

Use of LiDAR and Multispectral Imagery to Determine Conifer Mortality and Burn Severity Following the Lockheed Fire

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Abstract

The effects of wildfire on tree mortality, stand structure, and regeneration are major concerns in many California ecosystems. These effects are often highly variable across the landscape and can be difficult to assess at broad scales. There are few datasets that provide a detailed description of stand conditions, both before and after wildland fire, particularly in the Coast Redwood forest type. This study provides a unique collection of pre- and post-fire remote sensing data to evaluate the effects of the 2009 Lockheed Fire, a 7,817 ac wildland fire that occurred near Santa Cruz, California. High resolution, discrete-return airborne LiDAR collected in 2008 and 2010, provide detailed metrics of horizontal and vertical structure of second-growth Coast Redwood forest impacted by fire. In addition, 1 m color infrared imagery collected in 2009 and 2010, enable “fusion” of the three-dimensional LiDAR attributes with multispectral imagery. Remotely-derived estimates of burn severity will be compared to field-based assessments of burn severity and tree mortality conducted at 83 GPS-located forest inventory plots. With these data, many parameters are available to characterize changes in vegetation condition following the fire including overhead canopy cover, vegetation height, vertical distribution of LiDAR returns, and indices of surface reflectance, such as NDVI.

Key words: burn severity, coast redwood, GIS, LiDAR, remote sensing

Introduction

Wildland fire is an important natural disturbance that initiates dramatic changes to bio-physical structure and processes across the landscape. Areas of diverse vegetation and rugged terrain can experience fire behavior that is similarly diverse. Given these conditions, characterizing different types of ecosystem responses to fire, and mapping their spatial extent can be a difficult task. In addition, the rate at which fire-adapted vegetation communities respond to fire is tremendous compared to periods without disturbance. Finally, in managed timber lands, understanding the effects of actions such as timber salvage, occurring within this period of rapid change remains a challenge. Remote sensing offers the ability to collect data over broad extents and at increasingly higher resolutions, and can supplement field observations that are often limited. This project aims to provide a rich geospatial dataset to help characterize ecosystem responses in a system affected by fire and also intensively managed. The following is a preliminary report of objectives, methods, and data collected, and provides a brief outlook on analyses that may be useful for investigating fire response in managed second-growth coast redwood forests.

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Burn severity maps for major fires throughout the nation are produced by the USDA Forest Service Remote Sensing Applications Center and the USGS Earth Resources Observation and Science. The intent of these programs is to provide broad-scale, accurate and timely map information to support post-fire hazard assessments and mitigation planning. These maps, termed Burned Area Reflectance Classification (BARC), are derived primarily from pre- and post-fire Landsat TM or ETM+ images using the Difference Normalized Burn ratio method (dNBR) (Key and Benson 2006). This approach has been validated in number of field studies and is considered appropriate given the emergency response objectives that the maps serve (Hudak 2004). Burn severity estimated through dNBR is also widely used to characterize and predict a variety of ecosystem responses to fire (Keeley 2009). For detailed assessments however, the relatively coarse 30 m resolution of Landsat-derived products produces some limitations, which are especially apparent when compared to higher-resolution satellite data (Kokaly et al. 2007). As a spectral index, dNBR and other methods do not portray vegetation structure or changes in structure resulting from fire, only the relative change in spectral reflectance. In sparsely vegetated areas, it is possible that only a small change in reflectance is observed, despite significant changes occurring on the ground (Wang and Glenn 2009), thus severity in these cases may be underestimated depending on the density or reflectance of the pre-fire vegetation. As more remote sensing platforms become available, there are new opportunities to evaluate post-fire changes, beyond current operational methods. However, appropriate data analysis methods, and validation with field-measured ecological responses must also be developed.

