

Landscape Assessment (LA)

Sampling and Analysis Methods



Carl H. Key
Nathan C. Benson

EXECUTIVE 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 post-fire datasets to determine the extent and degree of change detected from burning (figure 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 calibrate and validate remote sensing results, to relate detected radiometric change to actual fire effects on the ground. Alternatively, plot sampling may be implemented in stand-alone field surveys for individual site assessment.

INTRODUCTION

Methods in this section are designed to provide a landscape perspective on fire effects. That is, spatial data on burn severity throughout a whole burn. They show the results of fire in context of regional biophysical characteristics, such as topography, climate, vegetation, hydrography, fuels, and soil. At this level, one can isolate burned from unburned surroundings, measure the amount burned at various levels of effect, and gauge the spatial heterogeneity of the burn (figure LA-2). Such methods provide a quantitative picture of the whole burn as if viewed from the air. They are adapted to remote sensing and GIS technologies, which in turn produce a variety of derived products such as maps, images and statistical summaries.

Documentation has been updated in Version 3 to reflect experience gained over recent field seasons. Changes were made to clarify some issues with the timing of Landsat data acquisitions and how that relates to burn severity, and also to refine severity rating-factor definitions to make ground sampling more broadly applicable across ecosystems of the U.S. To implement landscape assessment of burns, several factors must be considered; among them scale, resolution, standardization, and cost effectiveness. Methods herein furnish information covering potentially several tens of thousands of square kilometers at a time, with capability to monitor very large or inaccessible burns (figure LA-3). Small burns of a few hectares can be monitored as well, but that may not be cost effective unless those are covered in conjunction with other large burns. Cost per unit area diminishes as burn area increases over a region. Products also are useful to the manager dealing with local burn issues. Importantly, objectives are for standard approaches that can be applied uniformly over multiple concurrent burns, and that yield comparable metrics from region to region over time. This section identifies data sources and methods that can be broadly implemented on a National level for repeatable and routine assessment at an affordable cost, that is, in terms of the Federal and State land-based agencies accountable for wildland burn programs.

The Landsat satellite program has been well suited for burn area assessment. Landsat archives contain near global repeat coverage of multi-spectral data acquired since 1982 at 30-meter spatial resolution. With two operational satellites as of 2003 (Landsat 5 and Landsat 7), data acquisition is possible every eight days. Most importantly, Landsat is the only source for temporally and spatially consistent information on a continual basis nationwide. It allows one to compare both pre-fire and post-fire conditions when evaluating the magnitude of fire-caused change (figure LA-4). Moreover, resolution is efficient for broad-area coverage, in terms of computer resources and funds available to most land managers today. Such characteristics are key to methodologies presented here for whole-burn monitoring.

To be applied, Landsat data must be statistically related to particular features of interest on the ground. One must determine target characteristics that are important, and find ways to measure those that are complementary with the sensor (figure LA-5). Ground measures provide the basic way to gauge usefulness, and to understand the meaning of results. Thus to assess burned areas, a field-based sampling strategy has been developed to be compatible with the resolution and spectral characteristics of the Landsat TM/ETM+ data. Though relevant to signals relayed from satellites, field information also can be used independently, where applications on the ground call for broad-area coverage or synoptic levels of detail.

The FIREMON Landscape Assessment methods were developed along the lines of: 1) optimizing satellite-derived information; 2) matching ground-based methods to the constraints of remote sensing; and 3) standardizing procedures to meet the needs for comparable results and implementation. The following chapters cover the three interrelated elements of the approach:

Definition of burn severity. Adapted to moderate resolution, meso-scale perspectives, the definition influences how we interpret severity on the ground. It is the basis for understanding fire effects at the landscape level, encompassing perhaps many different types of communities over large areas. Definition is critical to correctly apply methods, use information appropriately, communicate results, and avoid misconceptions. To some extent, this may differ from concepts of severity based on individual trees, small-area micro-plots, or subsurface evidence of heating.

Ground measure of severity (Burn Index, BI). The protocol is designed to match field sampling with the definition of severity and the characteristics of TM/ETM+ data. The measure is called the Composite Burn Index (CBI). It also can be used for a variety of applications to estimate the general, average burn conditions of stands or communities.

Remote sensing measure of severity (Burn Remote Sensing, BR). This section shows how to process and map burn severity using Landsat TM/ETM+ data. A particular algorithm is used, called the Normalized Burn Ratio (NBR). Pre- and post-fire NBR datasets are differenced to isolate the burn from surroundings and provide a scale of change caused by fire. In most cases, the approach reliably separates burned from unburned surfaces, and optimally identifies a broad gradient of fire-effect levels within the burn.

