

# Initial Results From a Field Experiment to Support the Assessment of Fuel Treatment Effectiveness in Reducing Wildfire Intensity and Spread Rate

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## Introduction

Hazardous fuel reduction treatments conducted both through prescribed fire and mechanical means are a critical part of the mitigation of wildland fire risk in the United States. The US Federal Government has spent an average of \$500 million each year on fuel reduction, from 2002-2012 (Gorte 2011). At present, however, rigorous experimental measurement of the effectiveness of such efforts, as they impact wildfire intensity and spread rate, has been limited. The project presented here is aimed at addressing this knowledge gap by taking a combined experimental and numerical modeling approach to quantifying fuel treatment effectiveness in the New Jersey Pine Barrens. In particular, this project deals with prescribed fire as a fuel treatment, and it involves the observation and measurement of fire spread rate, fuel consumption, and environmental conditions during two experimental prescribed fires. Given measurements of the pre-fire fuel characteristics and the environmental conditions, a detailed description of the measured fire behavior can be used to evaluate the link between the fire characteristics and the achieved fuel reduction. Such information can also be extrapolated to understand how a subsequent fire might be affected by pre-fire fuel loading.

The project objective is to then to use results of the experimental investigations to drive the use of a detailed physical Computational Fluid Dynamics (CFD) fire behavior model—The Wildland-urban interface Fire Dynamics Simulator (WFDS). The model will first be used to simulate the experimental fires. Comparison of model outputs (such as spread rate, fuel consumption, local velocities, etc.) with experimental data will provide valuable information with respect to the current capabilities of the model.

Results will help pinpoint current limitations, such as physical assumptions, and guide future development. As the model is improved with such tests, it can be used to provide expanded information on different levels of fuel treatment and different environmental conditions. Combined, these experimental and numerical evaluations will aid in the understanding of fuel treatment effectiveness.

As the project is ongoing, the current focus is only on an initial description of the fire behavior in the first experimental fire. A variety of different measurements were made during this experiment, but this report focuses specifically on the range of surface fire intensities observed. A brief discussion on wind and canopy fuel consumption is provided.

## Study Site

The experimental fire was conducted in the Pinelands National Reserve (PNR) of New Jersey, United States. The PNR spans approximately 445,000 ha, and is host to an active fuels management program by the New Jersey Forest Fire Service (NJFFS) and federal wildland fire managers. Prescribed fires are employed by the NJFFS with the explicit intent of reducing fuel loads and thus mitigating fire risk. These managers, for the most part, currently rely on professional judgment when planning the temporal intervals and geographic position of these fires. The climate is classified as cool temperate, with mean monthly temperatures of 0 °C in January and 24 °C in July, and a mean annual precipitation of 1159 mm. The terrain consists of plains, low-angle slopes, and wetlands, with a maximum elevation of 62.5 m. A burn block covering an area of 16.6 acres was used for the experiment. The forest canopy in the block was comprised primarily of pitch pine (*Pinus rigida* Mill.), with intermittent oaks (*Quercus* spp.). The understory contained a mixed shrub layer of huckleberry (*Gaylussacia* spp.), blueberry (*Vaccinium* spp.), and scrub oaks (*Quercus* spp.).

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## Methods

The experimental fire was conducted on March 5th, 2013. Ignition was carried out with a drip torch along the northwest road, moving from northeast to southwest over a roughly 8 minute period. Due to safety concerns caused by rapid fire growth, a secondary ignition line was subsequently formed along the southwest road.

Point measurements of wind were made using 4 overstory towers, with one was positioned outside of the burn block to monitor ambient conditions (figure 1). At the top of each overstory tower (12.5 m) a 3D sonic anemometer was used to obtain velocity and turbulence measurements. 12 understory towers were also placed throughout the burn block (figure 1). While measurements from these towers are not discussed here, they serve as reference points for the locations of destructive fuel sampling and serve to facilitate discussion of local fire behavior. In addition to point measurements, sequential aerial IR images of the fire were recorded using Rochester Institute of Technology's Wildfire Airborne Sensor Program (WASP) (McKeown and others 2011). Images were time-stamped and georeferenced.

