FINAL REPORT

Title: **Masticated Fuels and Fire Behavior in Forests of the Interior West**

JFSP PROJECT ID: **13-1-05-7**

Sept 2017 (Revised May 2018)

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Final Report

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Abstract:

Managers masticate fuels to reduce extreme fire hazards, but the impact on fire behavior within the resulting compact fuelbeds is poorly understood. We burned 54 laboratory-based fuelbeds one and two growing seasons after mastication and 75 masticated fuelbeds in prescribed fires one growing season after treatment in three replicate *Pinus ponderosa* stands. Mastication treatments reduced density of trees >5cm by 30-72% resulting in total fuel depth of 6.9-13.7cm and surface woody fuel loading of 1.0-16.0kg m^{-2}. Flame length and rate of spread were low and similar for coarse and fine mastication treatments and controls. Smoldering combustion lasted 6-22h in prescribed fire experiments where fuelbeds included duff and were well-mixed by machinery, compared to <2h in the lab with varying fuel moisture. Compared to fine mastication treatments, coarse treatments took less time to implement and were more cost-effective. Tree mortality was nil, and post-fire diameter growth of ponderosa pine trees was greater following low intensity surface fires, similar to unburned and greater than trees where masticated fuels were burned with moderate intensity surface fires. Density of resin ducts in the wood, an indicator of tree defense against insect damage, increased following non-lethal surface fires burning in masticated fuels. While lab experiments expand our understanding of burning masticated fuels under controlled conditions, they did not readily translate to prescribed burning conditions where fuels, weather, and ignition patterns were more variable. This highlights the need for more lab experiments and in-situ research that together can be used to develop much needed, scalable predictive models of mastication combustion.

Objectives:

Our research had the objective of addressing these questions:

1) Do masticated fuels burn with lower intensity and more smoldering combustion compared to non-masticated fuels?
2) Do masticated fuelbeds exhibit greater consumption than controls?
3) How does moisture content and time since treatment affect consumption of when masticated fuels burn?
4) How well do laboratory-based regressions of fire behavior and consumption scale to stand-scale experiments?
5) How does the cost effectiveness in terms of monetary cost, treatment time, and reduction in fire behavior compare for coarse versus fine mastication treatments?

We have added two additional questions since the study was originally proposed:

6) How do understory plant species diversity and richness differ in burned and unburned coarse mastication, in burned and unburned fine mastication and in burned and unburned controls?
7) Why and how are soil nutrients and shrub response affected by depth and mass of masticated fuelbeds when they do or don't burn?

Together, these results will inform both science and management about the implications when masticated fuels burn in wildfires and prescribed fires.

Background:

