Assessing Changes in Canopy Fuels and Potential Fire Behavior Following Ponderosa Pine Restoration

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In 1995, the Ecological Restoration Institute (ERI) at Northern Arizona University, the U.S. Department of the Interior Bureau of Land Management (BLM), and the Arizona Game & Fish Department (AZGFD) began a collaborative effort to implement landscape-scale restoration treatments in a ponderosa pine ecosystem at Mt. Trumbull, located in northwestern Arizona. The primary goal of the project was to restore forest structure and ecosystem processes within the historical ranges of variability (Moore and others 1999) with an adaptive management approach. Other project objectives included reducing fuel loads, disrupting fuel continuity, and reducing the likelihood of stand-replacing crown fires by implementing mechanical thinning followed by prescribed fire (Moore and others 2003, Roccaforte and others 2008). The project also aimed at providing research opportunities in a southwestern ponderosa pine ecosystem.

We initiated a study to examine canopy fuels and potential fire behavior during three time periods: 1870 (prefire-exclusion), 1996/97 (pre-treatment), and 2003 (post-treatment). Our goals were to:

- Compare three common canopy fuel estimation approaches;
- Compare the output from two fire behavior models; and
- Use the comparisons to assess the effectiveness of landscape-scale restoration treatments on reducing crown fire hazard.

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The reduction in canopy fuels is visually evident in the treated area, where surface fuels, once dominated by forest floor and coarse woody debris, now consist of an abundant herbaceous understory.

Using tree-ring analysis, we reconstructed a prefire-exclusion stand structure for the year 1870. In 1996 and 1997, we installed permanent monitoring plots and collected pre-treatment forest structure data for estimating canopy fuel load (CFL) and canopy bulk density (CBD) across the ~3,000 acre study area (fig. 1). Approximately half of the study area, a contiguous, densely-treed area, was left untreated and used as a control. By 2003, most of the other half had received restoration treatments—thinned and/or burned with prescribed surface fire (Roccaforte and others [in press]). We collected post-treatment data for each plot in the summer of 2003. Stand structure data were used to derive CFL and CBD in the study area for all three time periods. Those estimates were then fed into two fire models to compare historic fire behavior with potential fire behavior on the control site and the site that received restoration treatments.

Estimating Canopy Fuels

Canopy fuels are critical inputs for models that predict crown fire (Scott and Reinhardt 2002) but they are rarely measured directly. There are various methods for estimating CFL and CBD, and the resulting estimates can vary widely. Many methods rely on allometric equations that estimate the mass of foliage and fine twigs based on tree diameter. We examined three common techniques that are based on the following equations:

- Fulé and others' (2001) allometric equations for foliage and fine twigs of ponderosa pine developed in Arizona,
- Brown's (1978) allometric equations for foliage and fine twigs of ponderosa pine developed in the northern Rocky Mountains, and
- Cruz and others' (2003) stand-scale equations based on tree density and basal area.

Changes in Canopy Fuels

For all of the time-treatment combinations, Brown's (1978) equations always produced the highest value for average CFL, the Fulé and oth-

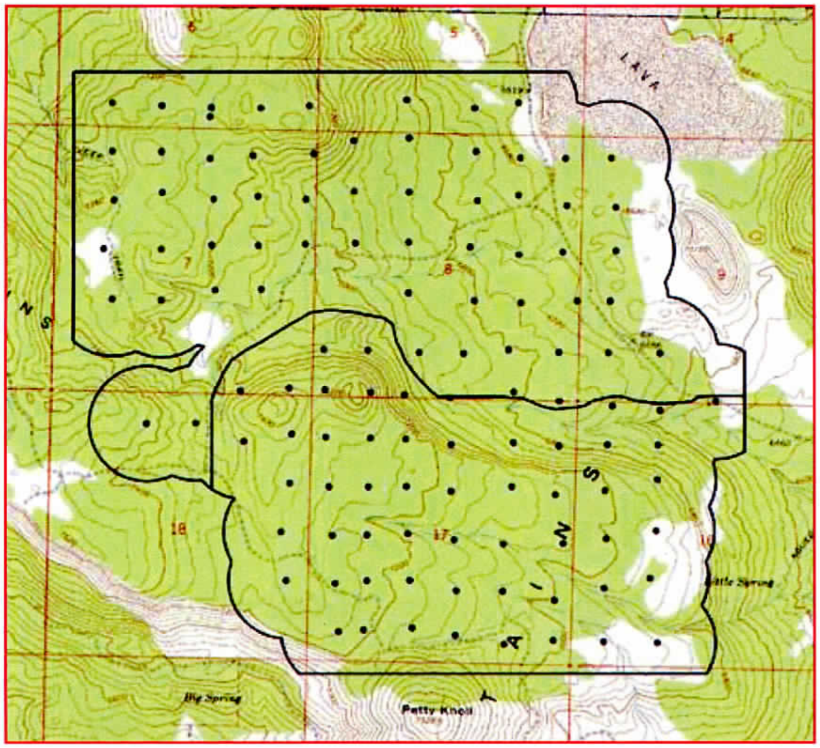

Figure 1—*A map of the study site (~3,000 acres) showing permanent plot locations (black dots). The treated area is in the northern part of the study area; the control is in the southern part.*