Field measurements of surface fuel loading were obtained by destructive sampling of the forest floor and shrub layer in 1 m<sup>2</sup> clipped plots. Thirty six of these measurements were made (three surrounding each understory tower at a roughly 14 m radius) both pre- and post-fire, to give an indication of surface fuel consumption. Measurements from the litter layer (O<sub>l</sub> horizon) on the forest floor were divided into categories of fine fuel (such as pine needles), reproductive material (such as pine cones), 1-hr wood, 10-hr wood,

and 100-hr wood. Measurements from the shrub and oak layer fuels were divided into categories of foliage (though deciduous species were leafless during the dormant-season burn), 1-hr wood, and 10-hr wood. Remote measurements of both pre- and post-fire canopy fuel loading were conducted using an airborne Light Detection and Ranging (LiDAR) technique. These data will allow the generation of a 1 m x 1 m resolution canopy height profile (Skowronski and others 2011), as well as 3D canopy bulk density (CBD) at a resolution of 10 m x 10 m x 1 m. CBD will be calibrated to profiles from an upward-sensing LiDAR unit in twelve 20 x 20 meter plots within the burn area. This unit was previously calibrated to represent profiles of CBD using equations developed through destructive harvest by Clark and others (2013). This calibration is currently ongoing, and the relative reduction in canopy fuel loading is only discussed qualitatively.

To characterize the type of fire observed, it was useful to estimate the quantity known as fireline intensity ( $I$ ), which indicates the energy release rate per unit length of fire front (Byram 1959). Fireline intensity is often calculated as  $I = H \cdot \Delta m \cdot R$ , where  $R$  is the rate of spread [ $\text{m} \cdot \text{s}^{-1}$ ],  $\Delta m$  is the mass of fuel consumed [ $\text{kg}$ ], and  $H$  is the heat yield of the fuel. In this study,  $H$  is taken as  $18700 \text{ kJ} \cdot \text{kg}^{-1}$  (Alexander 1982). Currently, only the physical measurements of surface fuel consumption are used. Thus, the quantity will be referred to as surface fireline intensity ( $I_{\text{surf}}$ ). Only fine fuel (primarily needle litter), 1-hr forest floor wood, and 1-hr oak and shrub layer material was used to calculate surface fireline intensity. Not only do these smaller fuels tend to be the dominant contributors, but due to the inability to collocate pre- and post-fire destructive fuel samples, consumption estimates for the larger, sparsely distributed fuel elements were considered less reliable. Spread rates were determined from the IR imagery.

## Results

IR images captured by the WASP allowed the tracing of fire contours and the mapping of fire progression (figure 2). Only seven of the sixteen available contours (P2-P8) are shown, as these represent the fire behavior of interest for this study. The primary fire front, originating from the northwest road, spread as a head fire in a southeasterly direction. It did not completely merge with the secondary (backing) fire front until sometime between fire contour P5 and P6. In a number of locations in figure 2, there appears to be a sharp dip, or discontinuity, in the fire contours. In a number of locations, this was due to a narrow track which ran along the center of the block (visible in figure 1). Vegetation in this track consisted of only a thin and scattered litter layer, causing an interruption in fire spread.

Using the fire contours to obtain spread rate, surface fireline intensity was estimated at the Understory 10, 5, and 11 towers (table 1). These sites only represent an initial investigation, but were situated in a region of headfire which was not influenced by the backfire. It can be seen that mean surface fire line intensities ranged between  $500\text{-}6000 \text{ kW} \cdot \text{m}^{-1}$ ,

