2011

Mastication on Red Mountain: Investigating Fuel Loads and Fire Effects

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Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

In the Red Mountain region of California's Sequoia National Forest, researchers investigated the impact of mastication on fuel loads and fire effects. Credit: Scott Williams, Adaptive Management Services Enterprise Team (AMSET).

Mastication on Red Mountain: Investigating Fuel Loads and Fire Effects

Summary

Although complete fire exclusion is a thing of the past in the Sierra Nevada, fire and fuel managers must still contend with dense forests and higher fuel loads that have built up over time. Controlled fire is a helpful fuel reduction method, but it can be tricky to manage, especially in an area with excessive fuels, or in plantations with trees having smaller diameters and lower crowns, which are more susceptible to heat damage. Mastication can also be a useful fuel treatment and has become a popular alternative, but includes its own set of drawbacks and uncertainties. Since little research has been done to measure the fire behavior and effects of masticated fuel beds, researchers conducted a study on mastication and combined mastication/prescribed burning fuel treatments in the Red Mountain region of California's Sequoia National Forest. Specifically, researchers hoped to get concrete answers to key questions, including: will mastication result in undesirably high surface fuels? How will mastication change fire behavior and effects? Will treatments involving mastication and prescribed fire lead to a healthier stand density and wildfire resiliency? And, will there be higher tree mortality when masticated sites burn in a wildfire? With this study, researchers also hoped to provide managers with the data for custom fuel models needed to effectively estimate masticated fuel loads, to predict how hot and fast they will burn, and to fine-tune fuel treatment planning efforts.

Key Findings

- Masticated fuel characteristics such as particle size, fuel load, fuel depth, and percent cover varied widely.
- Predicted flame length was higher for masticate-only treatments than mastication/prescribed underburn treatments.
- In areas treated with mastication/prescribed fire, mortality was 37 percent where fuels were pulled back to the driplines of trees and 51 percent where fuels were left in place.
- Predictive modeling indicated that the combined mastication/prescribed underburn treatment was effective in meeting desired fire behavior under extreme fire weather conditions.

Taming high fuel loads

Prescribed, or controlled, fire is a common method that effectively reduces fuels, but may not be practical in areas with high surface fuel loads and low canopy base heights. Fuel managers are increasingly turning to mechanical mastication as a preferred treatment in these conditions. Although mastication removes ladder fuels and helps reduce canopy bulk density, it doesn't actually reduce the fuel load. The fuels are simply transferred to the surface layer, which adds to the surface fuel loading and depth. This increased surface fuel load may then result in more severe fire behavior and fire intensity. Therefore, to adequately reduce surface and canopy fuels in this area, treatments with multiple applications may be required.

"It would be nice to let wildland fire play a more prominent role in areas like these fire-adapted stands of the southern Sierra Nevada, however, given the current fuel conditions and dense, young stands, the chances for large areas to support crown fire are high, so fuel modification needs to occur before wildland fire can be used for resource benefit," stated Alicia Reiner, co-principal investigator.

Little data exists on the fuel loads, fire behavior, or fire effects of masticated fuels, making it difficult for managers to accurately assess masticated fuels and adjust fuel treatments accordingly. This is compounded by the fact that no fuel models currently exist. To help provide the empirical data land managers need to make critical decisions, researchers conducted a study that focused on answering the following:

1. Will mastication alone result in undesirably high surface fuels?
2. How will mastication alone or coupled with prescribed fire change potential fire behavior and effects?
3. Will there be higher tree mortality when masticated sites burn in a wildfire?

Fuels, fire, and mortality

In 1970, a 2,500 acre wildfire swept through the Greenhorn Ranger District of California's Sequoia National Forest, an area that is now known as Red Mountain. After the fire, a plantation of ponderosa pine was planted and has grown into a productive site with 30 foot-tall trees and a nearly continuous canopy in some areas.

Researchers targeted the Red Mountain area to evaluate the effects of fuel reduction treatments on fuel loads and fuel characteristics, potential fire behavior, and tree mortality. Study plots included an untreated control along with plots that had been treated with mastication, mastication followed by prescribed burning, and mastication plus prescribed burning after fuels were manually pulled back from the boles of trees.

