HOW DO PILE AGE AND SEASON OF BURN INFLUENCE COMBUSTION AND FIRE EFFECTS?

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ABSTRACT:

Typical hazardous fuel reduction treatments target small diameter trees for removal producing large amounts of woody material, much of which is piled and burned on site. Little is known about how physical characteristics and the environmental conditions under which piles are burned affects atmospheric emissions, carbon pools and fluxes, soils, and vegetation. We conducted experimental pile burns in the Pacific Northwest and the Southwest to provide managers in these regions with new information documenting the effects of burning piles of increasing age under different environmental conditions. Specifically we measured duration of flaming combustion, fuel consumption, charcoal production, burn intensity (below ground heat fluxes), changes in soil properties (biochemistry and hydrophobicity), adjacent tree damage, surface vegetation responses, and changes in invasive species prevalence after pile burning.

Study sites were located in areas that had undergone a typical "thin from below" silvicultural fuel treatment in the summer of 2011. We constructed, characterized, and instrumented 100 piles (50 in Washington and 50 in New Mexico), and burned replicate piles (n=5) at approximately six-month intervals to test the effects on the above-listed measures of increasing age (0, 0.5, 1, 1.5, and 2 years since piling) under two different burning seasons (spring vs. fall). By tracking piles over time we found that volume loss resulting from compression appears fairly consistent and, for our sites, did not appear to be a function of the contents of the pile or the location. Mass loss rate, however, differed by location with piles in New Mexico, which lacked large woody material, decomposing at a faster rate than piles in Washington, which included numerous pieces of 10-20 cm diameter tree boles left over from thinning. Soil heating, even with relatively small (i.e., <1.2 m tall) hand piles was intense and long: maximum temperatures exceeded 400°C and temperatures in excess of 60°C – a point above which plant tissue depth is thought to occur when exposure is in excess of 1 minute – lasted for many hours. High temperatures and long duration, however, only occurred in the top 15 cm of the soil layer and only within approximately one-third to one-half of the pile footprint. Our study noted no significant damage to overstory trees, likely as a result of relatively limited depth and areal extent of soil heating and the wide spacing of overstory trees relative to the flame heights achieved during pile burning. Likewise, soil biochemical properties returned to unburned levels within one year of burning, although vegetation recovery is slow within the pile footprint. Despite an extended period of post-fire mineral soil exposure owing to slow vegetation recovery, invasive species colonization was minimal for our study sites.

In addition to a rich data set documenting pre-burn, day-of-burn, and post-burn measurements of a wide variety of metrics, this project is generating three peer-reviewed publications documenting the effects of burning piles of different age on combustion dynamics and soil, fuel, and vegetation properties, and one manager-focused article reporting on the current state of knowledge regarding what happens when wildfires burn through areas with piled fuels. Providing detailed, quantitative information about the effects of pile burning will help fuel and fire practitioners make informed management decisions about when to burn and how to minimize potential negative emissions, soil, carbon, and vegetation impacts.

BACKGROUND AND PURPOSE:

1. Introduction

Vast areas of conifer-dominated forests across the western United States (U.S.) are increasingly at risk of stand-replacing wildfires (e.g., Fulé et al. 2004, Noss et al. 2006). In many areas, a century of fire suppression, intensive grazing, and logging have created forests that are overstocked with small diameter trees (Covington and Moore 1994, Keane et al. 2002). To reduce the likelihood of uncharacteristic wildfire in these overstocked forests, vast areas of fuels reduction treatments are being implemented each year. For example, federal land management agencies treated fuels on 1.4 million hectares annually between 2005 and 2014.[1] Typical hazardous fuel reduction treatments target small diameter trees for removal producing large amounts of unmerchantable woody material and elevating surface fuel loadings (Agee et al. 2000, Finkral and Evans 2008, Fulé et al. 2002, Hjerpe et al. 2009). Currently there are few commercial markets for this woody material, so it is commonly piled by hand or with heavy machinery and burned on site (Evans and Finkral 2009, Han et al. 2010).

Research on pile burning has recently expanded to address key topics such as emissions, carbon dynamics, and ecological effects. Because of concerns about smoke and air quality, fire, fuel, and air-quality managers must understand and be able to quantify emissions when piles are burned. Pile burning releases CO_2 into the atmosphere and converts biomass to charcoal and pyrolized soil organic matter (pSOM) when combustion is incomplete. Both processes affect total ecosystem carbon pools and fluxes (DeLuca and Aplet 2008, Finkral et al. 2012, Forbes et al. 2006, González-Pérez et al. 2004). Pile burning can also significantly change soil processes (Seymour and Tecle 2005, Covington et al. 1991), plant establishment (Korb et al. 2004), and adjacent vegetation (Hillstrom and Halpern 2008). The effects of pile burning, however, may depend on factors that change fuel and combustion characteristics (e.g., Hardy 1996, Johnson 1984) such as pile age, the type of material piled, and season of burning. The purpose of this study was to examine how piles change with age and how those changes affect the amount of biomass consumed, the rate and intensity of pile combustion, carbon dynamics, soil characteristics, and vegetation response under different seasonal burning conditions.

2. Objectives

We addressed scientific questions regarding the effects of pile burning with an experimental design that tested the effects of pile burning across a range of pile

[1] FY 2014 Wildland Fire Management Annual Report [http://www.doi.gov/pmb/owf/upload/2016_01_12_FY-2014-WFM-Annual-Rpt_Final2.pdf]

attributes associated with pile age (i.e., time-since-pile-creation) in two locations where pile burning is a common method for removing surface fuels created by mechanical fuel treatment.

