

Establishing a Nationwide Baseline of Historical Burn-Severity Data to Support Monitoring of Trends in Wildfire Effects and National Fire Policies

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Abstract

There is a need to provide agency leaders, elected officials, and the general public with summary information regarding the effects of large wildfires. Recently, the Wildland Fire Leadership Council (WFLC), which implements and coordinates National Fire Plan (NFP) and Federal Wildland Fire Management Policies adopted a strategy to monitor the effectiveness and effects of the National Fire Plan and the Healthy Forests Restoration Act. One component of this strategy is to assess the environmental impacts of large wildland fires and identify the trends of burn severity on all lands across the United States.

To that end, WFLC has sponsored a 6-year project, Monitoring Trends in Burn Severity (MTBS), which requires the U.S. Department of Agriculture, Forest Service (USDA-FS) and the U.S. Geological Survey (USGS) to map and assess the burn severity for all large current and historical fires. Using Landsat data and the differenced Normalized Burn Ratio (dNBR) algorithm, the USGS/EROS Data Center and USDA-FS/ Remote Sensing Applications Center will map burn severity of all fires occurring from 1984 to 2010. Only fires that are greater than 500 ac in the East, and 1,000 ac in the West will be included. We anticipate mapping a total of more than 9,000 historical fires and fires that occur during the course of the study.

The MTBS project will generate burn-severity data, maps, and reports, which will be available for use at local, State, and national levels to evaluate trends in burn severity and help develop and assess the effectiveness of land management decisions. Additionally, the information developed will provide a baseline from which to monitor the recovery and health of fire-affected landscapes over time. Spatial and tabular data quantifying burn severity will augment existing information used to estimate risk associated with a range of current and future resource threats. For example, fire severity data along with associated biophysical characteristics provide an analytical basis for assessing risk from invasive species as well as native insects and pathogens. All data and results will be distributed to the public via a Web interface.

Keywords: Burn severity, Landsat, monitoring, spatial, temporal, trends, wildland fire.

Introduction

Consistent geospatial information characterizing effects of large wildland fires does not exist for lands within the United States. Changing trends in fire frequency, severity, and size have resulted in the need to acquire data and develop information that can establish a baseline for trend analysis and begin to look at recent historical shifts in these fire characteristics. Furthermore, there is a need to understand the impacts of fire and resource management policies on fire occurrence and severity (Stephens and Ruth 2005). These needs are recognized across agencies and at various levels within land management organizations. Moreover, the general public is increasingly exposed to information suggesting that increases in uncharacteristic fire are due in part to past land management practices. It can be assumed that public interest in current and future fire policy will increase.

The Wildland Fire Leadership Council (WFLC), a national-level interagency body with responsibility for implementing and coordinating the National Fire Plan (NFP) and Federal Wildland Fire Management Policies (<http://www.forestsandrangelands.gov/>), has adopted a strategy to monitor the effectiveness and effects of the NFP

and the Healthy Forests Restoration Act. One component of this strategy is to assess the environmental impacts of large wildland fires and identify the trends of fire severity on all lands across the United States (WFLC 2004 Monitoring Proposal, Module 2.1). In 2004, the Government Accountability Office recommended that the Forest Service and Bureau of Land Management develop and implement comprehensive assessments of fire severity to provide consistent summary information characterizing the environmental effects of wildland fires and to meet the requirements of WFLC.

Beyond the needs of WFLC, it is widely recognized that nationally consistent and current data are necessary to address issues of ecosystem health and sustainability. The National Report on Sustainable Forests (USDA Forest Service 2004) describes criteria and indicators that are an important framework for sustainable management. Whereas the report does not specifically address the need for fire occurrence and effects data, it is easy to see both the direct and indirect relationships that exist between these criteria and indicators and the understanding of spatial pattern, magnitude, and frequency of fire in ecosystems across the United States. Specifically, the criterion addressing the maintenance of forest ecosystem health and vitality and the criterion addressing maintenance of forest contribution to global carbon cycles are sensitive to the spatial and temporal variability of fire effects and the gradient of change in forest ecosystems.

Project Background

In 2006, WFLC sponsored a 6-year project to map the fire severity and perimeters on large fires (>500 ac in the East and 1,000 ac in the West) in the United States across all ownerships for the period of 1984 through 2010. The project is referred to as the Monitoring Trends in Burn Severity (MTBS) project and is implemented jointly by the U.S. Geological Survey (USGS), National Center for Earth Resources Observation and Science (EROS), and the USDA Forest Service, Remote Sensing Applications Center (RSAC). This work is an extension of the existing cooperation between these two national centers that has provided rapid-response burn-severity mapping products to Forest

Service and Department of the Interior Burn Area Emergency Response teams.

The primary objective of this project is to provide for a national analysis of trends in fire severity for the NFP. Due to severe periodic droughts, increased fuel loads, and a higher frequency of uncharacteristic fires in recent years (since 2000), it is essential for the trend analysis to span a significant period of time to better account for variability in factors potentially affecting fire severity (e.g., climate). Secondary objectives include providing geographic and fire-specific data for use at regional and subregional scales to support resource and risk assessments, resource management planning, project planning and implementation, monitoring, and research activities. Sufficiently fine spatial and thematic resolution is necessary to support the wide range of operational and research-related information needs at larger scales.

This project will serve four primary user groups with one set of data and information:

- National policymakers such as WFLC, that require information about long-term trends in burn severity and recent burn severity within vegetation types, fuel models, condition classes, and treatment accomplishments.
- Field managers that benefit from geographic information system ready maps and data for informing and supporting prefire and postfire management decisions and monitoring.
- Project managers for existing databases such as LANDFIRE and the National Land Cover Data set that benefit from burn-severity data produced at comparable spatial scales and resolution for validation and updating of geospatial data sets.
- Academic and agency research entities interested in fire-severity data over significant geographic and temporal extents.

Burn Severity Definition

Terminology commonly used when discussing fire behavior and fire effects is often inconsistently and interchangeably applied. Inconsistent definitions associated with risk,

hazard, and severity confound our ability to characterize and communicate postfire effects and their implications to resource and cultural values (Hardy 2005). Data and information developed by this project are intended to primarily characterize fire effects in aboveground biomass. Despite significant variation in published definitions of burn severity and fire severity (Lentile and others 2006), postfire effects in aboveground biomass have been described using both terms. The term burn severity as it applies to this project is best represented by the definition for fire severity in the National Wildfire Coordination Group Glossary of Wildland Fire Terminology, stated as the “Degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time” (NWCG 2005). The following additional statements have been adopted to further clarify the nature of the products developed by this project:

- Burn severity is a composite of first and second-order fire effects on biomass.
- Occurs on a gradient or scale (ordinal).
- Occurs within a fire perimeter.
- Occurs within landcover strata.
- Longer term effects are complicated by variables that this project is not characterizing.
- Severity is mapable.
- Remote sensing provides a measurement framework.