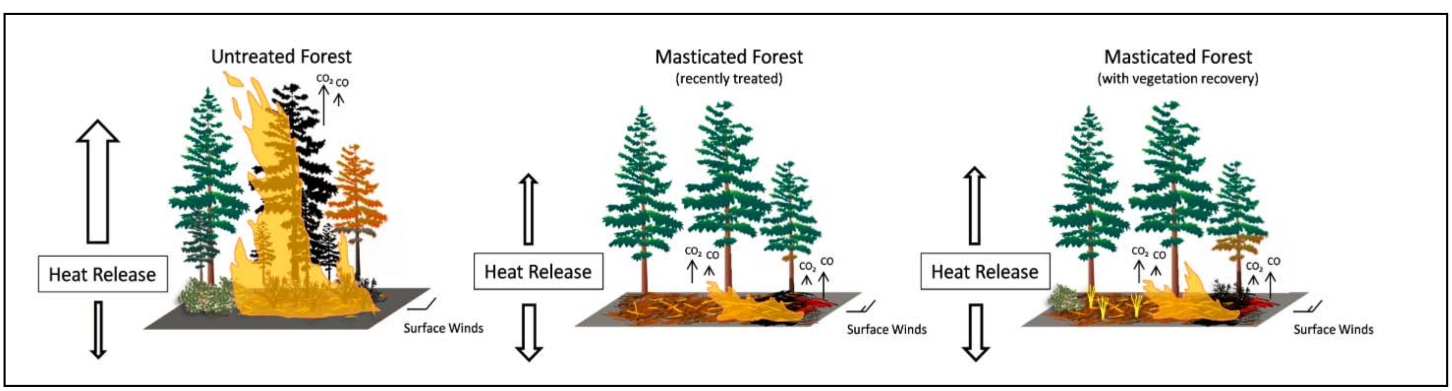


Figure 1. Mastication treatments are designed to reduce vertical continuity of fuels. The chipped and shredded fuels accumulate on the surface. From Kreye et al. 2014.

Managers masticate fuels using machines to chip and shred whole trees, shrubs and vegetation (Fig. 1). Kreye et al. (2014) used this figure to illustrate how this can reduce ladder fuel but adds a layer of surface fuels to the forest floor. Though mastication is commonly used before and during fires, we don't understand how these fuels burn in prescribed and wildfires. Fires burning in masticated fuels often burn with lower intensity (often with shorter flame lengths), but they smolder for longer which can lead to soil heating and smoke. Sometimes, managers use prescribed fires to consume the resulting surface fuels, but often masticated fuels are left to decompose. As fuel treatments expand, some will burn in wildfires. In Colorado in 2012, embers skipped across masticated fuels "like fleas" in a prescribed burn that escaped and burned homes and killed 3 people. The linkages between fuels, burning, and post-fire effects on plants and soils are poorly understood. Practice is far ahead of science for mastication is widely applied to protect people and property from fire. Careful experiments are needed to understand the "why" behind fire effects and quantify the impacts of different equipment configurations and treatment patterns.

Materials and Methods:

We compared coarse mastication to fine mastication to controls on the University of Idaho Experimental Forest (Fig. 1). About 2 ha (5 acres) in each of three 30-year old ponderosa pine stands was thinned in early June 2014 using a boom-mounted brushing head on a CAT 320B excavator. For the coarse treatment, the operator sectioned the trees in lengths of approximately 0.5m with the mastication head. For the fine treatment, the operator cut off the top and then masticated the whole tree and top more slowly. Fuels were measured and collected for characterizing fuelbeds. Tree density was reduced by 30-70% in mastication treatments. All treatments were implemented specifically for this research.

Lab burning experiments were conducted in dry, ambient and wet moisture conditions. These were conducted in the IFIRE lab. They were conducted in both the first and second growing season after treatment (hereafter Year 1 and Year 2).

Prescribed fire experiments were conducted in-situ. The upper half of each treatment was prescribed burned in October 2014. We were able to compare the lab to prescribed fires.

We added two research efforts to this project with the existing funding. First, we have a MS student evaluating the differences (if any) in the species diversity and richness as well as the abundance of selected shrub and plant species in the experimental treatments. She is comparing vegetation in burned and unburned coarse mastication, in burned and unburned fine mastication and in burned and unburned controls. Vegetation was sampled in summer 2015, about 16 months following mastication treatments. Data analysis is in progress; we plan to have a manuscript written for a refereed journal by May 2018 when the MS student is scheduled to complete her thesis and degree program. Second, in fall 2016, we implemented "burnlet" experiments on 1m-diameter plots with 7 replicates with different fuel loading: none, low burned, low unburned, moderate burned, moderate unburned, high burned and high unburned. Here our goal was to understand why and how soil nutrients and shrub response were affected. We will complete data collection in October 2017 (98% of data is complete), and proceed with data analysis and writing of one refereed journal manuscript scheduled for completion by May 2018.