Although pile construction methods and sizes vary across the western U.S., we chose to study hand piles of modest size (approximately 4 m^3) as these are typical for many "thin from below" fuel treatments that include piling and burning as a means to dispose of the thinning debris. The primary objective of this research was to determine how pile age (and the attendant changes in pile attributes that accompany aging) and environmental conditions affect fuel consumption, combustion characteristics, carbon dynamics, soil properties, and vegetation response in different geographic regions.

Specifically, we were interested in quantifying:

1. how pile attributes change with time,
2. how pile age and burn season affect combustion rate and intensity,
3. how pile age and burn season affect carbon dynamics (i.e., fuel consumption and charcoal production), soil properties, and vegetation response (including crown scorch; understory recovery, colonization, and re-growth; species richness and diversity; and invasive species presence and prevalence),
4. whether (1)-(3) differ regionally, and
5. how pile composition (i.e., fuel particle size) affects (1)-(3).

Providing fuel and fire practitioners with detailed, quantitative information about the effects of hand pile burning can be used to inform key management decisions about when to burn and how to minimize potential negative emissions, soil, carbon, and vegetation impacts.

As a secondary objective, we sought to understand the degree to which piled fuels burn during wildfires, and whether their presence affected the behavior of the wildfire and the post-fire effects. This objective was addressed by searching the literature and interviewing fire and fuel managers who had observed wildfires burning in areas with piled fuels. A synthesis of these findings (Evans and Wright *in press*) is reported in Appendix D.

STUDY DESCRIPTION AND LOCATION:

1. Study Areas

Two 2-3 ha study sites, one each on the Santa Clara Pueblo (hereafter Santa Clara) in north-central New Mexico and the Naches Ranger District (hereafter Naches) of the Okanogan-Wenatchee National Forest in central Washington, were selected for study

(Table 1, Appendix A). Both sites were in dry conifer forests that had been recently thinned of small diameter (<20 cm diameter at breast height; d.b.h.) trees to reduce stand density. Thinning debris at both sites had been piled by hand; piles were approximately 2.5-3 m in diameter and 1.2-1.5 m tall. Piles at the Santa Clara site were composed of <7.6 cm diameter woody material only (branches and small tops), as the area had been made available for firewood collection prior to piling. In contrast, the piles at the Naches site included tops, branchwood, and 2-m long pieces of bole wood up to approximately 20 cm in diameter.

Table 1. Site data for study locations on the Naches Ranger District, Okanogan-Wenatchee National Forest in central Washington and the Santa Clara Pueblo in north-central New Mexico.

Site characteristics	Naches, WA	Santa Clara, NM
Overstory		
Dominant tree species	Ponderosa pine	Ponderosa pine
Density (trees ha^{-1} ± SE)	274 ± 24	239 ± 19
Mean d.b.h. (cm ± SE)	18.9 ± 1.2	29.2 ± 2.0
Mean tree height (m ± SE)	8.9 ± 0.6	14.0 ± 1.0
Basal area (m^2 ha^{-1} ± SE)	10.0 ± 1.2	18.5 ± 1.6
Understory		
Dominant pre-burn species	Idaho fescue	Blue grama
Pre-burn coverage (% ± SE)	55.8 ± 3.2	20.5 ± 1.2
Pre-burn richness (spp. $plot^{-1}$ ± SE)	4.7 ± 0.1	3.3 ± 0.1
Piles		
Density (piles ha^{-1} ± SE)	90 ± 18	50
Pre-burn volume (m^3 ± SE)	2.34 ± 0.08	2.68 ± 0.06
Pre-burn biomass (kg ± SE)	203.0 ± 4.7	73.5 ± 2.0
Pre-burn bulk density (kg m^{-3} ± SE)	89.9 ± 2.9	27.9 ± 0.9
Soils		
Sand / silt / clay fractions (%)	67 / 28 / 4	63 / 29 / 8
Organic matter (% ± SE)	7.79 ± 0.18	6.54 ± 0.22

The Santa Clara site was located on relatively flat ground at 2,400 m elevation 20 km west of Española, New Mexico in the Jemez Mountains (N36° 0' 56.4"; W106° 16' 59.9"). The site is in a mature ponderosa pine (*Pinus ponderosa*) stand (±29 cm d.b.h.) with a sparsely vegetated understory. The stand was thinned to a basal area of 18.5 m^2 ha^{-1} in 2011; thinning debris (branches and tops only) was piled by hand at a density of 50 piles ha^{-1}. Total understory vegetation coverage was 21 percent before piles were constructed, and dominated by blue grama (*Bouteloua gracilis*), prairie Junegrass (*Koeleria macrantha*), and awnless brome (*Bromus inermis*). The site is characterized by hot summers (mean summer maximum temperature of 32°C) and cold winters (mean winter minimum temperature of -14°C) with an overall average temperate of 10°C, and gets between 26 and 38 cm of precipitation with much of it coming in the summer and fall during the monsoon period (Santa Clara Canyon RAWS). Soils are well-drained Totavi gravelly loam (NRCS 2015).