Project Scope

The project has been divided into geographic mapping zones representing broadly similar ecological conditions. The mapping zones illustrated in Figure 1 were created from aggregations of National Land Cover Data set (NLCD) mapping zones originally derived from Bailey’s ecological sections (Homer and others 2004). The primary purpose of the mapping zones is to provide ecologically meaningful processing areas that are also efficient production units. Secondary consideration was given to significant administrative boundaries where they correlated closely with ecological unit edges. We recognize that application of the products will occur at a variety of ecological and administrative extents, and the analysis and summarization of data

for the primary sponsors may have limited utility at larger scales. However, use at larger scales is both appropriate and technically feasible owing to the spatial and thematic resolution inherent in the products. Furthermore, the spatially aggregate nature of fires and the ability to easily identify discreet events within the product sets allow for analysis ranging in extent from a single fire to multiple fires spanning space or time, or both. This is not to say that all analysis scales will be supported by these data. Indeed, as with all geospatial data, there are limits to effective application, and users will be encouraged to consider their analysis objectives and information needs relative to the spatial and thematic characteristics of the products.

Burn-severity mapping is being conducted in two time phases. Fires occurring in 2004 through 2010 are considered current and will be mapped and reported annually for the entire project extent. Historical fires occurring from 1984 through 2003 will be mapped, analyzed, and reported by mapping zone through the duration of the project. Mapping zones have been prioritized based on fire frequency, acres affected, and data availability. Figure 1 also illustrates processing schedules for historical fires by mapping zone.

The historical range of this project (1984 through 2010) was determined on the basis of availability of remotely sensed data necessary to consistently characterize the extent and severity of individual fires. A longer historical period would afford the ability to more precisely analyze environmental and policy-based influences on wildland fire that are significant over decades and centuries. Recent land and fire management activities may be the most directly relatable influences on fire effects as depicted by these products. Beyond the scope of this project, but a valuable extension, would be the use of other, historically extensive sources of remotely sensed data to extend the fire effects record generated by MTBS, albeit with compromises in consistency.

Products

Products for the MTBS project fall into three categories: unclassified (input) data, geospatial layers and maps (raster and vector), and summary analysis.

Unclassified or input data are comprised of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper



Figure 1—Monitoring Trends in Burn Severity mapping zones. Historical fires are scheduled to be mapped during the fiscal years illustrated within each zone.

(ETM) images that form the basis for measuring spectral response of individual fires. Methods used to process and classify these data will be discussed in more detail under section 2. These data have been processed by USGS EROS through the National Landsat Archive Production System (NLAPS) (Huang and others 2002) and are representative of the level and format of Landsat data typically delivered to the scientific and operational communities.

A series of geospatial layers make up the intermediate and final products characterizing postfire spectral response, burn severity, and fire perimeters. The following are the principal outputs:

- 30-m resolution Normalized Burn Ratio (NBR) calculated from Landsat (prefire and postfire);
- 30 m-resolution, continuous differenced NBR (relative and absolute).
- 30-m resolution, arithmetic partitions of dNBR.
- Vector format fire perimeter based on dNBR.
- Metadata for geospatial data.

Analysis outputs are necessarily limited in scope to achieve the primary objectives of the project. In depth trend analysis, correlations to other factors, including climate change and management practices, and implications for other resources fall outside the scope of this project. Formats and resolution of the geospatial products are designed to allow flexibility for application to a wide range of analysis objectives that pertain to burn severity. Indeed, it is expected (and desired) that these data will be used in broad- and moderate-scale research and management activities

where a consistent data record of postfire effects is valuable. Primary analysis products delivered by this project include:

- Tabular data summarizing acres burned by severity class.
- Tabular data summarizing acres burned by severity classes and vegetation cover types (where available).
- Tabular data summarizing acres burned by severity classes and presence or absence of fuel treatments (where available).

Methods

Methods selection for this project was fundamentally driven by two requirements: (1) The need to develop consistent information across all lands within the project extent, and (2) the need to develop consistent information spanning a significant historical period. Based on these requirements, remotely sensed data were considered to be the only cost-effective and spatially resolved source to consistently delineate and measure the response of thousands of individual fires across a continental extent and multidecade timeframe. A significant body of literature exists evaluating the effectiveness of various scales of remotely sensed data to characterize fire severity (Brewer and others 2005, Chuvieco and Congalton 1988, Diaz-Delgado and others 2003, Fernandez and others 1997, Justice and others 1993, Kasischke and French 1995, Key 2005, Milne 1986, Patterson and Yool 1998, Pereira 1999, Roy and Landmann 2005, Sa and others 2003, Smith and others 2005, Sunar and Ozkan 2001, Wagtendonk and others 2004, White and others 1996). Scientific and operational precedent exists for the use of a remote sensing-based approach.

The Landsat TM and ETM data provide the longest record of relatively high spatial and spectral resolution data for mapping fire severity. Not only does this enable the mapping of historical fire severity, it also facilitates the use of multitemporal approaches for characterizing postfire effects. Landsat data have been shown to be responsive to relative changes in aboveground biomass as a result of fire (Epting and others 2005, Kushla and others 1998, Lopez-Garcia and Caselles 1991, Miller and Yool 2002). More specifically, multitemporal change detection approaches

based on prefire and postfire Landsat data have proven to be a cost-effective and relatively accurate means of mapping fire severity (Brewer and others 2005). Furthermore, the availability and low cost of Landsat data were additional factors supporting their use for a project of this geographic and temporal extent.

Multitemporal approaches applying image ratios and image differencing techniques to Landsat data have been developed for a variety of assessment objectives. Imagery is commonly transformed mathematically into indices by ratioing a spectral component(s) or band with another spectral component(s) for each pixel. The transformation of Landsat data into vegetation indices (e.g., Normalized Difference Vegetation Index) to strengthen the relationship between spectral response and vegetation characteristics has been widely used, and a number of indices exist (Lyon and others 1998). Lopez-Garcia and Caselles (1991) published the first index specifically derived to enhance the relationship between Landsat spectral response and burned vegetation. This Normalized Difference index was subsequently adapted and operationally implemented by Key and Benson (2002) and was used to develop historical fire-severity data and atlases on numerous national parks. The approach has been named the Normalized Burn Ratio (NBR) and, combined with multitemporal differencing, has been utilized in fire-severity mapping efforts by the USGS and the USDA Forest Service since 2002. The NBR is calculated as $(TM4 - TM7)/(TM4 + TM7)$ where TM4 represents the near infrared spectral range and TM7 represents the short wave infrared spectral range. A differenced NBR image (dNBR) is created by subtracting the prefire NBR image from a postfire NBR image.

The dNBR data have been used operationally for both rapid response and longer term assessment and monitoring (Bobbe and others 2003, Gmellin and Brewer 2002, Key and Benson 2002). Rapid response needs require the use of immediate postfire imagery to show first order fire effects on vegetation and soils and to prioritize rehabilitation resources. Longer term assessments have relied on image data typically acquired during the growing season following the fire in order to include delayed first order effects (e.g., delayed tree mortality) and dominant second order

Table 1—Brief description of database elements contained within the Monitoring Trends in Burn Severity (MTBS) fire history database

ID	Fire name		Agency	Year	Start date
Unique MTBS ID that includes source ID	Incident name from the source database		Reporting agency from the source database	Year occurred from the source database	Incident start day/month/year from the source database
Reported acres	Long	Lat	Path	Row	Disposition
	Incident acres from the source database	Longitude	Latitude	Landsat path	Landsat row

effects that are ecologically significant (e.g., initial site response and early secondary mortality agents). Extended assessments are intended to provide a more comprehensive ecological indication of fire severity. Both initial and extended assessments have uncertainty associated with the dNBR-based fire-severity characterizations. Prefire vegetation conditions and postfire management activity influence the nature and magnitude of this uncertainty. The sensitivity of a given set of analysis objectives to the uncertainties associated with initial and extended assessment dNBR data should be considered when using these data.