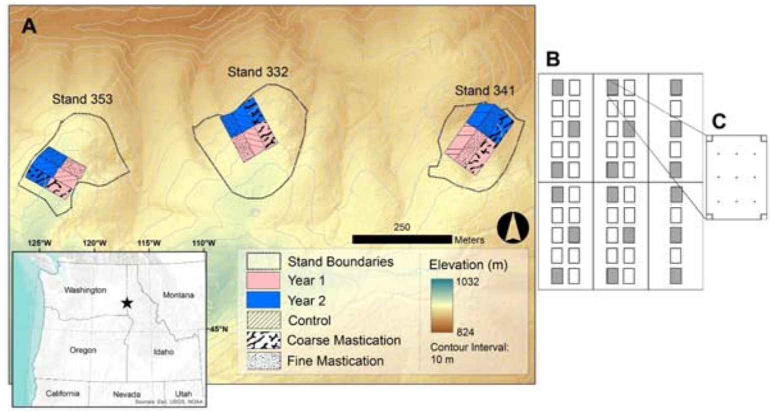


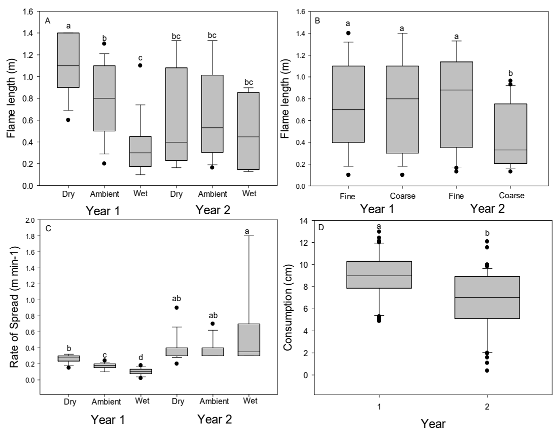
Fig. 1. (A) Map of project location with three study stands on the University of Idaho Experimental Forest in Idaho, USA. Treatments were randomly assigned in each stand, and the upslope half of each stand was burned in during the first fall after early summer mastication. (B) In both Year 1 and Year 2, all masticated fuel and litter/duff were collected for fuelbed characterization on four subplots (0.5 X 0.5 m) in each of 25 5m X 7m plots; sampled plots are grayed. (C) Nine duff pins were used in each plot to measure depth of consumption (cm) following prescribed burning were spaced 1m from left and right plot edges with 1.5m between pins (left to right). From top, the first duff pin was 1m down from plot edge with 2.5m between pins (top to bottom).

Results and Discussion:

Our results for fuels and fire behavior were

- Fuelbed depth was 7-14cm (3-6 in) with surface woody fuel loading of 1.0-16.0kg m^2 (1-18 lb/ac); this did not differ for coarse and fine treatments (Lyons et al. 2018, Sparks et al. 2017)
- Flame lengths and rates of spread were low and variable (Fig. 2, 3, and 4), so mastication did not reduce fire behavior in the our prescribed fires that purposely had low intensity to limit tree mortality in underburns (Lyons et al. 2018)
- In lab experiments, fuel moisture and mastication treatment influenced flame length, but not rate of spread or consumption (Fig. 3) (Lyons et al. 2018)
- Smoldering combustion lasted 6-22hr in prescribed fire experiments where fuelbeds included duff and were well-mixed by machinery, compared to <2h in the lab (Lyon et al. 2018; Sparks et al. 2017)
- Flame length and rate of spread predicted from lab experiments were less than fire behavior observed in the prescribed fire experiments (Lyon et al. 2018)
- Mastication will likely influence fire behavior in more extreme weather conditions, and more fuel (Lyon et al. 2018)
- Coarse treatments were more cost-effective. Compared to coarse mastication treatments, fine treatments cost 15% more because they took more time to implement, yet the fire behavior was similar (Lyon et al. 2018)
- Existing fire behavior fuel models are adequate for use in the BehavePlus fire behavior prediction system.
- We expect that when masticated fuels burn, the potential for soil heating and particulate emissions are high, particularly when the fuels smolder for long durations.

