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# Modeling of multi-strata forest fire severity using Landsat TM Data

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ABSTRACT

Most of fire severity studies use field measures of composite burn index (CBI) to represent forest fire severity and fit the relationships between CBI and Landsat imagery derived differenced normalized burn ratio (dNBR) to predict and map fire severity at unsampled locations. However, less attention has been paid on the multi-strata forest fire severity, which represents fire activities and ecological responses at different forest layers. In this study, using field measured fire severity across five forest strata of dominant tree, intermediate-sized tree, shrub, herb, substrate layers, and the aggregated measure of CBI as response variables, we fit statistical models with predictors of Landsat TM bands, Landsat derived NBR or dNBR, image differencing, and image ratioing data. We model multi-strata forest fire in the historical recorded largest wildfire in California, the Big Sur Basin Complex fire. We explore the potential contributions of the post-fire Landsat bands, image differencing, image ratioing to fire severity modeling and compare with the widely used NBR and dNBR. Models using combinations of post-fire Landsat bands perform much better than NBR, dNBR, image differencing, and image ratioing. We predict and map multi-strata forest fire severity across the whole Big Sur fire areas, and find that the overall measure CBI is not optimal to represent multi-strata forest fire severity.



## 1. Introduction

Landscape heterogeneity can change fire severity that often is classified into lightly burned, medium burned, and high burned patches (Hall et al., 1980; Van Wagner, 1983; Turner and Romme, 1994). Fire severity is associated with abiotic factors including weather, moisture, slope, and elevation (Romme and Knight, 1981; Christensen et al., 1989) and biotic circumstances, such as forest layers, stand structure, tree size, successional stage, pathogens, disease, mortality (Turner et al., 1999), and anthropogenic factors such as widespread logging, livestock, and urban development. On the other hand, large area fires could change landscape heterogeneity, ecosystem structure and local climate. Regional forest fire can have significant negative impacts on wildlife habitats and browsing (Romme and Knight, 1981). Forest fire often results in huge biomass and carbon loss, which may change local weather and climate. High soil burning leads to much more soil runoff and erosion compared with unburned and light burned areas (Robichaud et al., 2007). To understand the complex relationships between wildfire and forest ecosystems, we need to model multi-strata forest fire severity, which has not been explored. Compared to one overall estimate of composite burn severity (CBI), modeling and mapping of fire severity across forest strata (i.e., substrate layer, herb layer, shrub layer, intermediate-sized tree, and dominant tree) can provide deeper insight information for fire severity, interactions between fire and vegetation, and vegetation resilience analyses.

Fire severity is difficult to measure and quantify. Key and Benson (2006) indicated that "no common standard" exists. The choices of fire related variables and the rates of fire severity with quantitative or qualitative estimates are typically determined by management, ecological purposes, and field sampling designs (Ryan and Noste, 1985). If fieldwork extends from several weeks to several months, environmental factors, such as rain or wind, could affect fire severity measurements.

Fire severity analysis has been improved by using normalized burn ratio (NBR) of Landsat band 4 and band 7 in comparing to the initial method for detecting fire severity that were based on normalized difference vegetation index (NDVI), which is derived from post-fire Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) (Diaz-Delgado et al., 2003; White et al., 1996). Recently, multispectral satellite remote sensing derived suitable indices for fire severity detection were compared and explored (Norton et al., 2009; Veraverbeke et al., 2010). Landsat data are widely used to calculate a radiometric index of NBR (Key and Benson, 2006). Multi-temporal differencing was used to enhance the contrast and changes from pre- and post-fire Landsat TM or

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ETM+ bands 4 (0.75–0.90 μm) and 7 (2.09–2.35 μm), and band 4 is sensitive to the chlorophyll amount of leafy vegetation and band 7 is suitable for detecting moisture contents in both vegetation and soils. The difference between pre-fire and post-fire NBR (dNBR) is the widely used method for fire severity mapping. The dNBR is often assessed using an overall field measure of fire severity CBI. This approach rates fire severity in all the layers of a forest stand and results in an aggregated value CBI, which can be compatible with satellite imagery derived dNBR (Cocke et al., 2005).

The potential disadvantages of CBI, NBR, and dNBR are critical and were explored by Epting et al. (2005), Keeley (2009), Lentile et al. (2006), Robichaud et al. (2007), and Roy et al. (2006). For example, (1) Pearson correlation coefficients between dNBR and field CBI are 0.0253, 0.0968, 0.3794, 0.5303 and 0.5379 respectively for conifer woodlands, mixed forests, closed conifer forests, open conifer forests, and hardwood forests (Roy et al., 2006); and dNBR can be weak for modeling of large area fire severity due to heterogeneous forest landscapes. (2) There is not a common rule to group dNBR into fire severity classes, which are prone to be subjective. (3) The dNBR can be a bad predictor of ecosystem responses even when dNBR and CBI are highly correlated, since CBI is an aggregated overall measure of fire severity metrics and ecosystem responses including resprouting of different vegetation layers cannot be identified respectively. And (4) dNBR is not optimal in describing fire severity shortly after fire, because most spectral changes are almost parallel between the near-infrared and middle infrared and thus dNBR is not sensitive to fire-resulted changes (Roy et al., 2006).