Using a vertical shaft mastication head mounted to an excavator boom, mastication was completed between the fall of 2005 and the summer of 2006. The prescription included leaving trees over 38-centimeter diameter at breast height and thinning to a density of approximately 25 trees per acre. Prescribed burning was completed on December 5–6, 2007. Air temperature during the burn ranged from 41 to 60 degrees Fahrenheit and relative humidity ranged from 30 to 100 percent, with precipitation beginning during the burning of the last unit. Litter moistures ranged from 8 to 12 percent, and the Keetch Byram Drought Index (KBDI) was 476. Other than two days of trace precipitation, 0.1 inches of rain fell 24 days prior to the burn. Precipitation began while the last unit was burned. Wind speed during the burn ranged from 3 to 8 miles per hour with gusts to 13 miles per hour. Ignition patterns of the prescribed burns included both spot and strip firing. Spot firing is the ignition of separate, small dots and strip firing is the ignition of lines. The units were ignited starting from the uphill side of the unit and working downhill, unless wind direction dictated otherwise.

Prescribed burn treatments were ignited using spot and strip firing methods. Credit: Scott Williams, AMSET.

Getting answers

Fuel loads

During this study, data on canopy, live understory, surface and ground (litter and duff) fuel loads and masticated fuel characteristics were gathered and analyzed. Canopy fuel loads were modeled using FMA Plus, and onsite bulk densities for masticated and ground fuels were created.

Research results revealed that masticated fuel load, fuel depth, and percent cover varied widely, with most fuel falling within the 10- and 100-hour size classes. According to researchers, this variability is unfortunate, but not uncommon. Principal investigator Nicole Vaillant stated, “Unfortunately, nature is quite variable; this study took place in a plantation which would typically be less variable than a natural ecosystem. A larger sample size might reduce the overall variance per plot, but there will always be variability in fuel beds before and after mastication treatments.”

Masticated fuel loads were roughly ten times greater than natural downed woody fuels after mastication and before prescribed burning. Non-masticated, downed woody fuel did not change much before or after mastication and prescribed burn treatments. In the treatment area, canopy bulk density decreased by 38 percent for mastication-only, 50 percent for mastication/pull-back/prescribed burn treatments, and 54 percent for the mastication/prescribed burn treatments.

Fire behavior

To measure fire behavior of masticated fuels during prescribed burn treatments, researchers used thermocouples, or temperature sensors, video cameras, and passive flame height sensors. Potential wildfire behavior characteristics for post-treatment fuel conditions were calculated as well using FMAPlus with 90th and 97th percentile weather, common thresholds for high and extreme fire-weather conditions.

Placed at 1.5 inches below the surface, thermocouple temperatures ranged from 48 to 109 degrees Fahrenheit. These temperatures were much lower than temperatures recorded at the soil and fuel surface, which spanned from ambient temperature to 2,192 degrees Fahrenheit, or the thermocouple failure point. The lethal threshold for plant material is 140 degrees Fahrenheit, and during this study, temperatures exceeded that threshold for up to 476 minutes. “Fire behavior was more intense than reported by other researchers to date,” stated Jo Ann Fites-Kaufman, co-principal investigator.

According to fire behavior predictions for post-treatment fuels under 90th and 97th percentile weather conditions, the mean rate of spread and flame length would be higher for the untreated controls than the masticate-only or the combined mastication/burn treatments. Additionally, torching indices were higher for combined mastication/burn treatments, in comparison to the masticate-only treatment or the untreated control. This result indicates that higher winds must be present to produce torching in combined mastication/underburn units given post-treatment fuel conditions.

Tree mortality

Researchers used FMAPlus to predict post-wildfire mortality for post-treatment fuels during 97th percentile weather conditions, resulting in 28 percent mortality for masticate/burn treatments, 30 percent for masticate/pull-back/burn treatments, 57 percent for the untreated control, and 87 percent for mastication-only treatments. Indicating that wildfire mortality rates were highest for mastication-only treatments, with the untreated control having the next highest predicted mortality.

From left to right, the following treatment stages are shown: pre-mastication, post-mastication, and post-burn. Preliminary study results indicated that mastication increases surface fuel and prescribed fire reduces masticated fuels, but not necessarily to pre-burn levels. Credit: AMSET.

Actual tree mortality was assessed after the prescribed fire treatment and at the end of the first and second growing seasons by observing the presence and/or absence of green needles or buds. At completion of the first growing season after the prescribed burn, tree mortality was 38 percent in mastication/burn treatments and 29 percent in mastication/pull-back/burn treatments. Two years post-burn, mortality was 51 percent in mastication/burn treatments and 37 percent in mastication/pull-back/burn treatments. Mean percent scorch was also high for mastication/prescribed burning, at 74 percent, and 75 percent for mastication/pull-back/burn treatments.