Figure 2. Sampling masticated fuels pre-burn (LEFT), observing flame lengths and rate of spread during prescribed fire experiments (MIDDLE), and assessing depth of consumption post-burn (RIGHT). Some areas, as shown in the bottom row, had low fire intensity, while others (middle and top) had higher fire intensity, indicated here as Fire Radiative Energy (FRED). Photos from Sparks et al. (2017)



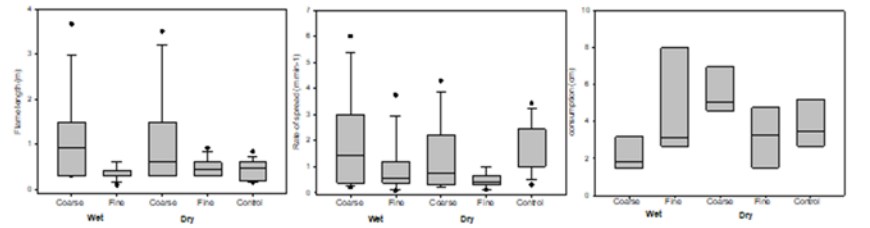


Figure 3 (left). Lab burning experiment results illustrating (A) the effect of age and moisture on flame lengths, (B) the effect of age and mastication type (fine and coarse) on flame length, (C) the effect of age and moisture level on rate of spread, and (D)the effect of age on consumption. From Lyon et al. 2018).
Figure 4 (above). Prescribed burning experiment results for flame length, rate of spread, and consumption (From Lyon et al. 2018).

The results for the effects of prescribed burning masticated fuels on tree growth and resin duct production have been published by Sparks et al. (2017).

- Some trees were injured by flying debris during treatment, but they rapidly recovered
- Tree mortality was nil when masticated fuelbeds were burned in thinned ponderosa pine stands
- Post-fire diameter growth of ponderosa pine trees was greater following low intensity surface fires, similar to unburned and greater than trees where masticated fuels were burned with moderate intensity surface fires (Fig. 5) (Sparks et al. 2017)
- Density of resin ducts in the wood, an indicator of tree defense against insect damage, increased following non-lethal surface fires burning in masticated fuels (Sparks et al. 2017)
- Understory vegetation, including shrubs such as ninebark and ocean spray, resprouted vigorously following burning.

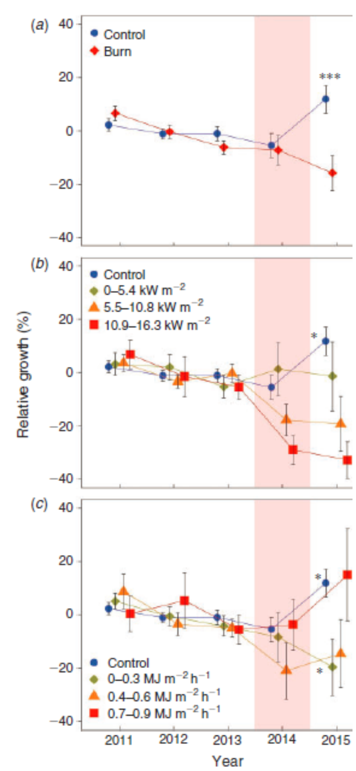


Fig. 5. Relative growth rate of ponderosa pine trees increased after 2014 prescribed fire treatments (pink highlight indicates timing) and was influenced by fire intensity. From Sparks et al. (2017)

Science Delivery and Preparing Current and Future Scientists and Managers

Our findings have been incorporated into academic courses offered both on-campus and online. We have reached more than 80 practicing or potential natural resource managers through our online courses taught to current and future fire professionals (FOR 451 *Fuels Inventory and Management*), and on-campus courses (FOR 427 *Prescribed Burning Lab*, FOR 430 *Forest Operations*).

This project was remarkable for the development of future professionals. First, more than 70 undergraduate students have learned while helping us with our research. This includes students from Brazil and Slovenia. Second, we had 4 MS students and 1 PhD students heavily involved in our research. We also had 3 different postdoctoral research scientists working with us. All of the latter are part of completed or planned publications and conference presentations based on findings from this project, and all have very high potential or already have jobs in their chosen profession, in part because of the experiential learning on this project.