Fire severity studies often use Landsat data derived NBR and dNBR, but the information provided by the original bands somehow is overlooked in fire severity detection. The comparison of fire severity detection between NBR, dNBR, the combination of Landsat bands, Landsat image differencing, and image ratioing needs to be evaluated to understand the potential contribution of Landsat data to fire severity analysis. It is important to make a comprehensive study of fire severity modeling of multi-strata forests in order to understand fire activities and vegetation responses in different forest layers, although the dNBR calculated from remote sensing data was used to represent CBI.

In this study, we disintegrated the composite burn index into fire severity matrix of five forest strata substrate soils, understory herb, understory shrub, intermediate-sized tree, and dominant tree; we designed multi-strata forest fire severity modeling in order to make comprehensive understanding of fire severity among different forest strata, identify responses of different forest strata to fire behaviors, and explore Landsat data derived different fire severity modeling and prediction across the five forest strata. In the process of fire severity modeling, we aimed to find whether Landsat data derived NBR and dNBR are superior to its bands, image differencing and ratioing for fire severity detection. We fitted the fire severity models using NBR, dNBR, combinations of Landsat TM bands, and Landsat image differencing and ratioing and then assessed the differences among these models. We mapped multi-strata forest fire severity using Landsat TM data as predictors, which provided much more fire severity information than other types of predictors of NBR, dNBR, band differencing and ratioing. This study was ended with a concise discussion and summarization of potential applications of Landsat remote sensing for fire severity modeling.

## 2. Study area

Big Sur costal ecoregion, the 90 miles (145 km) of coastline between the Carnel River and SanCarpoforo Creek, is highly marked by steep creeks and easily erodible drainages with significant changes of elevations from sea level to 1571 m (Fig. 1). Big Sur is a typical region that symbolizes the Mediterranean-type climate and

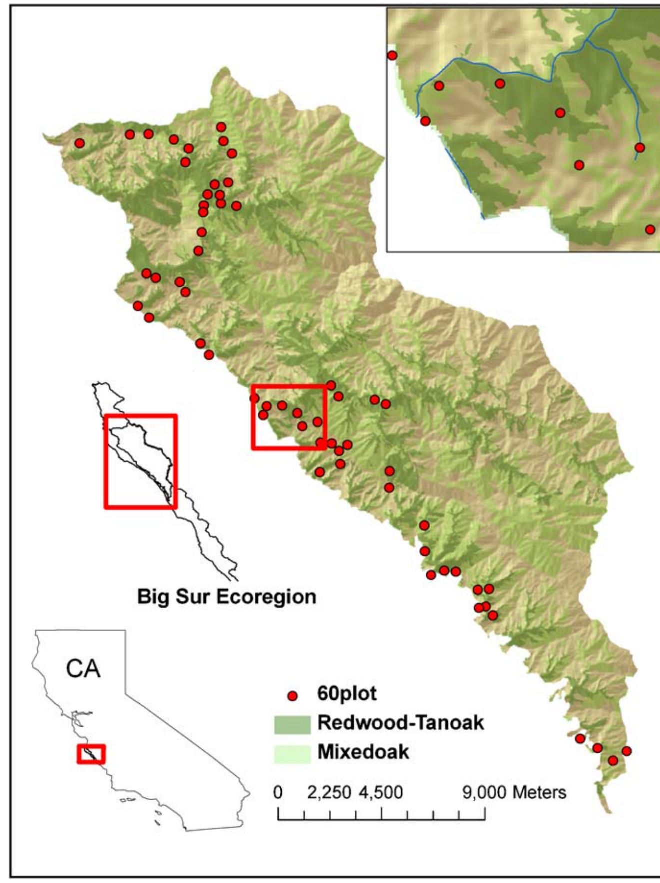


**Fig. 1.** Big Sur complex fire area, California, USA.

is characterized by warm to hot, dry summers but cool and wet winters. The recorded minimum temperature in December is −2.8 °C and the maximum temperature in June is 38 °C. The annual precipitation is often within the range between 1065 mm and 515 mm; that decreases from north to south, and more than 70% rainfalls occur from December through March. The dry and wet seasons, which are usually for describing tropics, are a significant characteristic within Big Sur ecoregion. The wet season is usually from November 1st to April 30th, and the dry season is from May 1st to October 30th. However, it is difficult to generalize more detailed climate characteristics within Big Sur, because highly heterogeneous changes in topography and landscape that causes different and separated microclimates. These complex Mediterranean-type climates provide optimal habitats for complex ecosystem and heterogeneous vegetation communities (Henson and Usner, 1996).

The Big Sur Basin Complex (BSBC) fire started on June 21, 2008 and was declared at 6:00 P.M. on July 27, 2008 (KUSP, 2008). This fire, being the historical recorded largest wildfire in California, resulted in a total burned area 95,000 ha with centroids of latitude and longitude (36.26, −121.72) (Fig. 1).

We analyzed fire severity in the two dominant forests mixed oak and redwood-tanoak forests (*Sequoia sempervirens–Lithocarpus densiflorus*), which are the primary habitats for *P. ramorum* (a type of mold) in this region (Maloney et al., 2005). Numerous oak trees died due to *Phytophthora ramorum*, which is usually called sudden oak death. Meentemeyer et al. (2008) mapped these two dominant forest types in this study region to understand the potential distribution of the sudden oak death disease. Mixed oak forests consisting of coast live oak, Shreve's oak, bay laurel (*Umbellularia californica*), and madrone (*Arbutus menziesii*) grow on moister slopes. At further lower elevations are redwood-tanoak forests, but