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Article

Ladder Fuel Treatments Effect Burn Area of Forest Fires in Semi-Arid High Elevation Climates

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SUMMARY

Forest fires destroy millions of acres, threaten populations, and are becoming increasingly severe. Efforts to reduce the starting of wildfires has led to increasing quantities of ladder fuels. Ladder fuels are any fuels that create a vertical continuity in a forest. When a fire does occur, these ladder fuels promote the spread of fires to the forest crown. We hypothesized that if the density of ladder fuel is reduced, the burn area in a semi-arid high-altitude forest will decrease. To test the hypothesis, a series of computer simulations were run testing 50 random ignition sites in a representative semi-arid high elevation forest with different levels of ladder fuel treatment using the FlameMap wildfire simulator with US Forest Service landscape and weather data. There was a large variation in the extent of the fires based on the ignition location, ranging from 13 to 22,506 acres. The study showed a statistically significant reduction in average total burn area after 10 days when 5% or more of the total acreage had been treated ($p < 0.01$). There were further reductions in burn area with increasing ladder fuel treatment from a 9% reduction with 5% treatment to a 51% reduction with 20% treatment ($p < 0.001$). This study supports the effectiveness of ladder fuel treatments in reducing burn area.

INTRODUCTION

In the United States, there are about 70,000 wildfires that affect millions of acres every year (1). The cost of wildfire suppression is almost one billion dollars a year (1). Over time, longer forest fires seasons and drought around the world have stretched limited wildfire fighting resources (1). The extensive property damage from forest fires, increasing cost of fighting wildfires, and limited firefighting resources make techniques which reduce wildfire damage even more valuable.

Forest fires are most common in the southwestern United States due to its semi-arid high elevation climate and large ponderosa pine forests. These forests are very homogenous, allowing forest fires to easily spread over a vast area (2). Before the 1820s, fires were smaller and burned less area than today (1). These fires occurring frequently in the semi-arid ponderosa forests (2). Through human intervention, smaller fires became less frequent as they were put out to protect the people who had settled in the region (3). Since there were fewer fires burning, fallen tree branches and other underbrush began to build up over the next several decades (3). One reason the underbrush build-up increased even more rapidly in the 1950s was because the United States Forest Service created Smokey the Bear to urge citizens to stop and prevent fires (4). Efforts to extinguish fires led to an excess of fuels in the forest (3). Due to the abundance of built-up fuels, when a forest fire did occur, the fires became large and uncontrollable (3). The massive increase in large fires also led to an outbreak of scientific research in the field of science ecology (3).

It is currently hypothesized inside the scientific community that these fuels cause more fires to become crown fires and therefore burn a larger area (4). Forest fires spread across horizontal and vertical continuities (5). Horizontal continuity is an unbroken existence of fuels in the horizontal direction. Ladder fuels create a vertical continuity of fuels in the vertical direction (6) and allow fires to spread via the tops of trees becoming crown fires which are the most dangerous and fastest moving type of fire (5). This fact is of great significance as crown fires are hazardous, difficult to extinguish, and most importantly, the number of crown fires is increasing (3). If ladder fuels are found to be the cause of ground fires becoming crown fires, decreasing ladder fuels can be used to prevent the increasing amount of crown fires.

Fuel treatments are any method that remove flammable materials in either the vertical or horizontal continuity from the forest environment to reduce the number and extent of forest fires (3). The most frequently used fire treatments are prescribed burns and thinning to prevent fires from spreading up trees and becoming crown fires (3). This project will provide information on how fuels can be treated to better protect people, wildlife, and property from forest fires.

Cochrane et al. found that there is a direct correlation between the burn area of forest fires and the density of both horizontal and vertical continuities (7). With this discovery, we hypothesized that if the density of ladder fuels decreases through clearing, the burn area will be reduced in the tested environments. This decrease is due to the belief that vertical continuity will influence the burn area of forest fires. The null hypothesis is true if the reduction of ladder fuels does not reduce the burn areas in the tested environments. It can be inferred in that situation that horizontal continuity affects the burn area of forest fires, but vertical continuity does not affect the burn area.