We scheduled 5 field trips with forest managers. The first three were highly successful. Unfortunately, the two scheduled for Sept. 2017 had to be canceled because our potential participants were heavily affected by ongoing fires and smoke. The fire and fuels managers at the Idaho/Montana Airshed Group were very enthusiastic about our project and findings when we presented to them twice (in 2015 and 2016) – they tell us they are increasing their use of mastication in their fuels and forest management programs.

Three refereed journal articles have been published based on our findings (Kreye et al. 2014, Sparks et al. 2017, Lyon et al. 2018). We have submitted a research brief (Morgan et al. Accepted) about our project that will be distributed through the Northern Rockies Fire Science Network.

We have drafted a photo guide for assessing masticated fuels. This is intended to be useful in the field for planning and understanding potential fire behavior. Thanks to help from Roger Ottmar and his team, we expect this to be published as a General Technical Report that will include fire behavior fuel models and FCCS, predicted and observed fire behavior, and predicted emissions.

Data and metadata (Morgan et al. In Review) were submitted to the RMRS Archive in May 2018.

Conclusions (Key Findings) and Implications for Management/Policy and Future Research

We made significant science contributions. The linkages between fuels, burning, and post-fire effects on plants and soils are poorly understood. This is especially so when the dense compact fuelbeds of mixed shreds and chips that result from mastication. Practice is far ahead of science for mastication is widely applied to protect people and property from fire. Careful experiments are needed to understand the "why" behind fire effects and quantify the impacts of different equipment configurations and treatment patterns.

Mastication, in which whole trees, shrubs and other fuels are chipped by machine, is increasingly used before and during fires. Results from this research and other projects clearly show that fires burn less intensely, though they smolder for longer which can lead to soil heating and smoke. As fuel treatments expand, many will burn in wildfires. In Colorado in 2012, embers skipped across masticated fuels "like fleas" in a prescribed burn that escaped and burned homes and killed 3 people. The compact fuelbeds of shredded pieces aren't well represented in fire behavior models; this project and partner project at the Missoula Fire Sciences Lab resulted in practical tools for managers to use: fuel guide, briefs, field tours, and publications that managers can use to inform their decisions.

Our findings support the use of mastication as a fuel treatment to alter fire behavior, especially when masticated fuelbeds burn when they are dry. We advise limiting the depth of masticated fuels to limit soil heating (we think this preliminary result will hold with ongoing analysis). Where fires burn with higher intensity in masticated fuels, managers can expect trees to grow more slowly.

Many managers are interested in our findings for mastication treatments are being widely applied in forests. In many areas fuels are masticated to alter the fire behavior when the compact fuelbeds burn. We look forward to sharing additional products from this research as they become available in the next year.

Acknowledgements

This project was funded by Joint Fire Science Program (JFSP 13-1-05-7) and the University of Idaho. A. Argona assisted with field data collection; she and K. Yedinak assisted with laboratory burning experiments. We thank the students in the For 427 Prescribed Burning Lab class who assisted with preparation, ignition and observing of prescribed fire experiments and the people who assisted with fuel collection and sorting. B. Austin and other University of Idaho Experimental Forest staff assisted with planning and implementing mastication treatments, field data collection, and prescribed burns. A. Abbott advised us on preliminary statistical analysis.

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Kreye JK, Brewer NW, Morgan P, Varner JM, Smith AMS, Hoffman CM, Ottmar RD. 2014. Fire behavior in masticated fuels: A review. *Forest Ecology and Management.* 314: 193–207.

Lyon ZD, Morgan P, Stevens-Rumann CS, Sparks AM, Keefe RF, Smith AMS (2018) Fire behaviour in masticated forest fuels: lab and prescribed fire experiments. *International Journal of Wildland Fire* 27: 280-292. https://doi.org/10.1071/WF17145

Morgan P, Smith A, Sparks A, Stevens-Rumann C, Lyon Z, Keefe R, Sikkink P. Accepted. Fire behavior and ecological effects resulting from burning masticated forest fuels. Research Brief. Northern Rockies Fire Science Network. Available https://www.nrfirescience.org/

Morgan P, Lyon ZD, Sparks AM, Smith AMS, Keefe RF. In review. Fuels and fire behavior from masticated treatments burned in laboratory and field experiments in thinned 30-yr old pine plantations, Idaho. Fort Collins, CO: USDA Forest Service, Forest Service Research Data Archive

Sparks AM, Smith AMS, Talhelm AF, Kolden CA, Yedinak KM, Johnson DM (2017) Impacts of fire radiative flux on mature *Pinus ponderosa* growth and vulnerability to secondary mortality agents. *International Journal of Wildland Fire* 26: 95-106.