Airborne Light Detection and Ranging (LiDAR) is a method of remote sensing capable of providing highly detailed measurements of ground surface topography and above-ground vegetation characteristics. Use of LiDAR for measuring tree height, canopy closure, stand density and other characteristics has received widespread attention for resource management applications (Hudak et al. 2009). The prospect of using LiDAR to evaluate post-fire conditions in forestland settings has been acknowledged as promising (Lentile et al. 2006), though this application has only recently been explored (Angelo et al. 2010, Wing et al. 2010, Wulder et al. 2009). Information derived from pre- and post-fire LiDAR flights provides the opportunity to evaluate burn severity, not only in terms of spectral response, but now with respect to changes in the horizontal and vertical structure of the burned vegetation (Wang and Glen 2009). The limited extent of current LiDAR availability, the relatively high cost of new acquisitions, and the unpredictable nature of when and where wildland fires occur, do limit opportunities for widespread use of such pre- and post-fire analysis. However, as larger regional LiDAR datasets are acquired the likelihood increases that “pre-disturbance” data will exist for future analyses.

While research specific to pre- and post-fire analysis is relatively new, use of LiDAR for characterizing forest structural attributes has grown tremendously in the past decade (Hudak et al. 2009). Generally, LiDAR-derived metrics of forest attributes are compared to field measurements at either the plot scale, or by identifying individual trees. When evaluated at the plot scale, LiDAR point data are typically aggregated into fairly large pixels (20 m), and a host of statistical metrics are computed to describe the vertical distribution of points within each pixel (Falkowski et al. 2009). Such statistics include the maximum, average, standard deviation, or any percentile of point heights, percentage of canopy returns versus ground returns, percentage of first returns, percentage of returns within a given height

bin, and so on. Calculation of these parameters can be facilitated through the Fusion software developed and made available by the US Forest Service Remote Sensing Application Center (McGaughey 2010). LiDAR-derived metrics of stand structure can then be related to traditional field-based measurements through either stepwise multiple linear regression, or the non-parametric Regression Tree approach (Falkowski et al. 2009). Once a suitable model is developed, plot-level structural parameters can be predicted from the LiDAR data for all remaining pixels, forest wide.

This general approach has been used to characterize stand successional class (Falkowski et al 2009), estimate basal area and trees per acre (Hudak et al. 2008), and to estimate canopy height, canopy base height, canopy fuel weight, and bulk density (Andersen et al. 2005). Examples of LiDAR analysis in stands of second-growth redwood are limited, but in one study Gonzales et al. (2010) used field-measured heights in plots dominated by second-growth coast redwood to validate plot-level LiDAR-derived height with suitable results ($r = 0.94$, $p < 0.0001$).

Approach

The purpose of this study is to evaluate the use of plot-level metrics derived from pre- and post-fire LiDAR and multispectral imagery to detect fire effects and mortality in second-growth coast redwood forest stands impacted by the 2009 Lockheed Fire. Forest inventory data collected at permanent, fixed-radius plots within the burn area have been updated with post-fire mortality information to characterize stand conditions following the fire. Vegetation characteristics derived from the vertical distribution of LiDAR points, and from color infrared imagery will be extracted at inventory plot positions. Relationships between field-based and remotely-derived parameters will be used to characterize post-fire conditions throughout the broader forest.

Study area

The study area is located approximately 22 km north of Santa Cruz, California at Swanton Pacific Ranch, a 1295 ha educational and field research facility managed by California Polytechnic State University, San Luis Obispo. Topography is rugged with elevations ranging from 2 m to 466 m and ground surface slopes ranging from 0 percent to over 100 percent. Approximately 512 ha of the property are forested, primarily by second-growth coast redwood, with associated species characteristic of the redwood series vegetation (Sawyer and Keeley-Wolf 1995). In August 2009 the Lockheed fire burned over 460 ha of Swanton Pacific Ranch, affecting approximately 340 ha of the forested area. Within the redwood forest type, burn severity was predominantly low to moderate, with some instances of high severity crown fire near the ridgetops.

Field data collection

Personnel and students at Swanton Pacific Ranch conduct forest inventory using a Continuous Forest Inventory (CFI) network comprised of permanent, 0.49 ha (1/5 acre) fixed-radius plots located on a 152 m (500 ft) systematic grid (Piirto et al. these proceedings). Diameter and species are recorded for all trees greater than 2.54 cm DBH, while tree height, height to crown base, and crown class are recorded for all

conifers. A total of 83 CFI plots were located within the burn perimeter of the Lockheed Fire (*fig. 1*). Thirty-five of these plots were inventoried last in 2008 with the remaining 48 inventoried in 2003.