Based on the scientific foundation in the literature and operational precedent, the dNBR approach was selected to characterize fire severity and delineate fire perimeters for this project. Extended assessments will be conducted on forest and shrub ecosystems, and initial assessments will be conducted on grasslands and other specific vegetation communities known to recover from fire within a single growing season. A simple production model was developed around this approach to ensure timely and consistent products. We recognize that application of a simple production model across the ecological extent and variation covered by the project may itself be a source of uncertainty. Indeed, limitations associated with this approach to characterizing postfire effects are not yet known in many ecosystems, and we expect the MTBS project to expand our understanding of how consistently and precisely Landsat data can map burn severity. The MTBS product suite is a reflection of the need for a range of data to suit specific analysis objectives.

The following steps outline the process of identifying fire locations through summarization of the results:

- Fire history database compilation
 - Data acquisition
 - Data standardization and aggregation
- Image data selection and preprocessing
 - Scene selection
 - Preprocessing
 - Delivery and archiving
- Fire-severity interpretation and perimeter delineation
 - Normalized Burn Ratio calculation and differencing
 - Interpretation and thresholding into severity classes
 - dNBR partitioning
 - dNBR fire perimeter delineation
- Stratification and summarization of severity information.

Fire History Database Compilation

Existing fire history and location databases were compiled into a single, standardized project database that formed the basis for image scene selection. Fire history sources were from two general origins—Federal agency databases and State databases. In some cases, State and Federal agencies have collaborated in developing and maintaining a single database for State and Federal incidents. Federal agency data are aggregated into the Incident Command System database known as the ICS 209 and are maintained by the

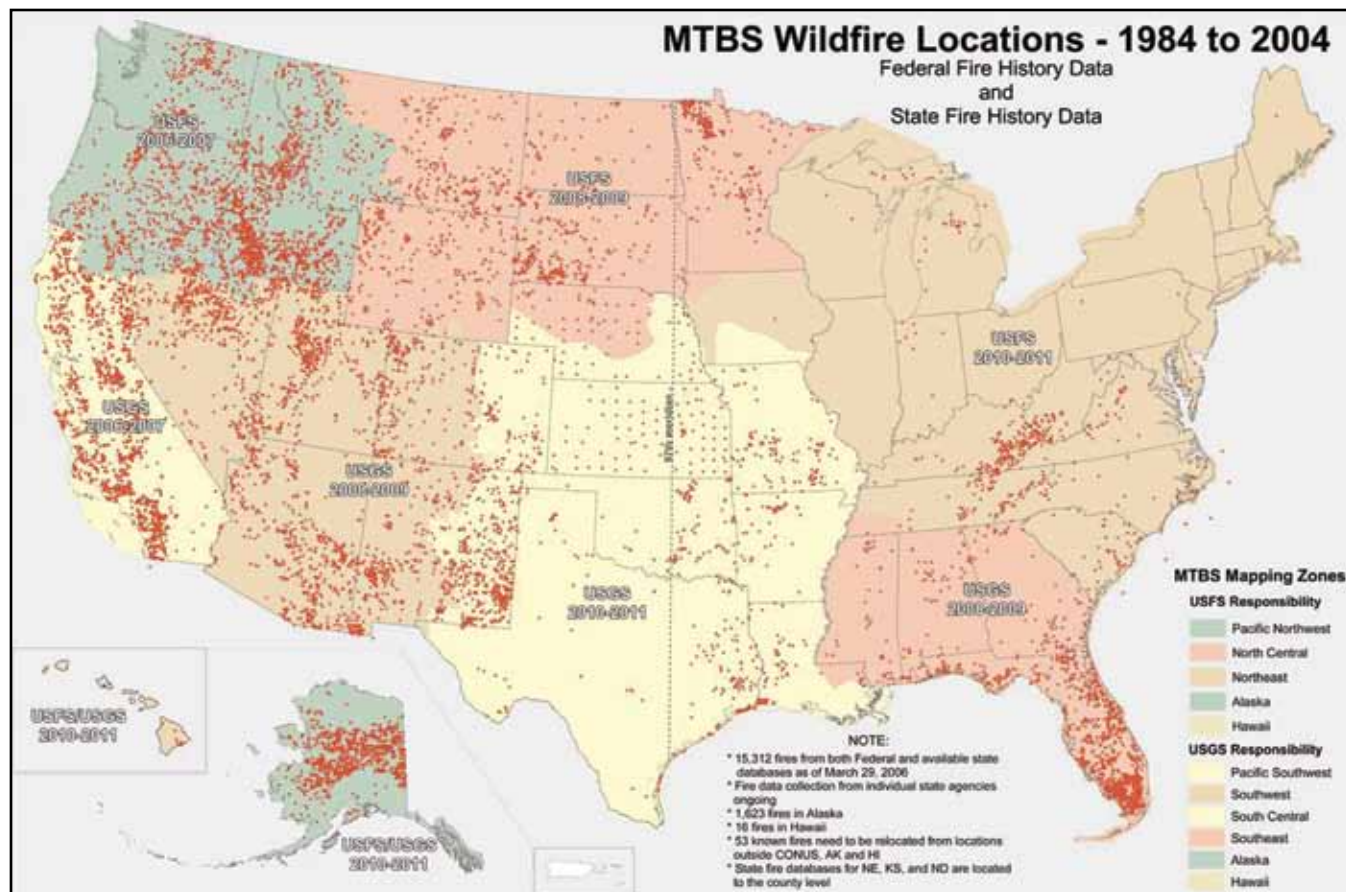


Figure 2—Wildland fire locations across the project extent. Patterns of fire frequency are clearly visible. Suspected omissions of fire occurrences as well as coarse spatial precision are also visible in portions of the project, particularly the Midwestern, Southern, and Northeastern United States. MTBS refers to “Monitoring Trends in Burn Severity.”

National Interagency Fire Center (NIFC) in Boise, Idaho (<http://www.nifc.gov/>). ICS 209 data make up the bulk records in the MTBS project database. States were solicited for State-maintained data where there was uncertainty of their inclusion in the ICS 209 data.

Whereas there is some level of standardization within ICS 209, Federal land management agencies have varying or no standards for content, geospatial accuracy, and nomenclature. Duplicate records and name changes are common because the same incidents are often reported by multiple agencies. Further standardization and correction, where possible, were performed as part of the compilation of an MTBS project database. For the purposes of this project, standardization was accomplished by selecting data elements common to the source databases and not through record editing or manipulation of the source data except

in the case of geospatial coordinates. Where a record was grossly and obviously incorrect, and a correction could be made confidently, coordinates were adjusted. Table 1 lists the elements that comprise the MTBS fire history database. Records for these elements were harvested from the ICS 209, and State data and source links were included to ensure that data could be traced to their databases of origin. Figure 2 depicts the spatial distribution and relative frequency of fire occurrences across the project extent. Likely omissions and coarse spatial precision are noticeable, particularly in the Central and Eastern portions of the conterminous United States.