The Naches site was located on gently sloping terrain (5-15 percent slope, easterly aspect) at 1,130 m elevation, above Rimrock Lake approximately 50 km southeast of Mt. Rainier in the eastern Cascade Range (N46° 39' 25.9"; W121° 09' 26.6") of Washington. The site is in a mixed conifer stand comprised of a mixture of 15 to 20 cm d.b.h. ponderosa pine, western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), and grand fir (*Abies grandis*), with scattered, remnant, old-growth (70-125 cm d.b.h.) ponderosa pine and western larch. The stand was thinned to a basal area of 10.0 m^2 ha^{-1} in 2011; thinning debris was piled by hand at a density of 90 piles ha^{-1}. Total understory vegetation coverage was 56 percent, and was dominated by herbaceous species, including Idaho fescue (*Festuca idahoensis*), Virginia strawberry (*Fragaria virginiana*), elk sedge (*Carex geyeri*), and pine grass (*Calamagrostis rubescens*), with scattered low shrubs, including kinnikinnick (*Arctostaphylos uva-ursi*), twinflower (*Linnaea borealis*), and grouse whortleberry (*Vaccinium scoparium*). The area is characterized by warm, dry summers (mean July-August maximum temperature of 23°C; July-August precipitation of 3 cm) and cold, wet winters (mean December-February minimum temperature of -5°C and precipitation of 43 cm), with most precipitation falling as snow (Prism Climate Group 2015). Soils are well-drained McDanielake ashy sandy loam (NRCS 2015).

2. Study Methods

a. Study Design:

To test for potential differences in the effects of burning piles of different ages under different environmental conditions (i.e., different seasons) we employed a blocked (2 locations), factorial design (5 pile ages × 2 burning seasons) with replication (5 replicates per factor combination; Figure 1).

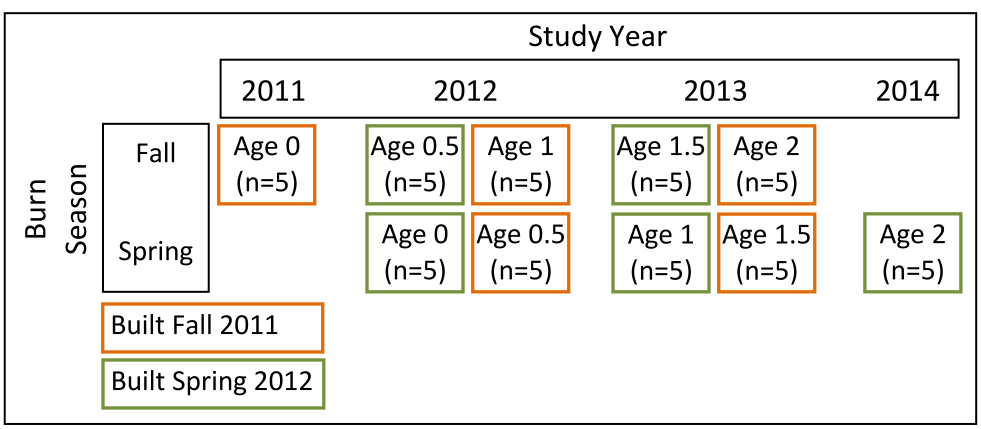

Figure 1. Experimental design and treatment timeline. A total of 100 piles of five different ages were burned under spring and fall burning conditions in Washington (n=49) and New Mexico (n=50).

Immediately before the first fall (2011) and spring (2012) burning periods we built 25 piles of equal size at each location and then proceeded to burn piles to achieve a fully crossed design. Piles were composed of coniferous thinning debris, sized to reflect typical piling specifications for the location (2-4 m^3), and separated by at least 10 m. Pile volume and oven-dry mass were measured, and piles were assigned to age-based treatment categories during this initial set-up phase of the experiment (see Field Measurements for additional detail on methods for determining oven-dry pile weight and volume). Burning occurred under weather conditions typical of pile burning during each burning season at each site. For each season × study year time period, all piles were ignited on the same day over a period of 2-3 hours to minimize differences in burning conditions. Safety concerns prevented simultaneous ignition of all scheduled piles during the burning periods.

b. Field Measurements:
Three to five person field crews from the Pacific Wildland Fire Sciences Laboratory (under the direction of PI Wright) and the Santa Clara Pueblo (under the direction of co-PI Evans) conducted pre-burn, day-of-burn, and post-burn fuel inventory measurements at the Naches and Santa Clara sites, respectively. Field personnel worked in close cooperation with fire managers at the selected sites to coordinate pre-burn and post-burn sampling activities and to conduct pile burns. All research personnel present during burning operations were fireline qualified and equipped with the appropriate personal protective equipment for fireline duty.

Understory vegetation, soil heating, pile construction, and pile inventory – A piece of 1.3-cm diameter, galvanized steel electrical conduit with a uniquely numbered steel tag was driven into the ground until 1.2 m protruded above the surface to mark the center of each experimental pile (Figure 2) adjacent to a randomly selected existing pile. A 1.2-m radius was marked around each pile center to define the 4.52-m^2 footprint of each experimental pile. Prior to experimental pile construction, understory vegetation composition (coverage by species) was visually estimated in three 0.25-m^2 square plots within the pile footprint. The corners of understory vegetation plots were marked with 15-cm long steel nails to facilitate plot re-establishment for post-burn sampling. Vegetation coverage was remeasured at one-year intervals (summers of 2012, 2013, 2014, 2015) to explore recovery rates and potential for invasive species colonization.