ers (2001) estimate was always lowest, and the Cruz and others (2003) estimate always produced intermediate values (fig. 2a). For CBD, Fulé's equation again produced the lowest estimate, but Cruz's estimate was highest and Brown's estimate was intermediate in all but the treated area in 1870 (fig. 2b).

Regardless of which equation was used, CFL and CBD values were relatively low over the entire study area in 1870, with dramatic increases across the entire landscape by 1996/97. By 2003, treatment lowered CFL and CBD by about 40-60 percent compared with slight increases in the control (fig. 2). The reduction in canopy fuels is visually evident in the treated area, where surface fuels, once dominated by forest floor and coarse woody debris, now consist of an abundant herbaceous understory (fig. 3).

Modeling Potential Fire Behavior

We used two common fire behavior models to predict potential fire behavior and evaluate treatment effectiveness:

- FlamMap, a spatially explicit model that assesses fuel hazards by simultaneously predicting fire behavior for each individual pixel on the raster landscape (Stratton 2004), and
- NEXUS, another hazard model, which uses plot- or stand-scale data to predict potential fire behavior (Scott 1999; Scott and Reinhardt 2001).

These fire behavior models are designed for assessing fuel hazards rather than fire growth; we selected them because both are ideal for evaluating treatment effects on fire behavior. We ran both models under scenarios of extremely dry conditions and a range of windspeeds to simulate the severe weather under which uncontrollable crown fires most commonly spread.

Changes in Potential Fire Behavior

Initial modeling results for the three CBD levels showed that crown fire activity was correlated with CBD for both FlamMap and NEXUS. However, the FlamMap simulations were sensitive to CBD, showing little active crown fire for any of the time-treatment combinations when the low and intermediate CBD values were used. Therefore, we restricted our analysis to results from the two fire behavior models using the highest CBD values (i.e., from Cruz and others 2003).

FlamMap predicted that active crown fire would not occur within the study area in 1870 even with 43 mph (70 km/h) windspeeds. By 1996/97, nearly 90 percent of the landscape was classified as either passive or active with 43 mph (70 km/h) windspeeds. After treatment, the percent of the landscape in the treated area susceptible to active crown fire was reduced from 46 percent to less than 5 percent compared to the control, which showed little change.

NEXUS predicted that some active crown fire would occur within the study area in 1870 with windspeeds greater than 31 mph (50 km/h), with up to 17 percent of the landscape supporting active crown fire when modeled with 43 mph (70 km/h) windspeeds. NEXUS predicted that 80 percent of the pretreatment landscape would support active crown fire with 43 mph (70

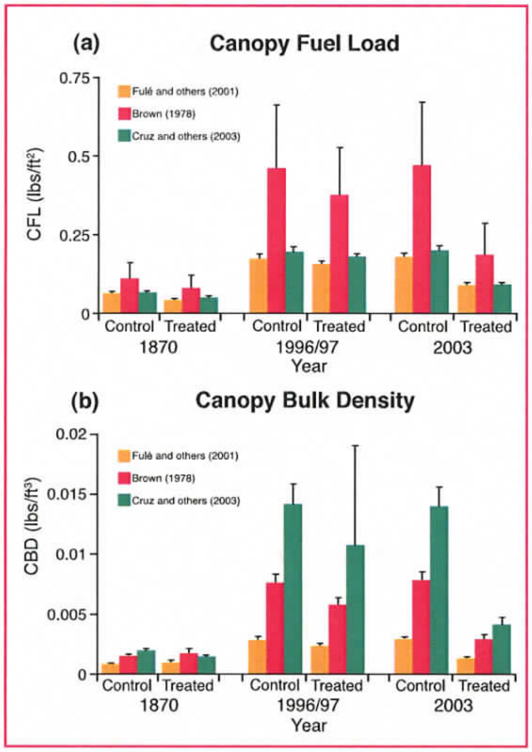

Figure 2—*Although canopy fuel load (a) and canopy bulk density (b) estimates were variable, all methods showed low values in 1870, marked increases by 1996/97, and substantial reduction in the treated area by 2003.*

km/h) windspeeds. By 2003, NEXUS predicted that active crown fire was reduced from 82 percent to 48 percent in the treated area with 43 mph (70 km/h) windspeeds with no change in the control over the same time period. NEXUS also predicted a substantial increase in crowning index (the windspeed required to sustain active crown fire) in the treated area (fig. 4).