Image Scene Selection and Data Preprocessing

Scene selection is driven by the MTBS fire history database. Scenes are selected using the Global Visualization Image

Selection (GLOVIS) browser developed by USGS-EROS (<http://glovis.usgs.gov/>). Enhancements were made to GLOVIS specifically to facilitate the magnitude of scene-selection effort required for this project. These enhancements, available to all GLOVIS users, include the ability to incorporate ESRI ARCGIS shape files in the viewer to aid scene selection and scene-specific Advanced Very High Resolution Radiometer greenness graphs for determining peak periods of photosynthetic activity, or peak-of-green periods. The fire history shapefile, specific to an MTBS mapping zone, is loaded into the viewer, and analysts use fire locations to guide scene selection for each fire. Prefire and postfire images are selected for each incident. Scenes selected for fires that will be processed as an extended assessment are based on peak-of-green condition or as close as cloud-free data are obtainable. Limitations in data availability due to atmospheric conditions will naturally compromise selections for fires in areas prone to summer and fall cloud and smoke obscurity. Northern latitudes will also be subject to a shorter period of optimal scene selection owing to undesirable sun angles in the fall.

Selected scenes are ordered and processed according to existing USGS-EROS protocols. Image data are geometrically (including terrain correction) and radiometrically corrected through the NLAPS process. Image data are delivered to EROS and RSAC analysts to be processed into fire-severity information. Landsat image data acquired for this project will become part of the national image archive and will be available at NLCD archive costs. Current estimates expect an increase in available archive data of more than 7,000 scenes. The existing USGS Multi-Resolution Land Characteristics image archive (<http://www.mrlc.gov/>), available through several existing Web portals (e.g., GLOVIS), will be the primary repository for these data.

Fire Severity and Perimeter Mapping

The NBR index is calculated for prefire and postfire images as described in “Methods.” Prefire and postfire images are inspected for coregistration accuracy and corrected if spatial differences are excessive and extensive (> 30 m). NBR images are differenced for each fire-scene pair to generate the dNBR. A relativized dNBR (RdNBR) is also calculated

based on the work of Miller and Thode (2007) to evaluate potential limitations of dNBR to characterize fire severity on low-biomass sites and potentially enhance interfire comparability of the results at larger scales. The RdNBR data have been shown to have stronger correlations to Composite Burn Index (CBI) plot data in some low-biomass western ecosystems (Miller and Thode 2007, Thode 2005). Figure 3 illustrates the sequence of data layers generated.

Ecological Severity Thresholding—

Processing the Landsat image data to dNBR is a straightforward series of objective calculations requiring limited analyst interaction and relying principally on automated production sequences. Subsequent to dNBR derivation, the process of developing fire severity and perimeter maps becomes much more dependent on analyst interpretation. The dNBR data are calculated as signed 16-bit with a maximum digital number (DN) range of -32,767 to +32,767. However, the practical range of DN values representing fire-related change and no change is typically within -2,000 to +2,000. Values further away from zero represent greater change as a result of both first and second-order fire effects (within the fire perimeter). Negative values indicate a positive vegetation response (growth) and positive values indicate a negative vegetation response (mortality). Figure 4 illustrates a dNBR image for the Cerro Grande Fire (2003), and Figure 5 depicts the associated data range. The analyst evaluates the dNBR data range and determines where significant thresholds exist in the data to discriminate between severity classes. Interpretations are conducted on the dNBR data aided by raw prefire and postfire imagery, plot data, and analyst experience with fire behavior and effects in a given ecological setting. The CBI data (Key and Benson 2006) have been the most commonly collected ground-based data to estimate postfire effects. Correlations between CBI and dNBR have been used to demonstrate the sensitivity of dNBR to postfire effects and to establish numerical thresholds in dNBR data that discriminate severity categories (Cocke and others 2005, Key 2005). Where CBI and similar plot data have been collected, and plot-dNBR relationships published, analysts will guide their interpretations based on these relationships. Limited extrapolation of

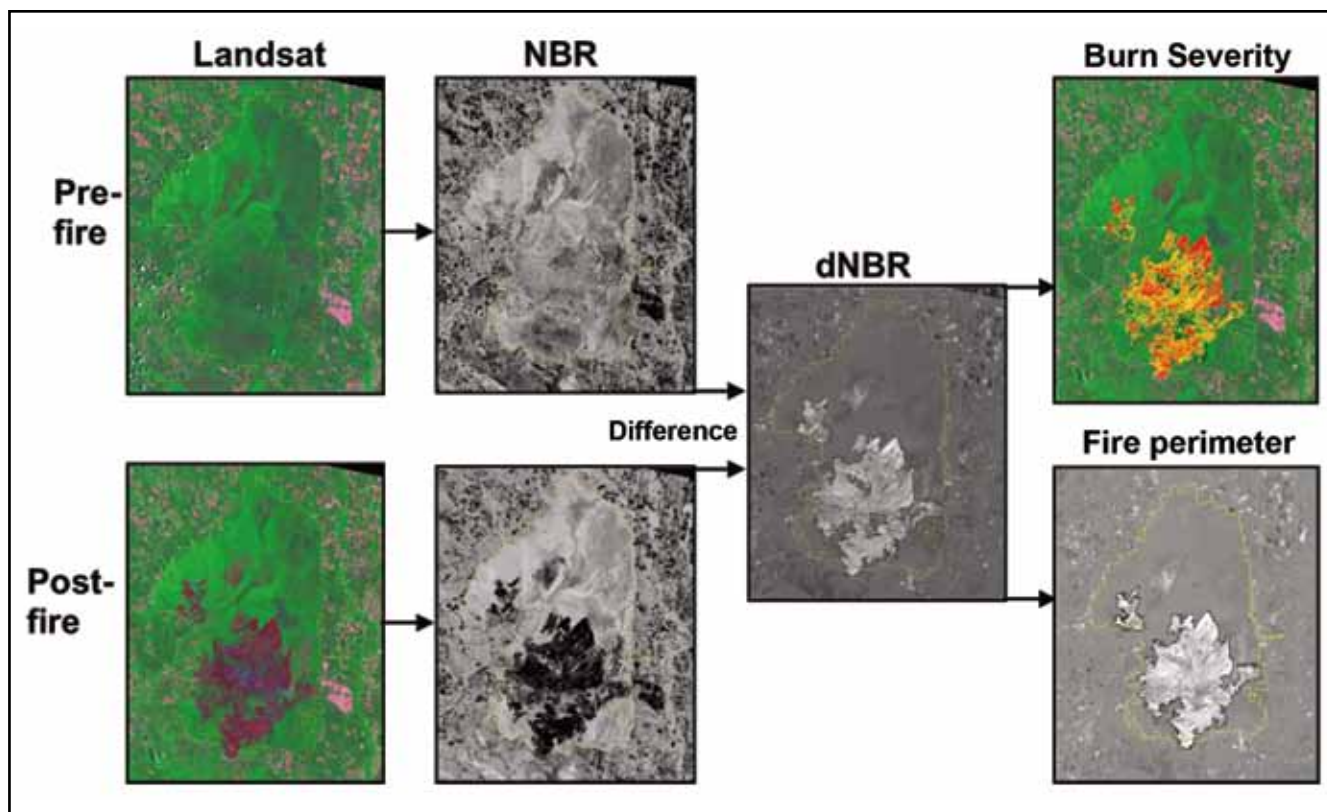


Figure 3—The sequence of layers produced between Landsat images and a fire perimeter. NBR = Normalized Burn Ratio. dNBR = differenced Normalized Burn Ratio.

plot-based thresholds beyond their geographic bounds but within ecologically similar conditions will be examined.