The study was conducted by running a simulator in

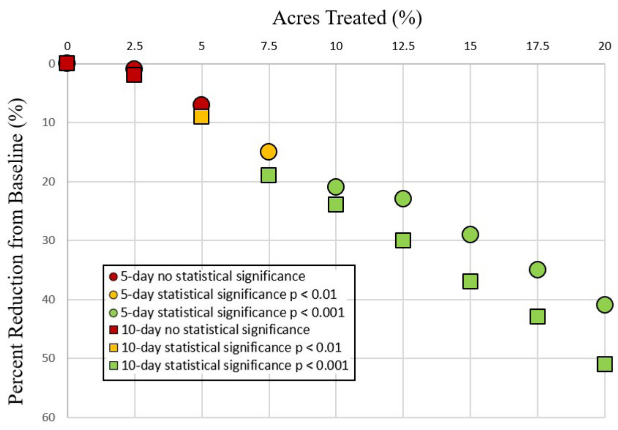

Figure 1: Five -day and ten-day measurements of average acres burned at different percentage of land pretreated levels (0-20% treated). Greater slope in 10-day vs. 5-day data shows greater impact of more extensive ladder fuel reduction with time. The difference between the two data sets demonstrates the effect of time on fire spread.

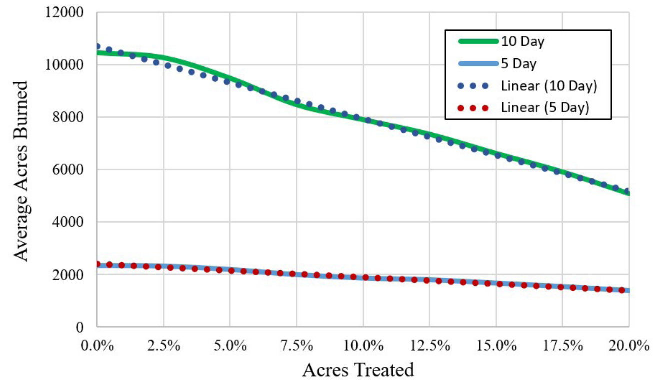

Figure 2: Ladder fuel treatment results in a significant reduction in acres burned over five- and ten-days. Statistical significance ($p < 0.01$) is shown beginning at 7.5% treatments with 5-day data and 5% with 10-day data. $p < 0.01$ is represented by yellow markers and $p < 0.001$ is represented by green markers. (For each treatment group, n = 50.)

different semi-arid high-elevation environments with different levels of ladder fuels. The burn area will be found for each of the simulated fires. This data was evaluated to find if there is a statistical difference between burn area when there is a difference in ladder fuels.

RESULTS

Using FlameMap, ladder fuels were reduced on varying amounts of the environment. Nine different percentages, from 0% to 20% of the total acreage, was treated to remove ladder fuels. The land treated was determined by starting at the lowest elevation. 50 simulated fire ignitions at each of the 9 different levels of fire ladder treatment produced 450 data points for 5- and 10-day data. There was a wide variation in total burn areas in the 10-day data from as little as 13 acres to as much as 22,506 acres depending on the location of ignition. The range was smaller for the 5-day data between only 2 and 5,800 acres. The duration of the fires also impacted the extent of burn area. The untreated baseline 10-day average burn area was more than 4 times the burn area of the 5-day measurement. The effect of fuel treatment was magnified with the longer duration simulations. Untreated 5-day burn area was 3.7 times greater than the heavily treated 20% landscape, but after 10 days was 4.4 times greater (**Figure 1**). The extent of area burned, and effectiveness of ladder fuel treatment varied greatly depending on the ignition location and the duration of the fire.

This study evaluated the effect of ladder fuel treatment on reducing burn area in semi-arid high elevation forest. The average burn area progressively decreased from baseline to 20% treatment in both 5- and 10-day data (**Figure 1**), showing a clear reduction in burn area with increases in ladder fuel treatments. One-way ANOVA analysis was done for both 5- and 10-day data. The 10-day results were statistically significant (p-value 1.1 x 10-5). ANOVA results from 5-day data had a p-value of 0.03 which did not meet the alpha of 0.01 used for this study. With the 5-day data, a statistically significant difference was seen beginning with 7.5% treated and above when compared with the untreated forest. There was also a statistically significant drop ($p < 0.01$) in burn area between each incremental increase in ladder fuel treatment beyond the first 2.5% in the 10-day simulations. In the 5-day data, statistical significance ($p < 0.01$) was seen between 7.5% to 10%, 12.5% and 15%, and 17.5% and 20%.