In response to the mortality results, Vaillant said, "The amount of tree mortality, especially with the pull back treatments, surprised me. The fire burned pretty hot which could be part of the reason for the high mortality rates." Reiner also commented, "When we took the tree mortality data, we were recording trees as living, even if they only had minute green buds amidst a largely scorched canopy. This gave us an idea of how many trees were actually living despite how scorched the stand looked. Two years after the burn, the average mortality across all the plots treated with burning was still less than fifty percent. At the field tour this summer, the third growing season after the burn, the remaining live trees are looking strong and some of the dead trees are beginning to fall. This leaves some open patches and some areas where the stand is now much less dense than it was before. Over the next decade the remaining trees will grow faster, plus, they will be more resilient to disease and future extreme fire events pushing through the area as crown fires…the canopy fuels in this area really don't look like they would support much crown fire."

Treatment	Masticated Fuels (Mgha^{-1})	Masticated Fuel Depth (cm)	Fuel Bed Bulk Density (kg m^{-3}) [a]
2005			
Masticated	n/a	n/a	27 (6)
Masticated/fire	n/a	n/a	27 (7)
Masticated/pull-back/fire	n/a	n/a	22 (7)
2006			
Masticated	42.9 (12.5)	3.4 (1.0)	32 (5)
Masticated/fire	25.9 (5.3)	2.1 (0.4)	30 (5)
Masticated/pull-back/fire	35 (6.3)	2.8 (0.5)	57 (9)
2008			
Masticated	48 (15.4)	3.8 (1.2)	47 (16)
Masticated/fire	5.3 (1.5)	0.4 (0.1)	29 (7)
Masticated/pull-back/fire	2.6 (1.1)	0.21 (0.1)	12 (4)

a. Fuel bed bulk density calculated from 1-h, 10-h, 100-h, litter, masticated fuel loads and fuel bed depth.

Mean (standard error) for masticated fuel loadings, masticated fuel depth, and fuel bed bulk density for pre-treatment (2005), post-mastication (2006), and post-fire (2008) years for masticated, masticated/fire and masticated/pull-back/fire plots.

Treatment tips

Knowing what they do now, researchers expressed that they would have benefitted from a more balanced sample size, which was originally planned for but not implemented due to complications. Vaillant and Reiner stated, "One way to work toward this would be to install extra pre-treatment plots, anticipating that some of the areas will just not get treated. This is a recurring issue in many research/monitoring projects involving treatments." Further, researchers stated that they would have liked to have kept the prescribed fires from burning as hot or intense as they did during the study.

Also, Vaillant and Reiner were asked if they would have observed different results if they had performed the prescribed burning in the spring: "We believe a spring burn, if under moister conditions, would have yielded different results. It is possible that the flame lengths and rate of spread would have been less during a spring burn and potentially more patchy leaving islands of unburned fuels in the mix, however, the residence times would likely be just as long or longer keeping the cambial heating similar or higher but the scorch heights lower."

To help managers, researchers provided the following treatment insights and recommendations:

- Be aware of the amount of masticated fuels generated by mastication treatments. Deep, continuous layers of masticated fuels are likely to produce a significant amount of heat, along with damaging fire effects and undesirable levels of tree mortality.
- Consider letting masticated fuels sit before burning. Decomposition time is uncertain, however, and is very dependent on the location, type, size, and amount of masticated materials. Masticated materials in wetter environments are likely to decompose faster.
- To treat overly dense stands, fuel reduction may need to involve multiple entries, and possibly treatments in addition to or instead of mastication. Hand thinning, piling, and burning is a treatment option, but use caution in crowded stands where piles are too close to trees, which can cause scorching during the burn process. Raking masticated fuels away from trees before burning may help, but researchers recommend scattering raked fuels to help reduce mortality and prevent build up near the canopies of small plantation trees.
- Use fire behavior models with caution, since masticated fuels are a novel fuel type and not yet included in current fuel models. Vaillant and Reiner agreed, "We do think it is possible to create masticated fuel models, but first more fire behavior needs to be gathered to validate models. But like the existing fuel models, these models would be somewhat general and should contain a few categories based on pre-existing vegetation type, mastication type (chipping versus shredding), and resulting masticated fuel loading, for example."

shredding), and resulting masticated fuel loading, for example."