Thresholding dNBR data into thematic class values results in an intuitive map depicting a manageable number of ecologically significant classes (typically 4 to 7 class values). Within this project, the thematic raster data will characterize severity in five discrete classes—unburned/unchanged, low severity, moderate severity, high severity, and increased postfire response. These classes will serve as a means to easily summarize severity across broad scales and provide a coarse look at effect gradients within fires. However, there are uncertainties in this approach stemming from analyst subjectivity and limited or no plot data to guide threshold selection. Large-scale analysis may best be conducted on the continuous dNBR data, which provide the greatest range of data quantifying postfire change. Although not a direct measure of fire severity, dNBR data have been shown to correlate to field-based estimations of fire severity (Hudak 2006, Key 2005).

Ecological significance is issue dependent, and one set of thresholds cannot be expected to apply equally well to all analysis objectives and management issues. Other severity classifications such as described by Stephens and Ruth (2005) may be used as the basis for thresholding but must be considered for the appropriateness of their application to dNBR data. Fire-severity classifications that are based on fire effects not readily discernible on Landsat data (e.g., subsurface biomass combustion or soil chemistry changes) should not be applied to these data.

dNBR Partitioning—

In addition to ecological thresholds as a means of discriminating severity classes, dNBR will be arithmetically partitioned into discrete classes to facilitate objective and flexible pattern-and-trend analysis. Arithmetic partitioning is not intended to provide information on the ecological severity of fires at large spatial scales or limited temporal extents. Methods for partitioning dNBR have yet to be

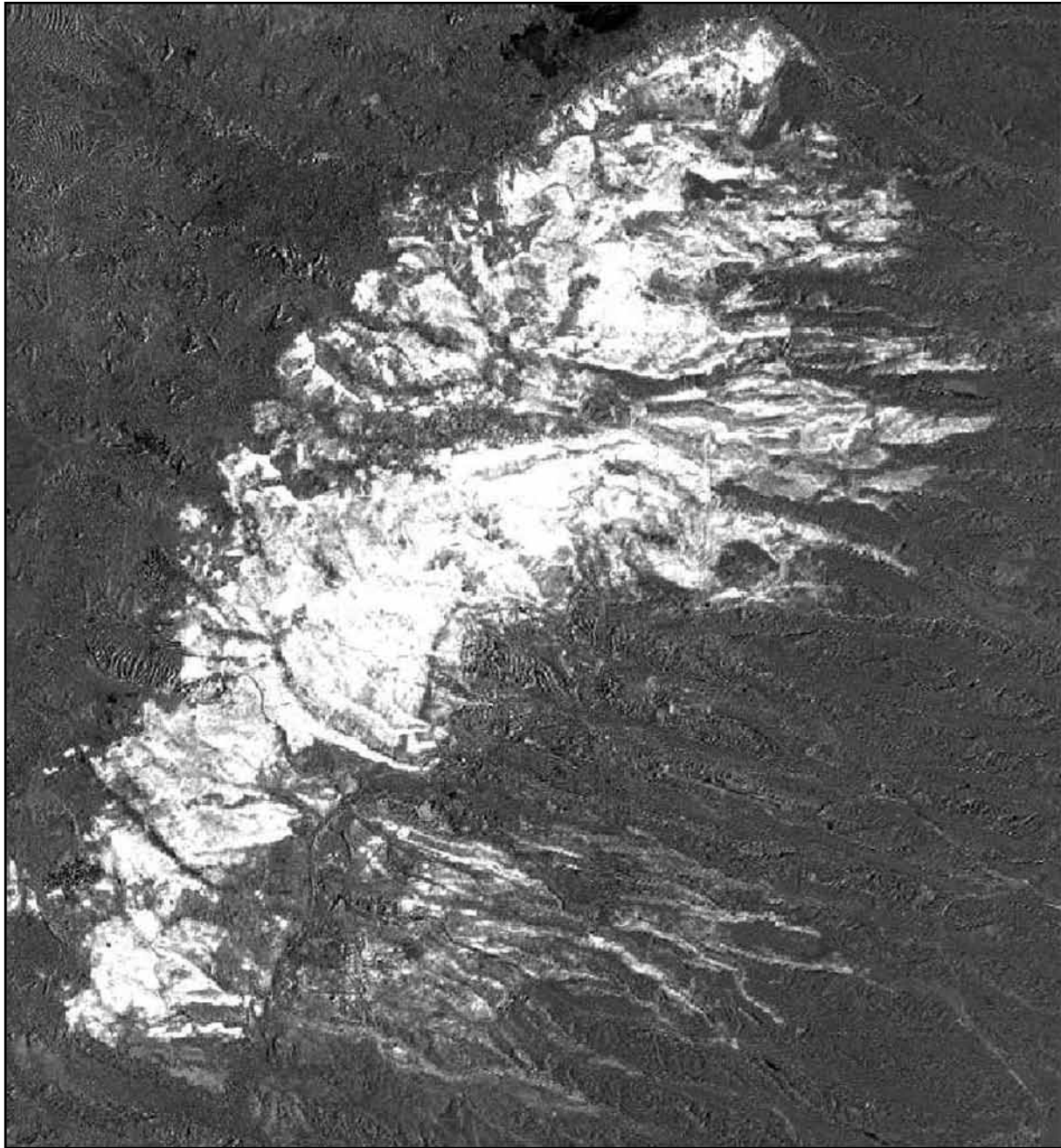


Figure 4—A dNBR image for the Cerro Grande Fire (2003) where dNBR refers to differenced Normalized Burn Ratio. Lighter areas represent higher positive values corresponding to greater degrees of change (i.e., higher fire severity).

determined, and the algorithm(s) and subsequent grain of partitioning will depend on a given technique's ability to reveal meaningful patterns in fire severity over time. Gmellin and Brewer (2002) used a simple equal-interval calculation to establish objective burn severity classes between observed unburned and high-severity conditions

in the Northern region of the Forest Service. Brewer and others (2005) used the same approach in a methods comparison study that concluded dNBR to be the most effective approach of those evaluated for mapping fire severity. The relative ease and quickness of arithmetically partitioning dNBR data will allow for rapid evaluation of meaningful