Sixteen type-K thermocouples (Omega[2] SRTC-TT-K, bead type, 24 gage with PFA insulation of varying length) were inserted into undisturbed soil beneath the pile footprint at four depths (0, 5, 15, and 30 cm) and four distances from the pile center (0.2,

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

0.7, 1.2, and 1.4 m) by way of a narrow trench dug with the contour from near the center of the pile outwards (Figures 2 and 3). All thermocouple leads were labeled with their horizontal and vertical position and terminated in a sealed plastic bucket buried near the pile edge to facilitate rapid data logger deployment on the day of burning.

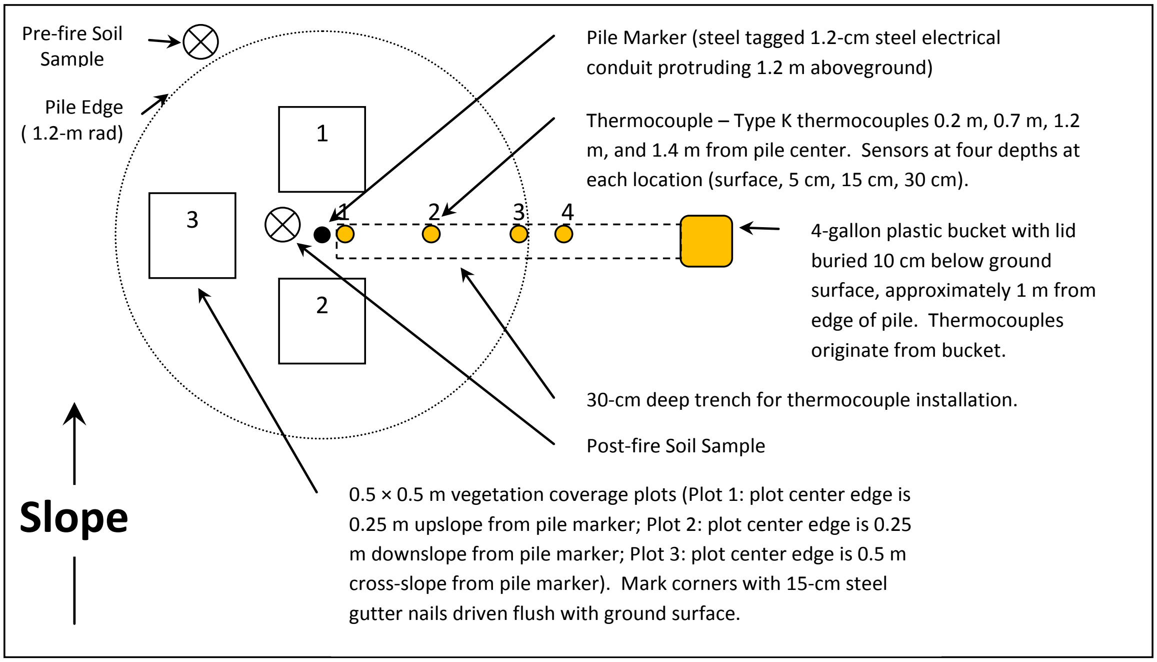

Figure 2. Pile, understory vegetation plot, soil core, and thermocouple layout.

Upon completion of understory vegetation measurements, soil core collection, and thermocouple installation, the adjacent pile was deconstructed, weighed with hanging scales, and re-constructed within the marked, 1.2-m radius experimental pile footprint using methods similar to those outline in Wright et al. (2010). Material was added to each pile until the pile height reached the top of the 1.2-m tall electrical conduit. At the Naches site, fuels were separated by size class (<7.6 and ≥7.6-cm diameter) during the deconstruction and weighing process; experimental piles at the Naches site were composed of alternating layers of small and large diameter fuels, and were covered with a layer of waxed craft paper. Pile biomass measurements were corrected to a dry weight basis by collecting moisture content subsamples that represented the size and type of material in each pile. Moisture content subsamples were weighed upon collection, returned to the Pacific Wildland Fire Sciences Laboratory, oven dried at 100°C to a constant weight (at least 48 hours) and re-weighed to determine the ratio of dry weight-to-wet weight for use in correcting to a dry weight basis. Attempts were made to build piles of comparable volume, weight, and size class composition within each site.