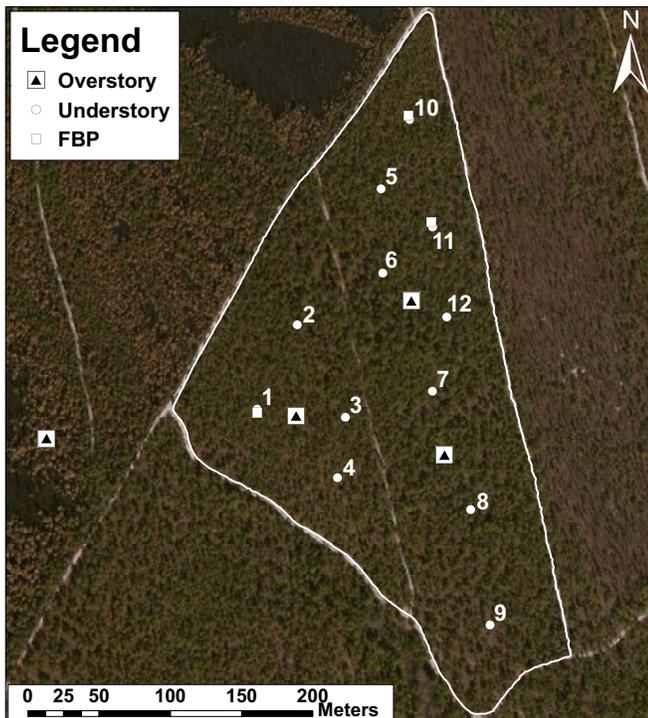
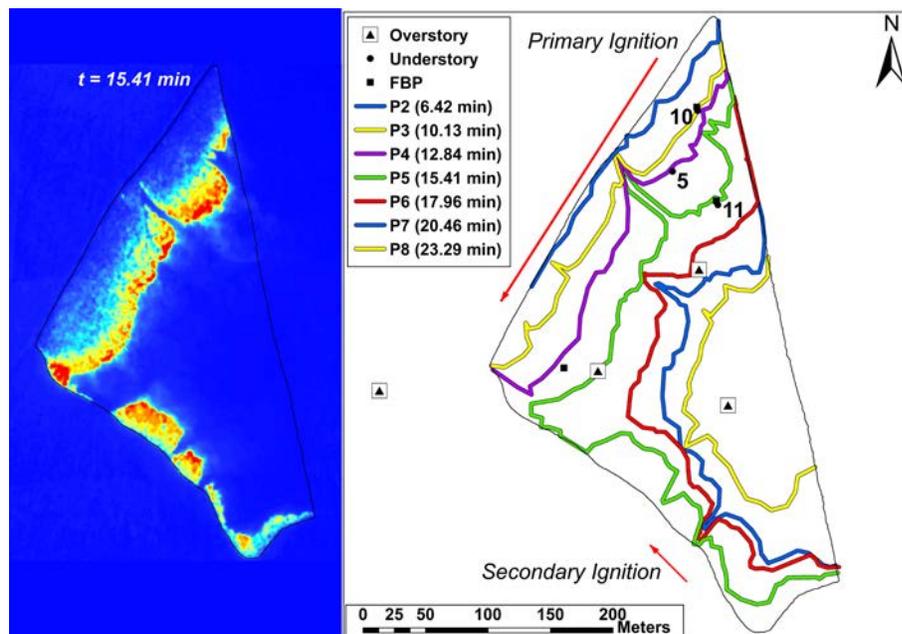


Figure 1—Layout of instrumentation in the study site with understory tower numbers labeled.



**Figure 2**—(Left) Example IR image from the WASP. (Right) Progression of the fire front, extracted from IR imagery. The fire progressed from West to East, with consecutive fire contours labeled P2-P8. The time of each contour is given in minutes after the start of ignition. Only the understory tower locations discussed are shown.

**Table 1**—Summary of  $\Delta m$  ( $\pm$  maximum relative difference in the 3 samples),  $R$  ( $\pm$  relative standard deviation), and  $I_{surf}$ . Values of  $I_{surf}$  are rounded to the nearest  $100 \text{ kW}\cdot\text{m}^{-1}$  and variation is estimated using the propagation of errors.

Location	$\Delta m$ [ $\text{kg}\cdot\text{m}^{-2}$ ] $\pm$ %	Contours	$R$ [ $\text{m}\cdot\text{s}^{-1}$ ] $\pm$ %	$I_{surf}$ [ $\text{kW}\cdot\text{m}^{-1}$ ] $\pm$ %
Understory 10	$0.73 \pm 41$	P2-P3	$0.095 \pm 7$	$1300 \pm 42$
		P2-P4	$0.074 \pm 10$	$1000 \pm 42$
		P2-P5	$0.073 \pm 9$	$1000 \pm 42$
		P3-P4	$0.039 \pm 36$	$500 \pm 55$
		P3-P5	$0.055 \pm 28$	$700 \pm 50$
		P4-P5	$0.074 \pm 49$	$1000 \pm 64$
Understory 5	$0.90 \pm 9$	P3-P4	$0.088 \pm 28$	$1500 \pm 29$
		P3-P5	$0.164 \pm 7$	$2800 \pm 11$
		P4-P5	$0.245 \pm 9$	$4100 \pm 13$
Understory 11	$1.32 \pm 8$	P4-P5	$0.245 \pm 9$	$6000 \pm 12$
		P4-P6	$0.222 \pm 3$	$5500 \pm 9$
		P5-P6	$0.191 \pm 7$	$4700 \pm 11$