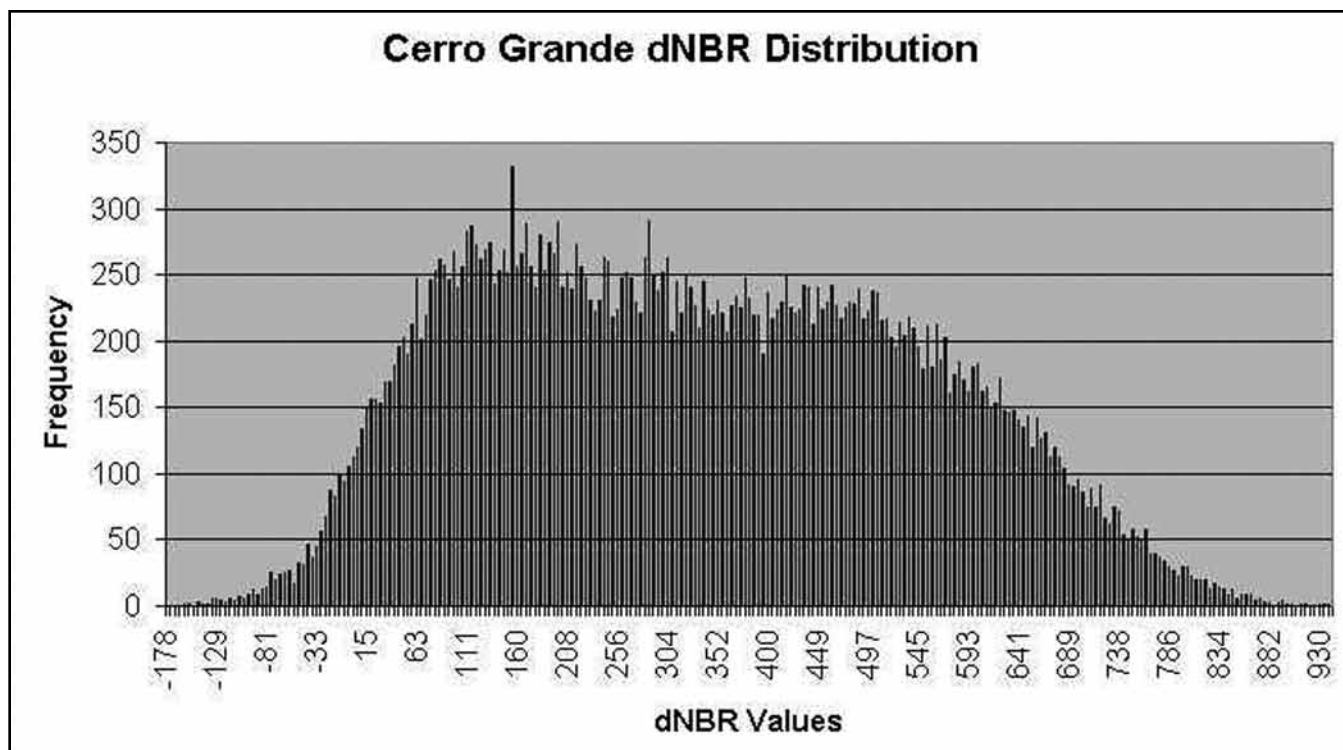


Figure 5—A graphical depiction of the dNBR data range associated with Cerro Grande Fire where dNBR refers to differenced Normalized Burn Ratio. Positive values represent a gradient of increasing fire severity whereas negative values represent increased spectral response usually associated with higher photosynthetic activity in postfire vegetation over prefire vegetation. Values near zero represent little or no change.

spatial and temporal scales in the context of fire severity trends. Moreover, dNBR data can be efficiently analyzed and classified to suit the fire severity information needs of a specific management issue.

Perimeter Delineation—

Fire perimeters will be generated by on-screen interpretation and delineation of dNBR images. Analysts will digitize perimeters around dNBR values reflecting fire-induced change. To ensure consistency and high spatial precision, digitization will be performed at on-screen display scales between 1:24,000 and 1:50,000. Incident perimeters, where available, will be used in an ancillary fashion to inform the analyst. This can be particularly useful in identifying unburned islands within a perimeter or isolated, disjunct spots outside the main perimeter. Owing to limited and variable availability, as well as inconsistent spatial precision, incident perimeters were not considered appropriate as a source for MTBS project perimeters.

Data Summarization

Tabular data will be generated from statistical summaries of the fire severity class layers. Reporting units will vary in extent depending on the needs of WFLC and other multiagency user groups but, at a minimum, summary data will be produced for each State as well as at a national extent. Three sets of tabular data are currently specified in the MTBS product suite and are listed in “Products.” Total acres burned by severity class are the most directly extractable information summary from the spatial data.

Summarizing acres burned by severity class and vegetation cover types requires consistent geospatial vegetation data of similar resolution to provide the most meaningful stratifications. Existing vegetation types currently being mapped by the LANDFIRE program (<http://www.landfire.gov/index.php>) will offer the most spatially extensive and nationally consistent data by which severity classes can be summarized. Since Landsat imagery is the spatial basis for both MTBS and LANDFIRE data, uncertainties that may

result from summarizing severity classes within vegetation cover types mapped at a significantly different spatial scale should be minimized. In conjunction with the information needs of WFLC, the accuracy of LANDFIRE data will need to be evaluated to determine the most appropriate thematic scale for reporting.

Summarizing acres burned by severity class in relation to fuel treatment activities will be dependent on the availability of spatial data depicting the location and extent of individual treatments. Currently, the National Fire Plan Operations Reporting System (NFPORS) database is the primary standardized Federal database containing such data in digital format. As described on the Web site (<http://www.nfpors.gov/>), “NFPORS is an interagency system designed to assist field personnel in managing and reporting accomplishments for work conducted under the National Fire Plan.” It is expected that non-Federal fuel treatment data will not be available, and spatial data on Federal lands will be sporadic. Tabular data generated under these criteria will only have applicability to specific administrative and geographic extents.

It is recognized that these tabular data may have limited utility at finer spatial scales and for addressing research and management information needs not considered within the scope of this project. A composite database containing additional ecological and administrative spatial units, including 4th-field hydrologic units (Seaber and others 1987) and Federal ownership, will be available to enable user-specified summarization of MTBS data at larger scales. The production and distribution of both continuous and thematic spatial data sets described in “Fire Severity and Perimeter Mapping” are considered the primary geospatial data legacy available to scientific and operational interests outside this project.

Data Distribution

All spatial and tabular data will be distributed through Web-based interfaces. Data portals developed and maintained by USGS and the USDA Forest Service will be primary access points for the data and associated reports as they are completed and become available. Access to MTBS data-distribution nodes will be through the project Web

site (<http://www.mtbs.gov>). Additional distribution nodes may be developed in partnership with other Federal and academic institutions.

A technology transfer phase of the project will be initiated subsequent to completion of the first historical data sets. The intent of this effort will not only be to educate potential users about the structure and content of the data but also to explore applications of the data at multiple scales. It is expected that independent studies that utilize MTBS data will reveal utility and limitations that will be important to guiding operational use. The technology transfer phase will make efforts to synthesize internal and external assessments of data utility and provide an efficient means to access this information. Web-based and workshop formats will be used to engage potential users.

Applications for Fire-Severity Data

Central to the missions of both the Western Wildland Environmental Threat Assessment Center and the Eastern Forest Environmental Threat Assessment Center is the early detection, identification, and assessment of multiple environmental threats such as insects, disease, invasive species, fire, loss or degradation of forests, and weather-related risks. The MTBS project will contribute to successfully accomplishing this mission by informing and supporting a variety of fire severity-related analysis applications.

It is beyond the scope of this paper for us to describe, in detail, specific examples of fire-severity data use. The few examples that follow suggest that burn severity or fire severity, or both, have been reported in a variety of research applications including surface runoff and sediment yields (Robichaud and Waldrop 1994), burned area relationships to natural reforestation (Lopez-Garcia and Caselles 1991), forest stand conversion and regeneration establishment (Blackwell and others 1992, 1995), restoration of natural fire regimes with prescribed fire programs (Brown and others 1995, Keifer and Stanzler 1995), and wildlife habitat components (Hutto 1995).

Although explicit analytical uses of the MTBS data are not provided in this paper, a general discussion on scale of application is warranted. Multiscale, integrated analysis to support planning at both strategic and tactical levels has

been presented as an effective way to accomplish management objectives within the context of ecological function (Hann and Bunnell 2001). As described in previous sections, MTBS data provide a practical basis for multiscale analysis. Barbour and others (2005) emphasized the need to look across scales in order to understand potential differences in perception of wildfire risk between planning scales and between management objectives. Using the analysis scales described by Barbour and others (2005), a simple conceptual step-down analysis demonstrates how MTBS data can generally be applied at broad, mid, and fine planning and monitoring scales.