The LA Cheat Sheets follow the BI and BR sections, and a field form is provided at the end of the BI section. Additional techniques specific to the LA methods are described in the **LA How-to** section. The **LA Glossary** follows the How-to document.

DEFINITION OF BURN SEVERITY FOR LANDSCAPE ASSESSMENT

Admittedly, there is still some discrepancy in the way researchers and managers use the term "burn severity." This section is an attempt to clarify how we intend to use it; so at least one might better understand our discussion regarding Landscape Assessment of burns. Whether or not these concepts become standard practice depends on repeated trial and acceptance, but we hope this contributes to more discussion and common understanding of the issues involved.

Some of the discrepancy arises from inconsistency in the combination of the relevant terms: *fire, burn, severity and intensity*. It is useful, therefore, to first define these for LA methods. The meanings we aim to convey are brief excerpts taken from the dictionary, followed by nuances imparted in the context of wildland fire.

FIRE (n). The phenomenon of combustion manifested in light, flame, and heat. The period of active flaming and smoldering.

BURN (n). Injury, damage or effect produced by heating. The result(s) of fire, also an area where fire has occurred in the past.

INTENSITY (n). The strength of a force, or the amount of energy expended. The level of heat produced by fire.

SEVERITY (n). The quality or state of distress inflicted by a force. The magnitude of environmental change caused by fire, or the resulting level of cost in socio-economic terms.

From these, it seems reasonable to apply the following two terms:

FIRE INTENSITY: The magnitude of heat produced by fire is an empirical measure that gauges the fire's status during combustion. This is commonly defined in reference to fire line intensity, which equals energy output per length of fire front per unit time. It may be measured

by thermocouple readings in time series, as in experimental situations; or more commonly on wildfires, in proportion to observed flame length and rate of spread. Fire intensity may be divided into two heat components: downward penetration into soil; and upward transfer to vegetation and the atmosphere. These depend on residual flame time, and are a function of fuel and weather characteristics. An analogy to fire intensity is storm intensity, which uses such parameters as wind speed and precipitation rate to describe the strength of a storm.

BURN SEVERITY: Socio-economic impacts associated with fire can be measured directly in terms such as cost of suppression, cost of rehabilitation, property loss, or human causality. For this discussion, however, we focus on the degree of environmental change caused by fire. This result of fire is the cumulative after-the-fact effect of fire on ecological communities comprising the landscape. An analogy to burn severity would be storm severity, which refers to the damage or outcome left in the wake of the storm. For example, you might say an intense storm resulted in severe consequences. The ecological criteria to judge burn severity differ, naturally, from those of storms. Here we are talking about physical and chemical changes to the soil, conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that bring about new microclimates and species assemblages. The scope includes all degrees of effect, ending with the most extreme where essentially all aboveground organisms are eliminated, and the community must regenerate from basically "ground zero".

Of the remaining two terms, "burn intensity" seems least sensible and should be avoided. "Fire severity", though, does make sense, so long as one clearly understands it references conditions left after fire. We have simply chosen to use the term "burn" with severity, mainly to reinforce the notion of an area where fire occurred some time in the past.

Discussion of Ecological Burn Severity

No common standard has emerged to measure burn severity ecologically. There may be, in fact, many valid ways to view burn severity, depending on the scale and the particular means available to measure it. On the other hand, a fundamental concept of burn severity, as we suggest here as a magnitude of change, may lead to designing measures of severity that are at least compatible over multiple scales.

How investigators choose to measure ecological burn severity is closely linked to the objectives of burn evaluation. In most cases, it is scale dependent, so definitions reflect the detail and complexity of systems described. You may be interested, for example, primarily in only one factor, such as potential for herbaceous recovery. In that sense, severity may be understood and scaled directly by a single measure such as depth of charring or scorching into soil and this measure may be well suited for evaluating small areas, but the method would be difficult to implement over large areas. There are literally thousands of individual ecological components that might be used to indicate severity. To some extent, each species potentially responds in a unique way to fire, and depending on objectives, change in abundance of just one species may be most relevant to describing severity.

In landscape ecology, however, we tend to look at burn severity holistically, such that it represents an aggregate of effects over large areas. This enables you to map and compare whole burns comprised of many communities, which occupy various topographic, climatic, and edaphic

situations. Here, severity is three dimensional, spread over multiple components and strata of the community, and across units of area that almost always display considerable heterogeneity. The severity of the site, then, is average of all that variability. Besides specific ecological consequences, like tree mortality, burn heterogeneity itself is a primary variable of interest. It reveals large-scale interactions of fire behavior with the environment (useful for fire modeling), and influences the kind and rate of recovery (useful for ecological projections). At the same time, it is advantageous for assessment of burns to retain some level of information about individual components, so you can break those out to evaluate specific conditions.

