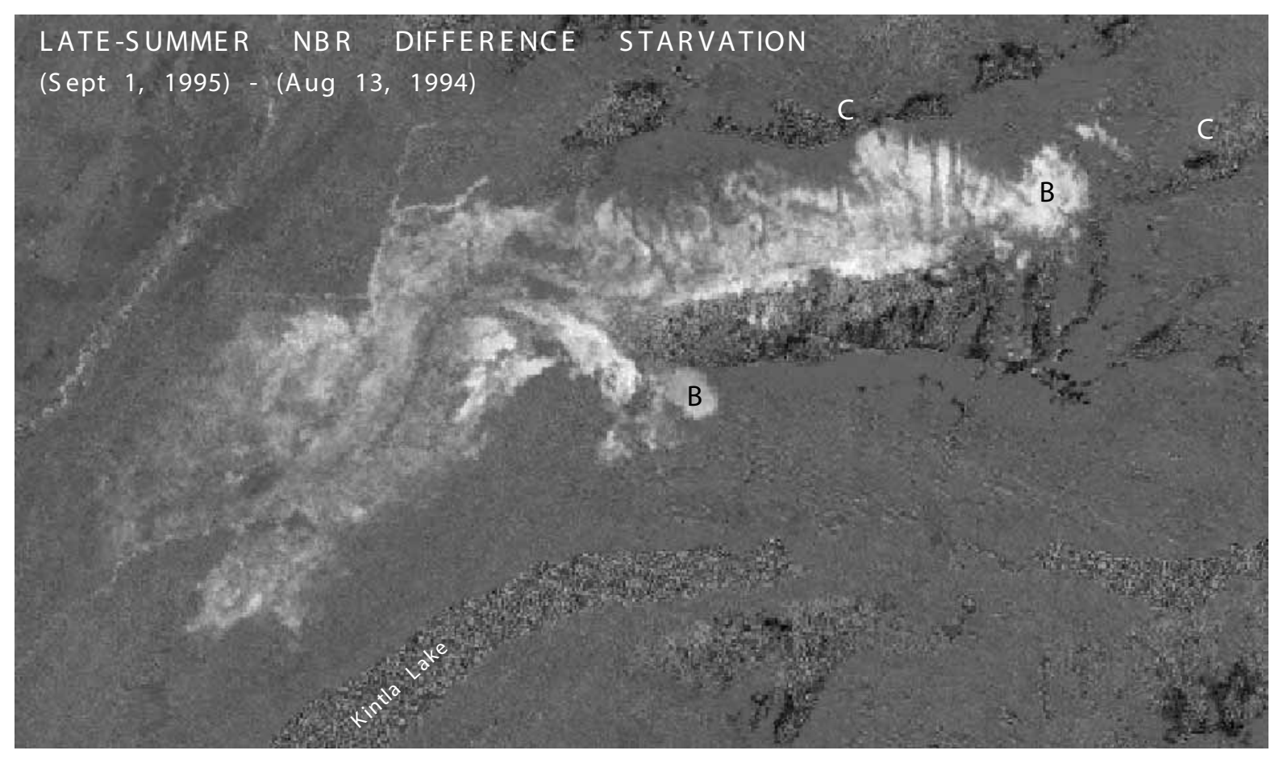


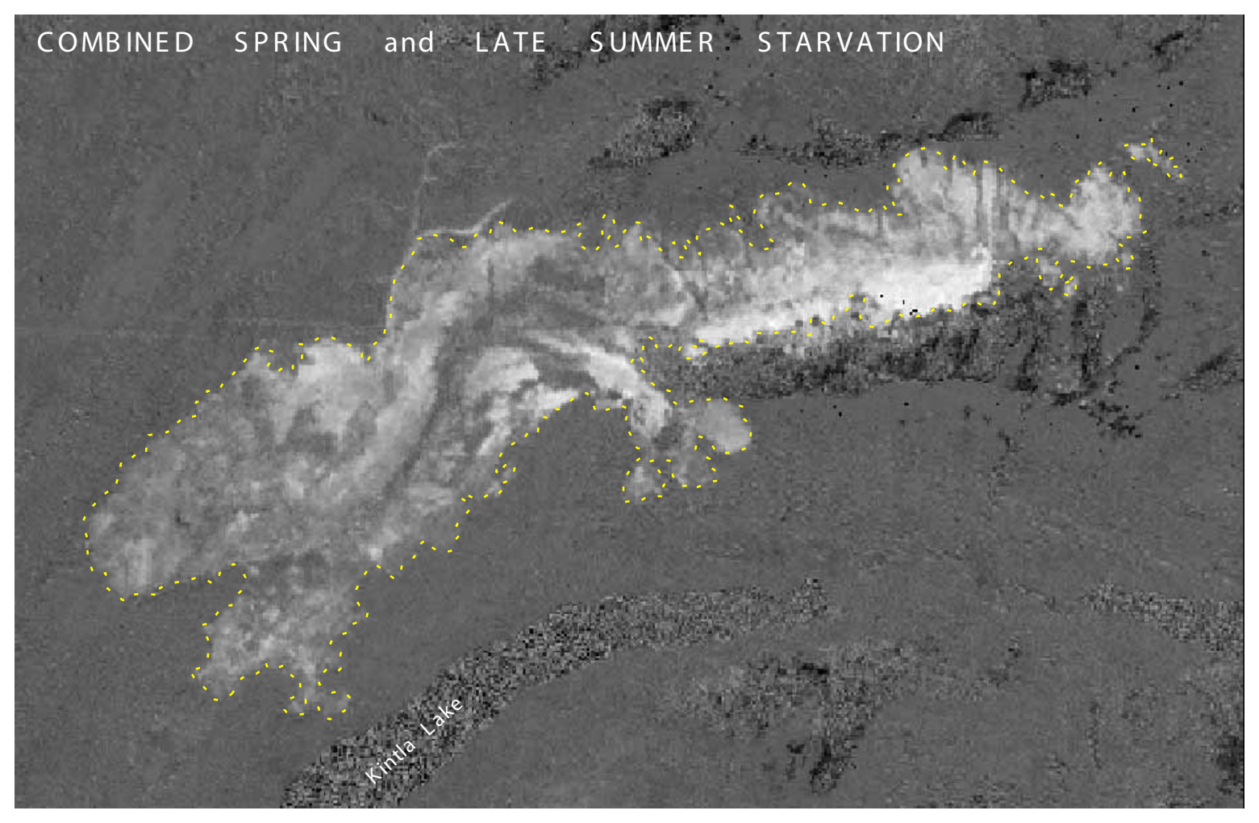
As needed, severity classes can be mapped to simplify interpretations. Such models provide useful ways to spatially assess impacts (good or bad) and target management.