- Consider modifying mastication contracts to remove more of the thinned material before mastication. Other methods that can help reduce the deep layers of masticated material include removing whole trees and/or performing offsite mastication or chipping.
- Prepare for post-prescribed burn tree mortality if using mastication followed by prescribed fire. To help lessen mortality, researchers recommend pulling masticated materials back from individual trees before burning. Overall, researchers agreed that prescribed burning after mastication is the most effective combined treatment for creating the most resilient stand if and when a wildfire passes through.

Ongoing progress

This study helped to answer some key questions, while others are still being answered. For example, study results revealed that masticated fuel loads vary widely and are difficult to measure. However, with help from this study and others, data sets are currently being built, which can then be applied to create fuel models that managers can use to quantify post-masticated fuels in the future. Also, with extra funding from the Sequoia National Forest, researchers were able to conduct further monitoring of post-treatment prescribed burning effects on tree mortality.

While strides have been made to provide the specific tools and knowledge that managers need to accurately assess the fuel loads and fire effects of mastication and combined treatments, researchers indicated that the following is still needed:

- Data on masticated fuels across a broader scale to help understand how topography, vegetation, climate, and mechanical equipment type relate to masticated fuel load and bulk density.
- Research on the changes in litter, duff, and masticated fuel bulk density after mastication and at various lengths of time to understand how older masticated fuels burn. Also, variation in decomposition rates with moisture and vegetation type need to be investigated.
- More specific information on how to define relationships between cambial heating (temperature and duration) and tree mortality by placing the thermocouples directly adjacent to the cambium of trees, and under the bark.
- Additional data collection to quantify fire behavior characteristics of masticated materials, such as residence time, rate of spread, flame length, etc., during prescribed fire, wildfire, and a variety of weather conditions.

Management Implications

Consider:

- Avoiding mastication treatments that result in deep, continuous layers of masticated fuels.
- Applying multiple treatment entries to reduce masticated fuel loads and harmful fire effects.
- Using caution when modeling fire behavior in masticated fuels, as masticated fuel models are still in their infancy.
- Altering management contracts to remove more of the thinned material before mastication.
- Performing mastication followed by prescribed fire to boost wildfire resiliency of the entire stand.

Further Information: Publications and Web Resources

Project Website: http://www.fs.fed.us./adaptivemanagement/projects/mastication

Reiner, Alicia L., Nicole M. Vaillant, JoAnn Fites-Kaufman, and Scott N. Dailey. 2009. Mastication and prescribed fire impacts on fuels in a 25-year old ponderosa pine plantation, southern Sierra Nevada: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T6X-4X66CFD-1&_user=10&_coverDate=11%2F10%2F2009&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=be31505c821d0c7f9880cf8c2b77bd10

Scientist Profiles

Nicole Vaillant received her PhD from the University of California Berkeley and has worked for the Forest Service for just over 10 years. Nicole is currently a Fire Ecologist for the Western Wildland Environmental Threat Assessment Center (WWETAC) in Prineville, Oregon. Prior to WWETAC, Nicole worked as a Fire Ecologist for Adaptive Management Services Enterprise Team (AMSET), and was a seasonal firefighter. Her research interests include fuel treatment effectiveness, fire behavior, fire effects, and quantitative fire risk at multiple spatial and temporal scales.

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Alicia Reiner is a Fire Ecologist with Adaptive Management Services, a Forest Service Enterprise Team, which specializes in providing science to land and fire managers. Alicia has worked as a firefighter for the Forest Service and Bureau of Land Management in between completing an MS at the University of Nevada, Reno. Alicia has participated in research focusing on characterizing fuels, fire behavior, and fire effects.

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During her 20 year career with the Forest Service, **Jo Ann Fites-Kaufman**, PhD, developed and led the Fire Behavior Assessment Team, measuring fire behavior on wildfires through different fuels with emphasis on crown fire to validate existing fire behavior models and support development of the next generation of predictive models. She currently serves on the California State Fire Safe Council and Nevada County Joint Protection Agency Boards and consults on fire science and ecology.

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The information in this Brief is written from JFSP Project Number 05-2-1-30, which is available at www.firescience.gov.

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is published monthly.
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