In a broad sense, the consequences of fire in a particular area are governed by short and long-term processes, so overall, the severity one recognizes is an amalgamation of factors. The most immediate effects are on the biophysical components that existed before fire on a site. Downward and upward heat transfer generated from fire intensity directly causes those effects. The amount of downed woody fuel consumed, or the biomass of living canopy that was killed are examples of this, and we refer to it as the short-term severity, or first-order fire effects (figure LA-6). Those effects, though, are dependent on sensitivities of the components where fire occurs, which are far from equal across the landscape. For instance, it is well known some species have adaptations that make them more resistant to fire than others. The implication is that the same fire intensity can produce different degrees of initial burn severity, depending on the community's pre-fire composition and structure. Thus, severity likely does not vary in parallel with intensity, especially through low-to-moderate ranges, though the two variables are obviously related. (At highest ranges of fire intensity, even fire-adapted species are likely to be severely impacted).

Beyond that, the longevity of impacts and the nature of post-fire responses are influenced by a number of locally unique conditions, including:

- The kind of seed bank species present, and whether or not they are able to mature under fire-altered microclimate and soil.
- Proximity to adaptive seed sources from unburned areas.
- Localized site properties, such as slope, aspect and soil moisture holding capacity.
- Successional pathways and the successional stage when the community burned.
- Subsequent climate, which may differ from historic climate existing when the pre-fire community became established and matured.
- Secondary ecological effects initiated by fire, like erosion and mass wasting.

These combine with initial effects on established components to shape *long-term severity* (figure LA-6), the magnitude of long-term change brought by fire. In most cases those local circumstances can be estimated, or at least inferred for an area, so it is really the spatial variation in short-term severity that must be determined. If that is known, then projections about long-term severity can be worked out. Thus, in the LA methods, we focus on first-order effects and attempt to define and map severity as it relates to the *magnitude of change to components existing at the time of fire*. To an extent, that includes near-term vegetative survivorship of the next growing season, which incorporates recovery and delayed mortality of burned vegetation as major expressions of short-term severity.

The measure of severity across landscapes, we propose, is first a combination of factor effects within strata, and then a combination of strata effects within communities or sub-regions of the burn. Such may be difficult to conceive, but if the degree of change is the focus, one can envision a numeric scale with zero (no change) being the starting point, and some positive number as the highest possible amount of change. We can apply the same scale to each stratum of the landscape, and combine those to derive an overall measure for an area. At the lowest level, factors within strata are rated independently. Then, factor values are averaged per stratum, and likewise, strata are integrated into higher levels to ultimately derive the severity of the whole community. The criteria may differ by stratum, but the scale applied to all is the same. It is the full range of change between no effect and greatest possible effect (due to fire), which forms a common denominator. The measure of severity, then, is a consistent numeric scale gauging the amount of change. It may represent a single factor, or a composite of multiple factors, depending on intent.

To successfully assess burn effects across landscapes, two methods are required; one for remote sensing and one for field validation and calibration. If comparable remote sensing data are available from before fire and after fire, magnitude of change can be determined empirically, as described in the section, **Remote Sensing Measure of Severity: The Normalized Burn Ratio**. Thus, the proposed definition of severity can fit relatively easily with available remote sensing technology, so long as guidelines on timing are followed. For field estimation, however, you must judge how much change occurred relative to pre-fire conditions for the individual rating factors and that can be difficult, given a typical lack of pre-fire data for most burns. Also, it is not ordinarily the case that significant portions of many large burns can be visited within one year after fire, and alternative information, such as aerial photography, is rarely available both from before and after fire. Consequently, you must rely heavily on expert knowledge and judgment when gathering field data.

Ways to sample for ecological severity in Landscape Assessment are presented in the section **Ground Measure of Fire Severity: The Composite Burn Index**. The breakout of strata and the rating factors for the CBI are discussed in detail in the **Field Documentation** section. Basically, they boil down to phenomena we can observe. Some pertain to the amount of organic material consumed and characteristics of residual inorganic carbon and ash, while others address short-term potential for vegetative regeneration and mortality. The amount of heating is also inferred by estimates of scorching, or changes in amount and color of exposed mineral soil. The selected factors are only a manageable subset of all the possibilities for judging severity. They were the ones that collectively seemed most recognizable and significant, while being most relevant to requirements of remote sensing and radiometric response.