Following the Lockheed Fire, a major effort was undertaken to re-establish CFI plots damaged from the fire. Plot center monuments lost or destroyed were re-established based on distance and bearing information from three witness trees spaced throughout the plot. In December 2009, a post-fire mortality assessment was conducted to update the existing forest inventory with tree status indicating “living”, “dead”, “removed”, or “missing”. Components of the field mortality assessment are discussed by Auten and Hamey (these proceedings). The procedure was repeated in August 2010 for a first-year mortality assessment (*fig. 2*), and again May 2011. In each case, plot inventory was updated to reflect new mortality and to identify trees harvested in salvage operations. State Plane coordinates for all plots were recorded using a Garmin 60CSx GPS unit, logging points with a 30 second average. This plot-level inventory data can be used to summarize different fire effects such as overall mortality, mortality by species, by diameter class and so on. Plot-level summaries will be related to remotely-derived metrics at these plots for the purpose of estimating fire-related changes throughout the forest.

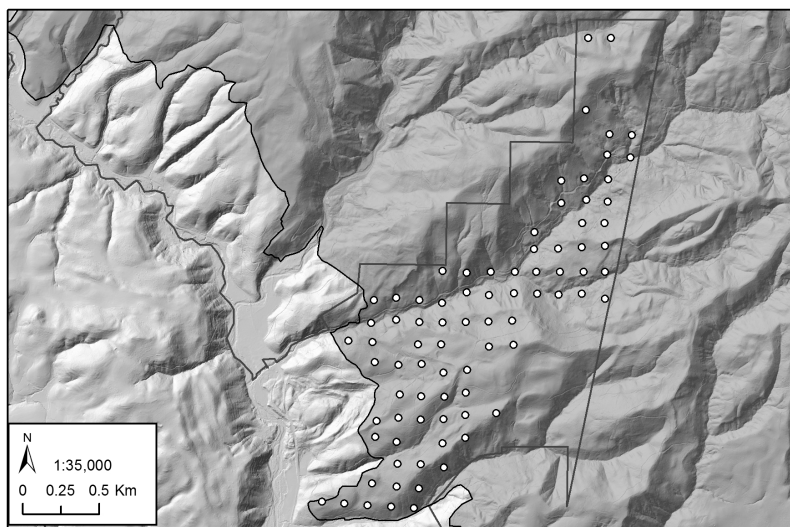


Figure 3—Eighty three continuous forest inventory plots located within the Lockheed Fire perimeter on Swanton Pacific Ranch, Davenport, CA.

LiDAR datasets

A total of four airborne LiDAR flights have been conducted over the study area from 2008 to present. This represents one of the richest datasets in the southern Coast Range, and may be unique for characterizing coast redwood response to fire. Of these, two were initially planned for use at the start of this study. The original, now “pre-fire” dataset was collected in February 2008 during leaf off conditions by Airborne 1, El Segundo, California. The LiDAR sensor used was an Optech ALTM 3100 sensor operating at 100 kHz pulse repetition frequency. The 2008 LiDAR flight and sensor parameters used (White et al. 2010) were:

LiDAR Survey Parameters

Altitude (m AGL)	850
Beam divergence (mrad)	0.23
Scan angle ($^{\circ}$)	14
Scan width (m)	425
Swath overlap (%)	50
Pulse rate (kHz)	100
Sampling density (pulses/m ²)	6

Following the fire, a second flight was contracted and flown by Airborne 1 with the goal of achieving the best possible bare-earth DEM given the reductions in overhead canopy and near-ground vegetation after the fire. This flight took place in March 2010 with similar flight parameters, but used an updated sensor, the Optech ALTM Orion operated at 150 kHz pulse repetition frequency. Two additional flights have taken place over the study area. The next flight to take place was a region-wide collection coordinated by the Association of Monterey Bay Governments (AMBAG) covering a 1700 square mile area including Santa Cruz County, and portions of Monterey and San Benito Counties. This flight was flown during leaf-on conditions in August 2010 with flight and sensor parameters designed to meet the USGS base LiDAR specifications for projects funded under the 2009 ARRA.

Finally, the most recent flight was coordinated by researchers at UC Santa Cruz and conducted by the National Center for Airborne Laser Mapping (NCALM). This flight took place in leaf-off conditions in February 2011 covering the Scotts Creek watershed. Together, these datasets present valuable opportunities by improving the temporal resolution of post-fire change analyses. This can be particularly important for understanding the sequence of natural and anthropogenic changes following the fire.