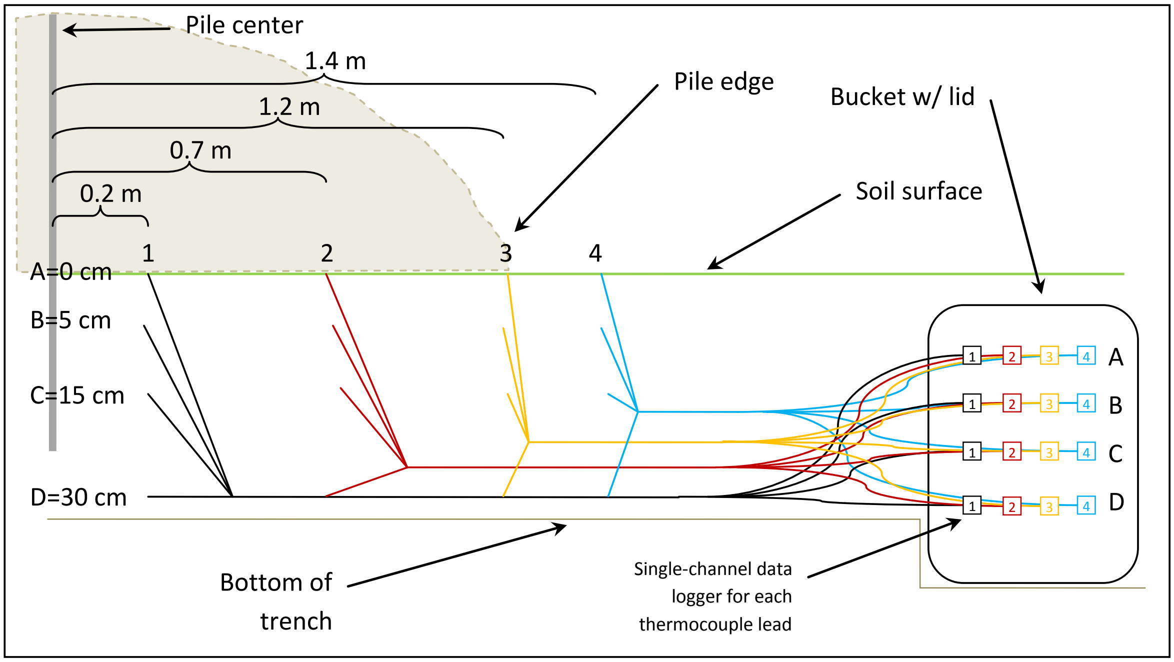

Figure 3. Thermocouple installation diagram.

Pile shape was noted and dimensions were measured upon completion of pile building and again prior to burning. Change in pile height with time was determined by measuring down from the top of the conduit to the top of the pile prior to burning. Standard geometric equations for parabolic, hemi-ellipsoidal, and hemi-spherical shapes were used to estimate the geometric volume of each pile.

Pile density was estimated visually at the Santa Clara site and measured at Naches site by counting the number of piles in eight 0.08-ha circular, fixed-area plots distributed systematically across each sample site. To be counted, at least half of a pile had to be located within the plot boundary.

Overstory structure and post-burn crown scorch – Overstory structure and composition of trees > 10 cm d.b.h. were determined by employing the point-centered quarter method (Cottam and Curtis 1956). Each pile center was considered a point, which yielded a sample with 50 points and 200 trees. The species was noted and the distance from the pile center, d.b.h., height, and height to crown base were measured for each of the four trees inventoried at each point. Only live trees were included in the inventory. Having been recently thinned, however, dead trees were essentially absent from both sites. Scorch height was measured if crown scorch was evident within the first year after burning to assess crown damage from pile burning.

Day-of-burn weather, fuel and soil moisture, and fire intensity – An automated, logging weather station was set-up at each site prior to burning to record ambient weather conditions (windspeed and direction, temperature, relative humidity, and precipitation) antecedent to and during the day of each burn.

Grab samples of needle litter and woody material by size class (<0.6 cm, 0.6-2.5 cm, 2.5-7.6 cm, and >7.6 cm in diameter) were collected immediately prior to burning to assess fuel moisture content at the Naches site. Fuel moisture samples from whole branches (i.e., a composite of the three smallest size classes) were also collected at both study sites. In addition an approximately 15-cm deep soil core was collected from beneath each pile scheduled for burning to measure the moisture content of the surface and upper soil layer. All moisture content samples were collected in heavy gauge re-sealable plastic bags, weighed shortly after collection, returned to the Pacific Wildland Fire Sciences Laboratory, oven dried at 100°C for a minimum of 48 hours and re-weighed to determine gravimetric moisture content.

Single channel data loggers (Onset U-12-014 and Lascar EL-USB-TC-LCD) were attached to each thermocouple and allowed to log soil temperature at 10-second intervals during and for several days following pile burning. Maximum temperature and duration of flaming combustion in excess 60°C – the temperature above which plant tissues are killed (Hare 1961) – were used to compare fire intensity and soil heating effects among piles, among treatments, and between sites.

All piles were ignited with drip torches and allowed to burn freely until they self-extinguished. Piles were only minimally tended during burning. Time of ignition, flame height at periodic intervals during flaming combustion, and flaming duration were noted for each pile. Three-meter tall steel poles, graduated in 30-cm increments were installed immediately adjacent to each pile to serve as scale references for visually estimating flame height during combustion. Thermal infrared images were captured periodically, as possible, during burning to try to characterize the nature of the upward and lateral, aboveground heat pulse.

Fuel consumption and charcoal – Immediately following completion of burning, fuel consumption and charcoal formation were assessed by collecting residual biomass in two 0.60 m^2 wedge-shaped plots located on opposite sides of the original pile footprint (Figure 4). All organic matter within the wedge-shaped plots was collected, sorted into unburned wood, charcoal, and ash and returned to the Pacific Wildland Fire Sciences Laboratory where it was oven dried at 100°C for a minimum of 48 hours. Partially combusted woody material was further processed during the sorting process; charcoal fragments were separated from unburned woody using small hand tools to get a full accounting of the fraction of organic material that was converted to charcoal for each burn pile. After oven drying, residual woody material, charcoal, and ash were weighed