Model Comparisons

The purpose of modeling fire behavior at Mt. Trumbull was to use the output as a way of comparing potential fire behavior between three time periods and between the control and treated areas following restoration treatments. One should always interpret model output with caution, and these model runs were not expected to accurately predict the behavior of an actual fire. Using the output from two different fire models is a way of validating each of their treatment comparisons.

There are two key differences between FlamMap and NEXUS. First, in FlamMap, the model inputs are interpolated or calculated across the plot grid to produce output across the landscape, whereas in NEXUS, inputs are calculated for each plot and outputs are interpolated across the landscape. Thus, even though the fundamental fire behavior predictions are nearly the same in the two models, the different approaches to modeling fire across the landscape lead to somewhat different results. Second, only NEXUS accounts for the occurrence of conditional crown fire, the situation where passive crown fire is not predicted to occur due to a high canopy base height even though active crown fire could occur due to high CBD (Scott and Reinhardt 2001).

Although FlamMap and NEXUS differ, predicted outcomes were consistent: under extreme drought and wind conditions, the proportion of the landscape susceptible to active crown fire decreased in the treated area. In contrast, the models show little change in crown fire hazard in the control over the same time period.

Figure 3—*This before and after photo series illustrates the reduction in canopy fuels and consequent increase in herbaceous surface fuels. The upper photo was taken in 1996 prior to treatment; the lower photo was taken in 2003 after the area was thinned and burned. Arrows indicate the same trees for reference. Photos: John Paul Roccaforte, Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ 1996, 2003.*

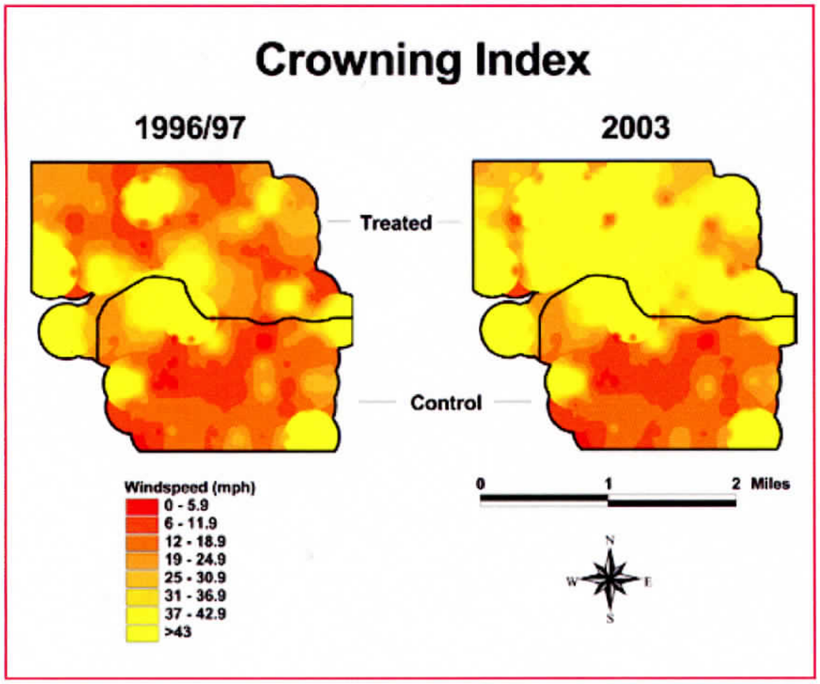

Figure 4—*Fire behavior modeling output from NEXUS shows that higher windspeeds are necessary to sustain active crown fire in the treated area in 2003; hence, active crown fire hazard was reduced following treatment. Alternatively, little change in potential fire behavior occurred in the control over the same time period. [Figure 4 in this electronic version varies from the printed publication to correctly portray the windspeeds required.]*

Management Implications

This study provided a quantitative evaluation of the effectiveness of landscape-scale restoration treatments on canopy fuels and crown fire hazard for the Mt. Trumbull landscape. Although canopy fuel estimates and fire behavior predictions varied depending on which models were used, all modeling scenarios resulted in substantially lowered canopy fuels and crown fire hazard in the treated area. This suggests that restoration treatments were an effective management strategy.

It should be noted that treatments have also resulted in the loss of some old trees from prescribed fire activities (Fulé and others 2002) and the spread of cheatgrass (Bromus tectorum), an invasive species (McGlone and others 2009). The ERI, BLM, and AZGFD will continue to address these and other challenges in the future.

The Mt. Trumbull ecosystem will never be "fireproofed." Maintenance of the surface fire regime will be vital to retaining open forest conditions and relatively low crown fire hazard into the future. Although the Mt. Trumbull ponderosa pine ecosystem is not yet "restored," restoration treatments have been successful at substantially reducing crown fire hazard and creating more sustainable forest conditions.

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