Image datasets

To complement the rich structural information provided by LiDAR datasets, natural color and near-infrared imagery was also collected over the study area in July 2010, approximately 1 year following the fire. This imagery provides additional high resolution (0.5 m) spectral information of overstory crown condition, which can be used to characterize fire effects. Three consecutive years of infrared imagery are planned to document changes in vegetation condition over an intermediate timeframe. Work is presently underway to orthorectify the first- and second-year imagery using the LiDAR-derived Digital Surface Model. Together these data will provide coincident information of tree crown reflectance and vertical structure.

Preliminary analysis

The following example may illustrate how the data available in this study can be used to investigate different types of ecosystem responses. For example, the loss of the understory strata in the uneven-aged structured coast redwood forest type may be difficult to assess using airborne imagery alone, especially where the overstory remains intact (*fig. 2*).



Figure 2—Understory coast redwood before fire in 2008 (left), and after fire (2009).

Characterizing the vertical distribution of LiDAR returns before and after the fire may enable such distinctions to be made. For an initial evaluation, a 5 m resolution grid measuring percent canopy cover was derived from the 2008 and 2010 LiDAR. Canopy cover was calculated as defined by McGaughey (2010) as the ratio of LiDAR returns falling above a given height (in this case 1 m), divided by the total number of returns for each pixel. The difference in 2008 and 2010 canopy cover layers (*fig. 3*) indicates areas experiencing drastic reductions in cover (dark regions), whereas other areas, predominantly the near stream channels, experienced little to no measured reduction in cover. Further vertical stratification of LiDAR returns within the canopy may be useful for identifying changes to specific understory strata.

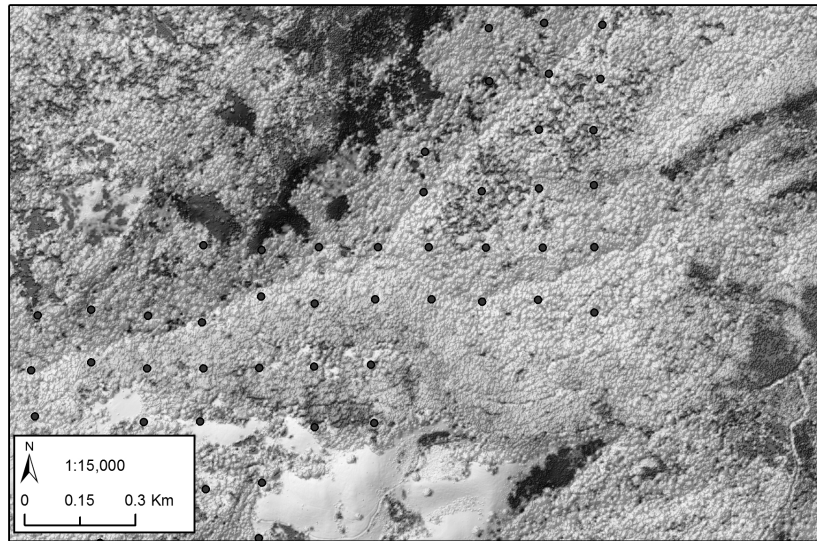


Figure 3—Difference in percent canopy cover: Mar 2010 - Feb 2008. Darker shading represents reductions in canopy cover.

Separate types of analysis are possible with this dataset, and the choice of analysis method can highlight different changes across the study area. In a second example, the Digital Surface Models (1 m resolution grids of highest-hit elevations) from three datasets Feb 2008, March 2010 and August 2010 were differenced to identify trees removed over the intervening time periods (*fig. 4*). This map provides an estimate of overstory trees removed a) following the fire, b) during initial salvage operations, and finally c) combined over the time period from 2008 to 2010.