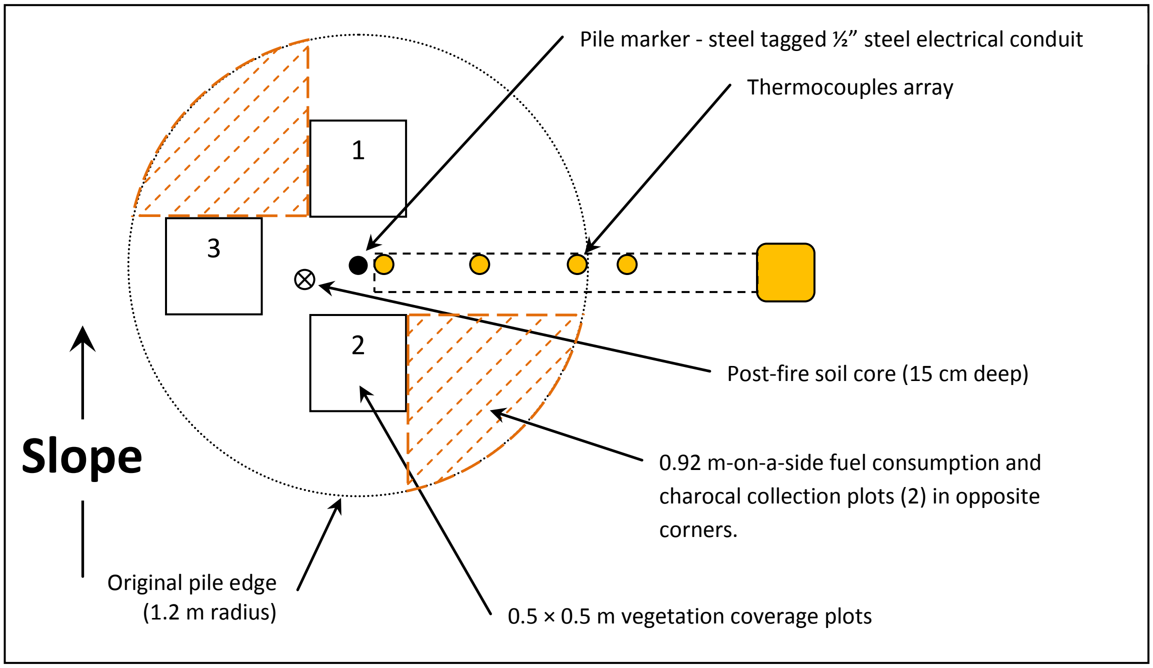

Figure 4. Post-burn fuel consumption and charcoal measurement plot layout.

on a precision balance to determine post-burn oven-dry weight, fuel consumption, and charcoal conversion fraction.

Pile mass loss rate – As pile mass declines with age owing to breakage and decomposition, and we expected these changes to affect combustion properties and attendant fire effects, we measured pile mass loss on five additional piles at each site. Mass loss rate piles were constructed on top of reinforced chain-link fence panels wrapped in galvanized steel mesh (6-mm hole size) to minimize material loss through fine branch breakage and needle excision as piles aged. Mass loss pile construction followed the same methods as described for burn piles. Mass loss piles were re-weighed on every burn date (roughly every six months) and for one year following the completion of the burning schedule. Weighing was accomplished by hoisting the entire chain-link fence panel off the ground using slings attached to a high-capacity hanging scale and chain hoist suspended from a 4.2-m tall aluminum utility tripod centered over each pile (Figure 5).

Figure 5. Pile mass loss measurement apparatus.

Day-of-burn fuel moisture samples were used to adjust field weight to an oven-dry basis.

Pile mass loss rate was determined by fitting a negative exponential curve of the form $X/X_0 = e^{-kt}$, where X_0 is the starting dry mass, X is the mass at time t (in months) and k is the fractional mass loss or decay rate constant (Olson 1965). Separate mass loss rate constants were derived for the Santa Clara and Naches sites. The site specific decay curves were used to adjust each pile commensurate with the time since it was built so that estimates of fuel characteristics (i.e., loading and bulk density), consumption and charcoal production were based on the pile weight at the time of burning.

Soils – To minimize soil disturbance within the experimental pile footprint, a 4-cm diameter, 15-cm deep soil core was collected adjacent to each experimental pile at the time of pile construction. Additional soil cores were collected immediately after burning and at the conclusion of the study period in the summer of 2015 from within 50 cm of the pile center.

Soil samples were stored in heavy gauge re-sealable plastic bags and shipped immediately to Northern Arizona University where they were stored at 4°C until analysis. All soils were passed through a 2 mm sieve prior to processing. Samples from the 2011 collection (pre-burn) were analyzed for texture and total organic matter. Particle size analysis was conducted on a 30-g subsample from each pile via the hydrometer method (Gee and Bauder 1986). A 5-g oven-dried subsample was combusted at 350°C to estimate total organic matter content via loss on ignition (Schumacher 2002). To assess the effects of pile burning on soil properties, samples from the 2015 collection (post-burn) were subjected to chemical and biological analyses: total organic matter, available nitrogen (N), available phosphorus (P), micronutrient concentrations (Mg, Ca and K), and both ectomycorrhizal (EMF) and arbuscular mycorrhizal (AMF) inoculum potential.