At the broad scale, general spatial and temporal patterns of fire can be juxtaposed against generalized depictions of biophysical setting, current vegetation, and historical vegetation conditions to identify landscapes that are experiencing fire frequency and behavior outside estimated historical ranges of variability. This information may serve the purpose of streamlining resource allocation decisions at the national level and provide risk strata for larger scale analysis. Landscapes with potential for higher risk can be assessed at the midlevel for specific patterns of fire occurrence and magnitude that threaten resource and social values (e.g., sensitive species habitat, hydrologic function, rural communities, and recreational opportunities) identified in regional and forest plans. The spatial resolution of MTBS products align closely with resource data layers commonly found at the regional and forest unit levels of the Forest Service (Brewer and others 2003, Franklin and others 2000, Mellin and others 2004). The scalable nature of dNBR values also allows for severity characterizations specific to analysis needs. Management activity planning and design intended to specifically address issues identified in midscale planning efforts are based principally on fine-scale analyses. Management activities designed to mitigate potential future threats, including severe fire and insect and disease outbreaks, require precise information about landscape condition and disturbance history. At site-specific scales, MTBS data reveal important information about severity patterns within fires, which are necessary to understand current condition and to relate past management activities.

It is our belief that the geographic and temporal extents, along with the consistency of MTBS data products, will provide a rich data legacy from the project. These data will provide the analytical basis for research that would have been logistically impossible without the MTBS project. These data provide the opportunity to stratify by appropriate biophysical environment settings and generate efficient and effective sampling strategies for agents such as insects, pathogens, and invasive plant species. They also provide the basis to substitute space for time to evaluate factors such as climatic effects or site water balance characteristics on timing and duration of water yield. Whereas these data do not address all environmental threat assessment needs, they do provide high-quality, consistent data and a contextual framework for the keystone disturbance agent for many wildland ecosystems.

Conclusions

The MTBS project will develop the data and information necessary to meet the strategic analysis objectives of WFLC and other policymaking and monitoring bodies. In addition to meeting the primary objective of providing the information necessary to support an assessment of recent trends in fire severity, a valuable data legacy will be available to support a broad range of research and operational uses at multiple scales. High-resolution fire-severity data generated at the individual fire scale, yet assembled at broad geographic extents, offers the potential to support analysis ranging in scope from event-specific to continental. Future applications will explore the utility of these data to support threat assessments across a wide range of ecological systems and provide a spatial and temporal framework to better understand the immediate and longer term inter-relationships of wildland disturbance agents and risk factors in postfire settings.

Literature Cited

- Barbour, R.J.; Hemstrom, M.; Ager, A.; Hayes, J.L.**
2005. Effects of spatial scale on the perception and assessment of risk of natural disturbance in forested ecosystems: examples from northeastern Oregon. *Forest Ecology and Management*. 211: 210–225.

- Blackwell, B.; Feller, M.C.; Trowbridge, R. 1992.** Conversion of dense lodgepole pine stands in west-central British Columbia into young lodgepole pine plantations using prescribed fire: 1. Biomass consumption during burning treatments. *Canadian Journal of Forest Resources*. 22: 572–581.
- Blackwell, B.; Feller, M.C.; Trowbridge, R. 1995.** Conversion of dense lodgepole pine stands in west-central British Columbia into young lodgepole pine plantations using prescribed fire: 2. Effects of burning treatments on tree seedling establishment. *Canadian Journal of Forest Resources*. 25: 175–183.
- Bobbe, T.; Finco, M.V.; Quayle, B. [and others]. 2003.** Field measurements for the training and validation of burn severity maps from spaceborne remotely sensed imagery. Final project rep. USDI Joint Fire Science Program-2001–02. [Place of publication unknown]: [Publisher unknown]. 15 p.
- Brewer, C.K.; Barber, J.A.; Willhauck, G.; Benz, U.C. 2003.** Multisource and multiclassifier system for regional landcover mapping. In: Proceedings of the IEEE workshop on advances in techniques for analysis of remotely sensed data. Greenbelt, MD: Institute of Electrical and Electronic Engineers; Geospatial and Remote Sensing Society, NASA Goddard Flight Center. [Pages unknown].
- Brewer, C.K.; Winne, J.C.; Redmond, R.L. [and others]. 2005.** Classifying and mapping wildfire severity: a comparison of methods. *Photogrammetric Engineering and Remote Sensing*. 71(11): 1311–1320.
- Brown, J.K.; Arno, S.F.; Bradshaw, L.S.; Menakis, J.P. 1995.** Comparing the Selway-Bitterroot fire program with presettlement fires. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H., eds. Proceedings of the symposium on fire in wilderness and park management. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 48–54.
- Chuvieco, E.; Congalton, R.G. 1988.** Mapping and inventory of forest fires from digital processing of TM data. *Geocarto International*. 4: 41–53.
- Cocke, A.E.; Fule, P.Z.; Crouse, J.E. 2005.** Comparison of burns severity assessments using differenced normalized burn ratio and ground data. *International Journal of Wildland Fire*. 14: 189–198.
- Diaz-Delgado, R.; Lloret, F.; Pons, X. 2003.** Influence of fire severity on plant regeneration by means of remote sensing imagery. *International Journal of Remote Sensing*. 24(8): 1751–1763.
- Epting, J.; Verbyla, D. 2005.** Landscape-level interactions of prefire vegetation, burn severity, and postfire vegetation over a 16-year period in interior Alaska. *Canadian Journal of Forest Research*. 35(6): 1367–1377.
- Fernandez, A.; Illera, P.; Casanova, J.L. 1997.** Automatic mapping of surfaces affected by forest fires in Spain using AVHRR NDVI composite image data. *Remote Sensing of Environment*. 60: 153–162.
- Franklin, J.; Woodcock, C.E.; Warbington, R. 2000.** Multi-attribute vegetation maps of Forest Service lands in California supporting resource management decisions. *Photogrammetric Engineering and Remote Sensing*. 66(10): 1209–1217.
- Gmelin, M.; Brewer, K. 2002.** Operational change detection-based fire severity mapping using Landsat TM data. In: Greer, J., ed. Rapid delivery of remote sensing products (electronic resource): Proceedings of the 9th Forest Service remote sensing applications conference. San Diego: ASPRS: 1–8.
- Hann, W.J.; Bunnell, D.L. 2001.** Fire and land management planning and implementation across multiple scales. *International Journal of Remote Sensing*. 10: 389–403.
- Hardy, C.C. 2005.** Wildland fire hazard and risk: problems, definitions, and context. *Forest Ecology and Management*. 211(1/2): 73–82.
- Healthy Forest Restoration Act of 2003 [HFRA]. 2003;** 16 U.S.C. 6501 et seq.