There was an inverse relationship between the average acreage burned and percent of landscape treated (**Figures 1 & 2**). A comparison of 10-day and 5-day data showed a greater reduction in burn area in total acres burned and a greater reduction in the percentage of acres burned with the longer simulation time (**Figure 1**). For example, with the 20% treatment group, average burn area for 10 days was 5,365

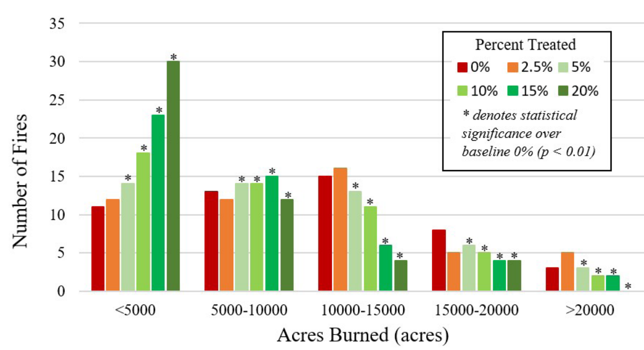

Figure 3: Percent of land pretreated organized by number of acres burned. ANOVA analysis of 10-day data showed a statistically significant variation in the different treatment levels. Green shaded data is significantly less ($p < 0.01$) then baseline (0%) group. The graph demonstrates the extent that increasing ladder fuel treatments constrains wildfires to smaller areas. The highest levels as ladder fuel treatments increase, there is a progressive reduction in forest fire size. Only the most extensive fuel treatments completely prevent the largest burn areas (zero fires of greater than 20,000 acres with 20% treatment).

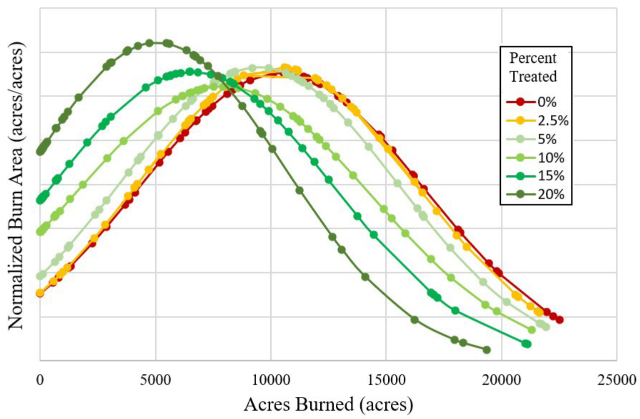

Figure 4: Ten-day data normalized to a Gaussian distribution showing acres burned for each percent of land treated. There is a shift to the left with higher levels of pretreatment showing reduced average burn areas. Narrowing of the distribution curve with increasing fuel treatment shows a reduction in the variability of wildfires with greater fuel reduction.

acres less and 51% less than baseline, while the 5-day data was 971 acres less and 41% less than baseline (**Figure 1**).

The fire data was divided into groups of 5,000 acres burned (**Figure 3**). With higher levels of ladder fuel treatment, the fires were less extensive. At 20% treatment, 60% of fires were less than 5,000 acres after 10 days. With little treatment of 0% or 2.5%, 20 percent or more of fires were greater than 15,000 acres.

The 10-day data was normalized to a Gaussian distribution (**Figure 4**). The graph shows a shift to the left as the mean burn area is reduced 50% with highest levels of pretreatment. Only at the higher levels of ladder fuel treatment tested, particularly at 20%, is there an increase in the height of the of the curve and narrowing of curve width indicating the variation in burn areas is reduced. The reduction in standard deviation data with 20% ladder fuel treatment confirms the reduced variability.

DISCUSSION

In this study, through utilization of the FlameMap simulator, a statistically significant reduction in burn area in semi-arid high elevation forest fires with ladder fuel treatment in 5% or more of the acreage. The extent of reduction in burn area correlated with the degree of pretreatment to reduce ladder fuels. The simulated comparison between untreated and treated areas was made using identical wind, weather, and moisture conditions. There was also a marked variation in the size of forest fires depending on the location of ignition, duration of fire, and extent of ladder fuel treatment. These findings illustrate the effectiveness of ladder fuels reduction on forest fire containment.