Appendix A: Contact Information for Key Project Personnel

Principal Investigators:
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Appendix B:
List of Completed/Planned Scientific/Technical Publications/Science Delivery Products

1. **Articles in peer-reviewed journals**

   Kreye JK, Brewer NW, Morgan P, Varner JM, Smith AMS, Hoffman CM, Ottmar RD. 2014. Fire behavior in masticated fuels: A review. *Forest Ecology and Management.* 314: 193–207.

   Sparks AM, Smith AMS, Talhelm AF, Kolden CA, Yedinak KM, Johnson DM (2017) Impacts of fire radiative flux on mature *Pinus ponderosa* growth and vulnerability to secondary mortality agents. *International Journal of Wildland Fire* **26**, 95-106.

   Lyon, Z. P. Morgan, A. Sparks, C. Stevens-Rumann, R. Keefe, and A.M.S. Smith. In prep. Fire behavior in masticated forest fuels: lab and prescribed burn experiments. Submitted to International Journal of Wildland Fire in September 2017.

   Smith, AMS, P. Morgan et al. In preparation. Soil heating, soil chemistry, and plant response when masticated fuels burn. Intended refereed journal not identified yet (submit by May 2018)

   Tomayko, A., P. Morgan, et al. In preparation. Vegetation response to burning and mastication. Forest Ecology and Management (submit by May 2018)

   Becker, R., R. F. Keefe et al. In preparation. Real-time positioning to quantify operational efficiency and soil impacts during stand mastication treatments. Canadian Journal of Forest Research. (submit by May 2018).

2. **Technical reports**

   Morgan P., PG Sikkink, AM Sparks, ZD Lyon, A Tomayko, A Andreu, FA Heinsch, S Prichard, R Ottmar, TB Jain, J Hyde, R Keefe, AMS Smith. In preparation. Guide for Assessing Masticated Fuels in Mixed-Conifer Forests in Western US. General Technical Report PNW-GTR-xxx.

3. **Text books or book chapters**

   None

4. **Graduate thesis (masters or doctoral)**

   Lyon ZD. 2015. Fire Behavior in Masticated Forest Fuels: Lab and Prescribed Burn Experiments. University of Idaho MS Thesis.

   Sparks AM. 2017. Development of a Spatial Severity Model for the Quantification of Wildland Fire Effects in Coniferous Forests. University of Idaho PhD Dissertation.

   Tomayko A. 2018 (planned). Vegetation diversity and growth in burned and unburned mastication treatments in forests. University of Idaho MS Thesis.

5. **Conference or symposium proceedings scientifically recognized and references (other than abstracts)**

   None

6. **Conference or symposium abstracts**

   Many.

7. **Posters**

   Tomayko A et al. 2017. Vegetation response to burning and mastication. Society of American Foresters Annual Meeting. Nov. 2017. Poster

Tomayko A et al. 2017. Vegetation response to burning and mastication. AFE International Fire Ecology Congress, Nov. 2017.

Morgan, P and R Keefe. 2016. Fire behavior in masticated fuels. MT-ID Airshed Group Annual meeting. Feb 10, 2016. 45 participants. Invited The fire and fuels managers at the Idaho/Montana Airshed Group were very enthusiastic about our project and findings when we presented to them twice – they tell us they are increasing their use of mastication in their fuels and forest management programs.