Post-burn samples were analyzed for organic matter content as described for pre-burn samples above. To analyze post-burn samples for P availability, the widely used Olsen method (Olsen et al. 1954) was followed. In brief, ~10 g air-dry subsamples were dispensed into 100-mL specimen cups then extracted in 50 mL of 0.5M $NaHCO_3$. Samples were placed on a shaker at 100 RPM for two hours with the refrigeration set to 4°C. After settling overnight at 4°C, samples were filtered through 11-cm diameter Whatman #1 filter papers. Samples were then frozen before colorimetric analysis (Lachat QuikChem Method 10-115-01-1-A, Orthophosphate in Waters). To analyze samples for N availability (NH_4^+ and NO_3^-), a 14-day aerobic incubation was conducted. Two ~20-g field-moist subsamples from each pile were dispensed into 120-mL specimen cups. One was immediately extracted in 50 mL of 2.0M $BaCl_2$. The other was tightly capped and placed in a dark cabinet at room temperature to incubate for 14 days, after which it was extracted in 50 mL of 2.0M $BaCl_2$. After extraction, samples were shaken for 1 hr then filtered through 11-cm diameter Whatman #1 filter paper. Samples were then frozen until colorimetric analysis (Lachat QuikChem Method No. 12-107-06-2-A and 12-107-04-1-B for NH_4^+ and NO_3^-, respectively). A separate aliquot was dispensed from unincubated $BaCl_2$ extracts to analyze for nutrient cation (Mg, Ca and K) concentrations on a flame atomic absorption spectrophotometer (Perkin-Elmer 100).

Figure 6. Ponderosa pine seedlings in greenhouse will be assayed for ectomycorrhizal inoculum potential.

To analyze soils for mycorrhizal inoculum potential two sets of soils were prepared: one set from all 55 piles (i.e., the 50 burn piles and 5 mass loss piles) from each site (total n = 110) was prepared for AMF potential analysis, and a second set was prepared for EMF potential analysis. All soils were sieved then dispensed into 12-cm conetainers (cylindrical containers with drainage holes; Stuewe and Sons, OR). Two seeds of organic (untreated) corn were placed in each conetainer in the set for AMF potential, and three seeds of ponderosa pine (of northern AZ provenance) were placed in each conetainer in the set for EMF potential (Figure 6). Conetainers were watered daily until germination. Following germination, seedlings were allowed to grow for ~3 days (corn) and ~7 days (ponderosa pine) at which point all conetainers were thinned to one seedling (Figure 6). Corn seedlings were harvested after 6 weeks of growth and ponderosa pine seedlings were harvested after 12 weeks of growth. At harvest, roots were separated from shoots and soil was gently washed from the root mass. Roots were patted dry, placed in plastic resealable bags, and frozen (4°C) until staining and clearing (for AMF) or microscopy (for EMF).

Corn roots were stained and cleared following the protocol of Vasquez et al. (2000). Ten 1-cm lengths were cut randomly from each root sample and mounted on slides with grids. Roots were then viewed under 10X magnification, and AMF structures were noted at each grid intersection (McGonigle et al. 1990). The number of grid intersections occupied by structures was used to calculate a proportion for each sample, which was used to express abundance. Similarly, ponderosa pine roots were examined under a dissecting microscope to identify the proportion of root tips colonized by EMF structures.

Soil water repellency/hyrophobicity was assessed immediately post-burn by using the water drop penetration time method (Letey 1969). Water drop penetration time tests were performed at the soil surface and at 2-cm depth from within the burned pile footprint. Soils were classified based on water drop absorption times outlined by Doerr (1998) as very hydrophillic (<5 seconds), hydrophilic (5-60 seconds), slightly hydrophobic (60-180 seconds), or moderately to extremely hydrophobic (>180 seconds).

c. Data Analysis:

The experimental design allowed us to test for mean differences in response variables associated with pile age, season-of-burn, and location (site) using a two-factor analysis of variance (ANOVA) with site as an added blocking factor (Zar 1984). If the site main effect was significant, separate 2-factor ANOVAs were performed for each site to test for the effects of treatment (i.e., pile age and season-of-burn) on the different response variables. *Post-hoc* Tukey HSD multiple comparison tests (Tukey 1949) were used to identify significant differences among means within treatments.

KEY FINDINGS AND MANAGEMENT IMPLICATIONS:

1. Pile properties change with time

- Piled debris compresses over time following pile construction. This leads to losses in volume. Volume loss resulting from compression appears fairly consistent and, for our sites, did not appear to be a function of the contents of the pile or the location. Larger logs can weigh down more flexible branches and tops layered beneath them, but also resist compression owing to their less flexible nature, perhaps contributing to the patterns observed in this study (Figure 7). Location (i.e., an area's snowpack) may

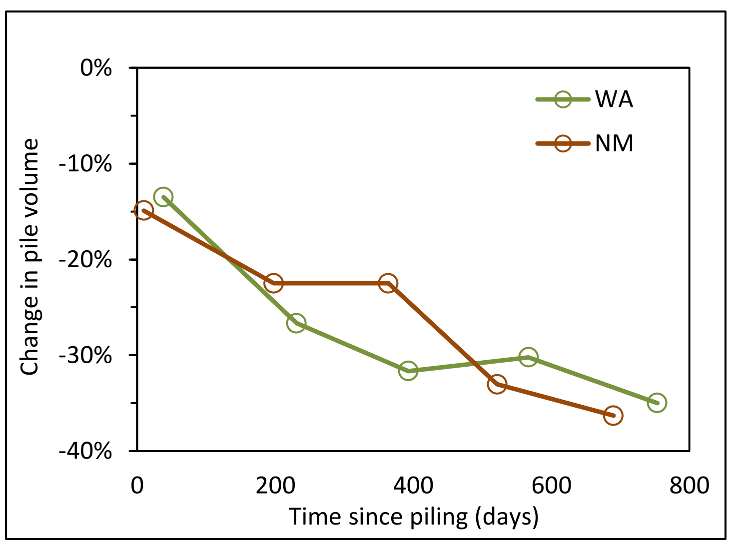

Figure 7. Change in pile volume for piles in Washington with large woody material and piles in New Mexico without large woody material.

also be an important factor over longer time periods, as over-wintering piles may become more compressed in snowier environments, or may experience greater compression after the first winter season owing to elevated snow loads.