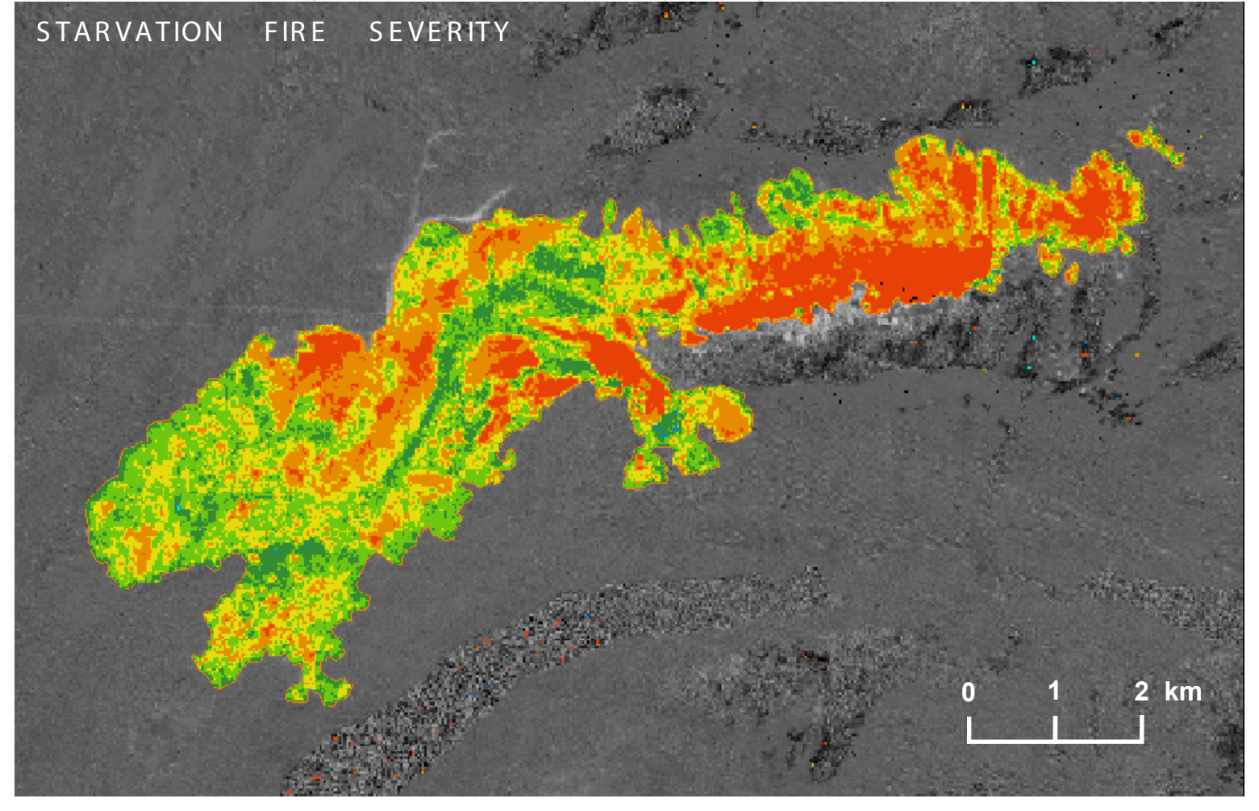
Seasonality of results is really a phenological effect. Where fires burn up into high elevation, as in the Starvation Fire, below, combined Spring and Summer data optimizes measured burn response in low and high zones, and can mitigate irrelevant effects, such as, B) areas snow covered in both spring scenes; or C) clouds in the 5/28/95 scene.







Are you interested in habitat enhancement, erosion potential, future fire breaks, weed invasion, biodiversity, how wildfires burn, or just a good place to find woodpeckers?



LEGEND for SEVERITY MAPS, left

	Severity Class	Δ NBR Value Range
🟦	Meadow A	-550 to -250
🟦	Meadow B	-251 to -120
🟩	0 Unburned	-119 to 99, and < -550
🟩	1 Low	100 to 255
🟨	2 Moderate Low	256 to 410
🟧	3 Moderate High	411 to 660
🟥	4 High	> 660