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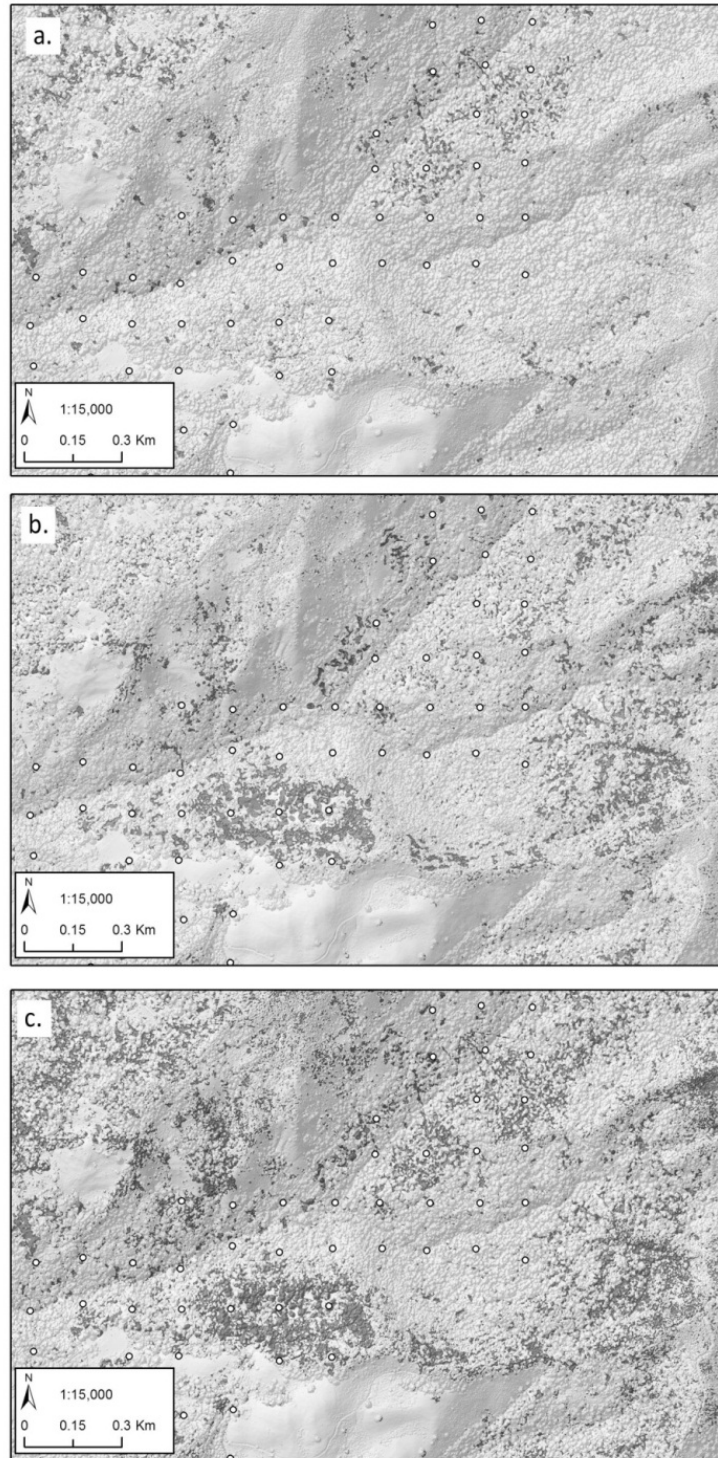


Figure 4—Difference in DSM: a) Before and after fire, Feb 2008 to March 2010, b) Before and after salvage operations, Feb 2010 to August 2010, c) Cumulative change, Feb 2008 to August 2010. Shaded regions indicate a negative height change greater than 3 m.

Conclusion

While preliminary in nature, this effort documents the field-based and remote sensing data collected at Swanton Pacific Ranch following the Lockheed Fire. Field-based forest inventory at permanent plots provide a basis for evaluating changes in stand characteristics over time. Relating field-measured stand characteristics to remotely-derived metrics from LiDAR and multispectral imagery can expand the spatial extent of forest measurement and provide a continuous map of forest attributes. Utilizing high resolution remote sensing products both before and after disturbance can further enhance our understanding of how forest attributes respond to disturbance. This preliminary exploration of the data suggest many potential modes of data analysis, useful for addressing different ecological responses following fire, however, these methods must be further developed and ultimately validated by field measurement. As remote sensing data are collected at higher spatial and temporal resolutions opportunities exist to supplement traditional forest inventory approaches, particularly useful for areas of heterogeneous forest conditions and areas responding to both natural and anthropogenic disturbances.

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