Ladder fuel reduction treatment on 5% of the forest produced a statistically significant reduction in burn area of 9% after 10 days (p < 0.01) and treating 20% of the land reduced the burn area 51% (p < 0.001). The study refuted the null hypothesis, demonstrating a significant reduction in burn area with increasing ladder fuel reduction.

These results are particularly important with the increasing severity and cost of forest fires. While increasing costly firefighting resources are needed, efforts to limit the severity and destructiveness of forest fires before burning begins deserves additional consideration. This study shows that ladder fuel reduction can have a significant impact on the speed and size of fires. The cost of ladder fuel reduction varies greatly depending on access to mechanical equipment, topography, and remoteness (8). Estimates for the western US range from $1,000 to more than $3,000 per acre (8). Even using the low-end estimate, the cost would be greater than $350 million dollars just to treat 5% of the test landscape which is an exceedingly small portion of the US semi-arid high elevation forest. While treatment is not economically viable on a national level, ladder fuel reduction around the intersection of forest with urban areas could be useful and economical. Judicious use of ladder fuel treatments could reduce some of the annual one billion dollars spent on fighting forest fires (1).

Our study was limited by several factors including the testing of ladder fuel treatment to reduce vertical spread without the combination of horizontal barriers. This limitation, as well as additional questions, can be addressed by further research. The simulation was specifically based on environmental data from the 2016 peak fire season (9). Further simulated studies using a wider variety of environmental conditions such as other seasons of the year and data from other years than 2016 could further support the effectiveness of ladder fuel reduction. This research looked at seven million acres of semi-arid high-altitude forest, but this is only a small portion of this type of forest in the United States and might not be representative of other areas. Running the simulation software over a wider range of forests including other types of forests would determine the generality of this study's results. This study-based treatment on altitude but it may be more realistic to base areas of treatment around access roads which would be critical for large scale ladder fuel reduction. One significant advantage of using a simulated comparison is the ability to adjust and control the environmental conditions. Further studies with simulated environmental conditions anticipated by climate change could provide insight on the future utility of ladder fuel treatment.

This study demonstrated the effectiveness of ladder fuel treatment in semi-arid high elevation forest and this technique maybe beneficial when combined with horizontal barriers to reduce the destructiveness of forest fires at the intersection of forest with urban areas.

MATERIALS AND METHODS

The FlameMap software was downloaded from the US Forestry website. The FlameMap Simulator is known for its accuracy in predicting forest fires (5, 6, 10-13). This simulator is also currently in use by the American government and forest firefighters (5). The FlameMap Simulator allows for a variety of input environments and an accurate simulator for determining the burn area and category for each test.

Environmental Data

The landscape data was retrieved from landfire.gov (9). A rectangular 7,083,100 acre landscape from latitude 37° longitude -106° to latitude 36° longitude -105° was used. Landscape files were the latest available from 2019. Historical weather data from forestry service weather stations was used from July and August of 2016.

The FlameMap simulation used generated gridded wind from the available weather input data. Fuel moisture conditioning was started 10 days prior to the ignition of the fire. Ember spot probability was set to 0.10 and crown fire calculation was Scott/Reinhardt. The ignition start points were determined randomly using the Microsoft Excel random number generator to determine a matrix location on the landscape.

Pretreatment Parameters

The landscape was tested using baseline state and various degree of pre-treatment. The baseline was determined by running the FlameMap simulation utilizing weather, topography, and fuel data from US Forestry website for July and August 2016. The ladder fuels were reduced at the lowest levels of elevation first as these would be the least costly to effect. Pre-treatments at 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% were used. Previous studies in other environments have shown using ladder fuel reduction treatment in 8% of the area creates a significant reduction in burn area (14).

Statistical Analysis

Fifty ignition points were tested at baseline and treated landscapes. The data for burn area was collected at both 5- and 10 -days. The data was then collected and analyzed using Microsoft Excel. Both one-way ANOVA and two-tailed t-test were run, in order to determine if there was statistical significance between the different environments. In addition, according to Devore, the t-test was created to determine the existence of statistical significance and that the bright-line for statistical significance for computer studies is 0.01 (15).

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