Morgan, P. Z. Lyon, A. Sparks, A.M.S. Smith and R. Keefe. 2015. Fire behavior in masticated fuels burned in lab and field experiments. 6th International Fire Ecology and Management Congress, San Antonio, Texas, 17 Nov 2015. Oral presentation, Invited

Lyon, Z., A. Sparks, Penelope Morgan, R.Keefe, and A.M.S. Smith. 2015. Prescribed burns in masticated fuels. 6th International Fire Ecology and Management Congress, San Antonio, Texas, 17 Nov 2015. Poster presentation.

8. Workshop materials and outcome reports

None

9. Field demonstrations/tour summaries

5 were planned and 3 were completed by Sept. 2017. Since then many others have visited the field sites and IFIRE combustion lab where they heard about our research.

10. Website development

None

11. Presentation/webinars/other outreach/science delivery materials

Our findings have been incorporated into academic courses offered both on-campus and online. We have reached more than 80 practicing or potential natural resource managers through our online courses taught to current and future fire professionals (FOR 451 *Fuels Inventory and Management*), and on-campus courses (FOR 427 *Prescribed Burning Lab*, FOR 430 *Forest Operations*).

Presentations

Morgan, P and R Keefe. 2016. Fire behavior in masticated fuels. MT-ID Airshed Group Annual meeting. Feb 10, 2016. 45 participants. Invited

Morgan, P and R Keefe. 2015. Fire behavior in masticated fuels. MT-ID Airshed Group Annual meeting. Feb 10, 2016. 45 participants.

Morgan, P. Z. Lyon, A. Sparks, A.M.S. Smith and R. Keefe. 2015. Fire behavior in masticated fuels burned in lab and field experiments. 6th International Fire Ecology and Management Congress, San Antonio, Texas, 17 Nov 2015. Oral presentation, Invited

Appendix C: Metadata and Data Submitted to RMRS Data Archive in May 2018

These were submitted to RMRS for data archiving on 18 May 2018 following earlier email contact with Laurie Porth for advice about format and content. As outlined in our Data Management Plan metadata and data were provided for the USDA Forest Service, Forest Service Research Data Archive. For each spreadsheet file, there is a data description for all the variables included in the spreadsheet, and also a metadata description document following the RMRS guidelines.

1. Spreadsheet of fuels and fire behavior from Year 1 prescribed fire field and laboratory experiments; includes tree inventory before and after mastication
    a. Year1_FuelsAndFireBx_RxBurnsFieldAndLab
    b. Metadata_JFSP13-1-05-7UnivIdaho_MasticationFireBx_Fuelbeds_FieldAndLab_Year1
2. Spreadsheets of observed fuel loading by size class observed in replicate stands with mastication experiments in Year 2 (this is late summer 2015).
    a. Fuel_Loading_Year2
    b. Metadata_JFSP13-1-05-7UnivIdaho_MasticationFuelLoading_Year2
3. Spreadsheets of observed flame length, rate of spread and consumption (depth and mass) for laboratory and prescribed fire experiments conducted in laboratory burn experiments organized by mastication treatment and stand.
    a. FireBx_and_Consumption_LabFireExperiments_Year2
    b. Metadata_JFSP13-1-05-7UnivIdaho_MasticationFireBx_Consumption_Lab_Year2
4. Master spreadsheets of fuel and fire behavior from Year 1 and Year 2 organized by stand, treatment and plot (some data duplicate other spreadsheets)
    a. FinalMasterMasticationLabFireBxAndFuels
    b. Metadata_JFSP13-1-05-7UnivIdaho_Mastication_FinalMasterMasticationLabFireBxAndFuels
5. Spreadsheet of tree-ring relative growth rate and resin duct counts with fire intensity values inferred from the videos from prescribed burns. Data include 1) active fire measurements derived from tower-mounted, dual-band infrared radiometers located in October 2014 mastication prescribed burns at the University of Idaho Experimental Forest, and 2) post-fire radial growth and axial resin duct characteristics derived from increment cores for 62 ponderosa pine individuals in the mastication project plots.
    a. post_Rxburn_PIPO_growth_and_resin_ducts
    b. Metadata_RMRS_MasticationFireBx_postfire_Tree_Growth_and_ResinDucts_UnivIdaho