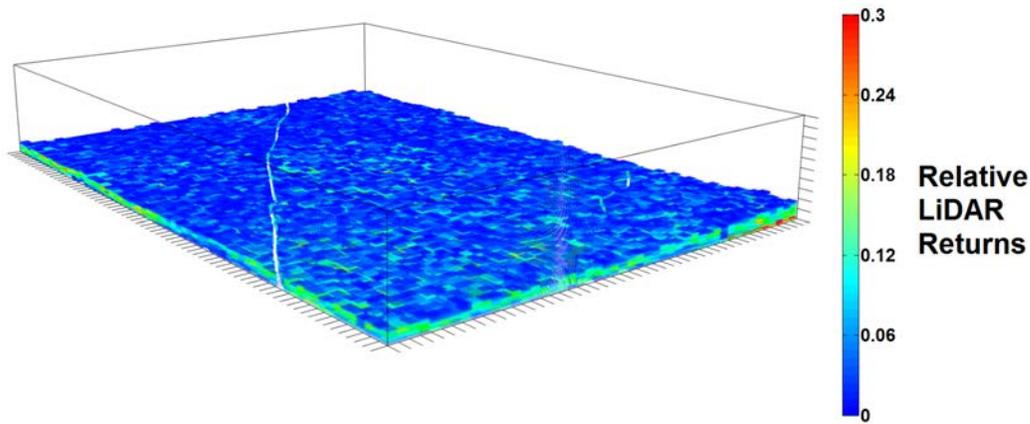
with the lowest values being near the Understory 10 tower, and the highest near the Understory 11 tower, resulting from variations in mass consumption and spread rate.

Of particular note in the area studied is a period of slow spread between P3 and P4 followed by an acceleration between P4 and P5 (figure 2). Ambient horizontal winds, measured at the top (12.5 m) of the exterior control tower to the west, averaged  $1.8 \text{ m}\cdot\text{s}^{-1}$  during the fire and tended to be consistent with the direction of spread. However, the ambient wind shifted by about  $60^\circ$  away from the dominant direction during the period of diminished spread. During the subsequent acceleration, winds again aligned with the fire spread, and a peak magnitude of  $6.4 \text{ m}\cdot\text{s}^{-1}$  was observed—the largest measured during the fire. Though it appears that wind played a role in this modification of fire behavior, a detailed investigation of the pre-fire ladder and canopy fuel arrangement from the LiDAR will be an important aspect of future work. With a linked analysis, these two variables will

give significant insight into the observed fire behavior. A preliminary examination of canopy fuel consumption did reveal that this acceleration corresponded to a transition from a predominantly surface fire to canopy fuel involvement.

## Discussion and Future Work

This first investigation helps to quantify the type of fire which was observed. Surface fireline intensities can be compared to other fires, such as those summarized by Morandini and Silvani (2010). While spread rates were within a similar range of those determined here, the upper range of reported shrubland fire intensities was eight times greater. Winds in these studies had similar or slightly higher magnitudes, though the measurements discussed from this experiment were made above the canopy, and the drag of the canopy vegetation will cause lower values at the level of the shrubs.



**Figure 3**—Example of relative canopy densities in the burn block from LiDAR data, input into the WFDS model. Colors represent the relative raw LiDAR returns along height, which will subsequently be calibrated to model the 3-dimensional CBD. View is towards the northeast, with the primary ignition road visible on the left. Axis tick mark divisions are 10 m.

Beyond the influence of wind, the high surface fireline intensities presented by Morandini and Silvani (2010) can be linked to the fuel loads. The open shrub layers of these studies tended to be denser than the shrub layer of the forested PNR environment. However, canopy fuel involvement presents a whole other challenge for fuel management which is not present in shrublands.

A continued study of the wind and fuel arrangement will aid in identifying scenarios where transition to tree crowns is a risk, and post-fire fuel loading will indicate the degree to which this fire reduced dangerous fuel configurations. In an effort to build on this information, work has begun to simulate this fire in WFDS. The model will be tested against the experimental conclusions, and will also allow the simulation of a wide variety of different environmental and fuel conditions. The first challenge lies in the adaptation of LiDAR data into model inputs, as the model requires a high spatial resolution. Potential methods include directly sampling the data at a higher resolution, using an interpolation technique to smooth the data over the high resolution cells, or using an object-oriented processing approach which would attempt to

identify individual trees, or groups of trees, and estimating fuels from the LiDAR for each individual. An example of the first is given in figure 3. As the project progresses, the combination of the two experiments and the modeling will result in a clearer picture of the impact of these prescribed fires and how they can be optimized for the purposes of hazardous fuel reduction.

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