- Homer, C.; Huang, C.; Yang, L. [and others]. 2004.** Development of a 2001 national landcover database for the United States. *Photogrammetric Engineering and Remote Sensing*. 70(7): 829–840.
- Hudak, A. 2006.** Sensitivity of Landsat image-derived burn severity indices to immediate postfire effects. In: 3rd International Fire Ecology and Management Congress. Athens, GA: Southern Regional Extension Forestry. [Number of pages unknown].
- Huang, C.; Zhang, Z., Yang, L. [and others]. 2002.** MRLC 2001 Image Preprocessing Procedure, USGS White Paper. 10 p. <http://www.mrlc.gov/pdf/image-processing.pdf>. [Date accessed unknown].
- Hutto, R.L. 1995.** The importance of intense crown fires to some bird species in Rocky Mountain coniferous forests. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H., tech. coords. Proceedings of symposium on fire in wilderness and park management. Gen. Tech. Rep. INT-320. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 204.
- Justice, C.O.; Malingreau, J.P.; Setzer, A.W. 1993.** Satellite remote sensing of fires: potential and limitations. In: Crutzen, P.J.; Goldammer, J.G., eds. *Fire in the environment*. New York: John Wiley: 77–88.
- Kasischke, K.S.; French, N.H.F. 1995.** Locating and estimating the aerial extent of wildfires in Alaskan boreal forests using multiple-season AVHRR NDVI composite data. *Remote Sensing of Environment*. 51: 263–275.
- Keifer, M.; Stanzler, P.M. 1995.** Fire effects monitoring in Sequoia and Kings Canyon National Parks. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H., tech. coords. Proceedings of symposium on fire in wilderness and park management. Gen. Tech. Rep. INT-320. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 215–218.
- Key, C.H. 2005.** Remote sensing sensitivity to fire severity and fire recovery. In: Riva, J.D.L.; Perez-Cabello, F.; Cuvieco, E., eds. *The 5th international workshop on remote sensing and GIS applications to forest fire management: fire effects assessment*. Spain: Universidad de Zaragoza: 29–39.
- Key, C.H.; Benson, N.C. 2002.** Measuring and remote sensing of burn severity. In: U.S. Geological Survey wildland fire workshop proceedings. Open-File Rep. 02-11. [Place of publication unknown]: USGS: 55.
- Key, C.H.; Benson, N.C. 2006.** Landscape assessment: sampling and analysis methods. Gen. Tech. Rep. RMRS-164. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: CD.
- Kushla, J.D.; Ripple, W.J.; Roy, D.P.; Landmann, T. 1998.** Assessing wildfire effects with Landsat thematic mapper data characterizing the surface heterogeneity of fire effects using multitemporal reflective wavelength data. *International Journal of Remote Sensing*. 19(13): 2493–2507.
- Lentile, L.B.; Holden, Z.A.; Smith, A.M.S. [and others]. 2006.** Remote sensing techniques to assess active fire characteristics and postfire effects. *International Journal of Remote Sensing*. 15: 319–345.
- Lopez-Garcia, M.J.; Caselles, V. 1991.** Mapping burns and natural reforestation using thematic mapper data. *Geocarto International*. 1: 31–37.
- Lyon, J.G.; Yuang, D.; Lunetta, R.S.; Elvidge, C.D. 1998.** A change detection experiment using vegetation indices. *Photogrammetric Engineering and Remote Sensing*. 64(2): 143–150.
- Mellin, T.C.; Krausmann, W.; Robbie, W. 2004.** The USDA Forest Service, Southwestern region midscale existing vegetation mapping project. In: Greer, J., ed. *Proceedings of the 10th Forest Service remote sensing applications conference*. Salt Lake City: ASPRS. [Number of pages unknown].
- Milne, A.K. 1986.** The use of remote sensing in mapping and monitoring vegetational change associated with bushfire events in Eastern Australia. *Geocarto International*. 1: 25–32.

- Miller, J.D.; Thode, A. 2007.** Quantifying burn severity in a heterogeneous landscape with a relative version of the delta normalized burn ratio (dNBR). *Remote Sensing of Environment*. 109(1): 66–80.
- Miller, J.D.; Yool, S.R. 2002.** Mapping forest postfire canopy consumption in several overstory types using multi-temporal Landsat TM and ETM data. *Remote Sensing of Environment*. 82: 481–496.
- National Fire Plan [NFP]. 2004.** <http://www.forrestsandangelands.gov>. [Place of publication unknown]: [Publisher unknown]. [Date accessed unknown].
- National Wildfire Coordinating Group [NWCG]. 2005.** Glossary of wildland fire terminology. <http://www.nwcg.gov/>. Boise, ID: National Interagency Fire Center. [Date accessed unknown].
- Patterson, M.W.; Yool, S.R. 1998.** Mapping fire-induced vegetation mortality using Landsat thematic mapper data: a comparison of linear transformation techniques. *Remote Sensing of Environment*. 65(2): 132–142.
- Pereira, J.M.C. 1999.** A comparative evaluation of NOAA/AVHRR vegetation indexes for burned surface detection and mapping. *IEEE Transactions on Geoscience and Remote Sensing*. 37: 217–226.
- Robichaud, P.R.; Waldtrop, T.A. 1994.** A comparison of surface runoff and sediment yields from low- and high- severity site preparation burns. *Water Resources Bulletin*. 30(1): 27–34.
- Roy, D.P.; Landmann, T. 2005.** Characterizing the surface heterogeneity of fire effects using multi-temporal reflectance wavelength data. *International Journal of Remote Sensing*. 26: 4197–4218.
- Sa, A.C.L.; Pereira, J.M.C.; Vasconcelos, M.J.P. [and others]. 2003.** Assessing the feasibility of subpixel burned area mapping in miombo woodlands of Northern Mozambique using MODIS imagery. *International Journal of Remote Sensing*. 24: 1783–1796.
- Seaber, P.R.; Kapinos, F.P.; Knapp, G.L. 1987.** Hydrologic unit maps. Water Supply Pap. 2294. Corvallis, OR: U.S. Geological Survey. 63 p.
- Smith, A.M.S.; Wooster, M.J.; Drake, N.A. [and others]. 2005.** Testing the potential of multispectral remote sensing for retrospectively estimating fire severity in African savanna environments. *Remote Sensing of Environment*. 97: 92–115.
- Stephens, S.L.; Ruth, L.W. 2005.** Federal forest fire policy in the United States. *Ecological Applications*. 15: 532–542.
- Sunar, F.; Ozkan, C. 2001.** Forest fire analysis with remote sensing data. *International Journal of Remote Sensing*. 22(12): 2265–2277.
- Thode, A. 2005.** Quantifying the fire regime attributes of severity and spatial complexity using field and imagery data. Davis, CA: University of California Davis. [Number of pages unknown]. Ph.D. dissertation.
- U.S. Department of Agriculture, Forest Service [USDA Forest Service] 2004.** National Rep. on Sustainable Forests-2003. FS-766. Washington, DC: U.S. Department of Agriculture, Forest Service. 139 p. <http://www.fs.fed.us/research/sustain/documents/SustainableForests.pdf>. [Date accessed unknown].
- Wagtendonk, J.W.; Root, R.R.; Key, C.H. 2004.** Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. *Remote Sensing of Environment*. 92(3): 397–408.
- Wildand Fire Leadership Council [WFLC] 2004.** Monitoring Proposal, Module 2.1. [Place of publication unknown]: [Publisher unknown]. [Number of pages unknown].
- White, J.D.; Ryan, K.C.; Key, C.C.; Running, S.W. 1996.** Remote sensing of forest fire severity and vegetation recovery. *International Journal of Wildland Fire*. 6(3): 125–136.

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