- Reductions in pile volume coupled with slow loss of mass through decomposition, causes bulk density to increase as piles age. Although volume changes over time were not appreciably different between study sites in Washington and New Mexico, the pile decomposition rates did differ (Figure 8), contributing to piles with different bulk properties and combustion characteristics at the time of burning. The observed difference among study sites is likely a function of the differences in pile composition more so than the actual location, although environmental conditions, as well as species characteristics have been shown to affect decomposition rates (Edmonds 1980, 1987). Piles with large woody material, such as those in Washington, had a slower overall decomposition rate, as large logs decay more slowly than small woody material (Harmon et al. 1986). Owing largely to the different decomposition rate between piles with and without large woody material, bulk density will have a tendency to increases more over time for piles with large woody material.

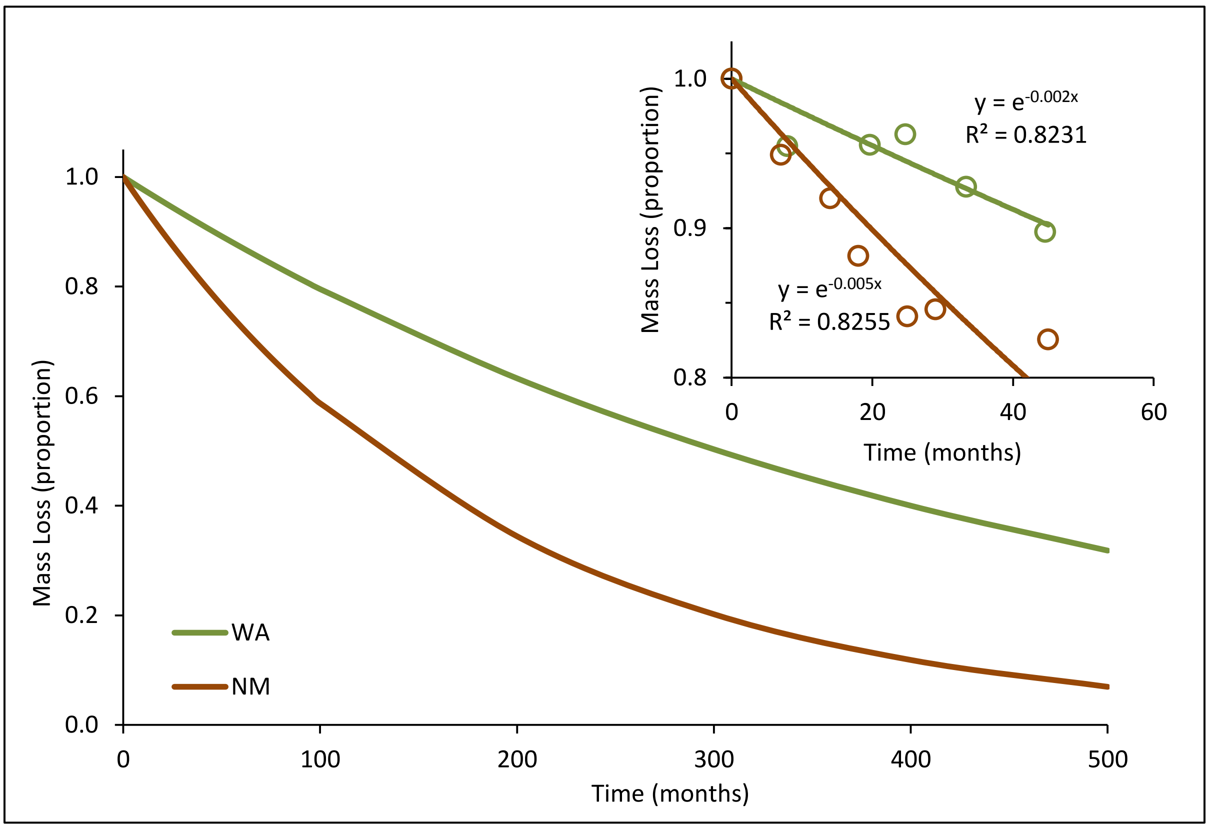

Figure 8. Plot of pile decomposition rate over time for piles in Washington with large woody material and piles in New Mexico without large woody material. The same five piles at each location were re-weighed approximately every six months for four years; dots are the average weights of the five piles at each location at each re-weighing (inset).

2. Pile properties affect combustion

- Pile properties, including overall size, weight, composition (both in terms of size class and species mixes), and bulk density can ultimately affect combustion dynamics. Over time, as piles compress, bulk density increases in excess of levels that are optimal for efficient combustion, which increases potential emissions and smoke impacts (Hardy 1996). We did not measure combustion efficiency or emissions during this study, so further research is warranted to better understand potential relationships between physical properties and potential smoke production.

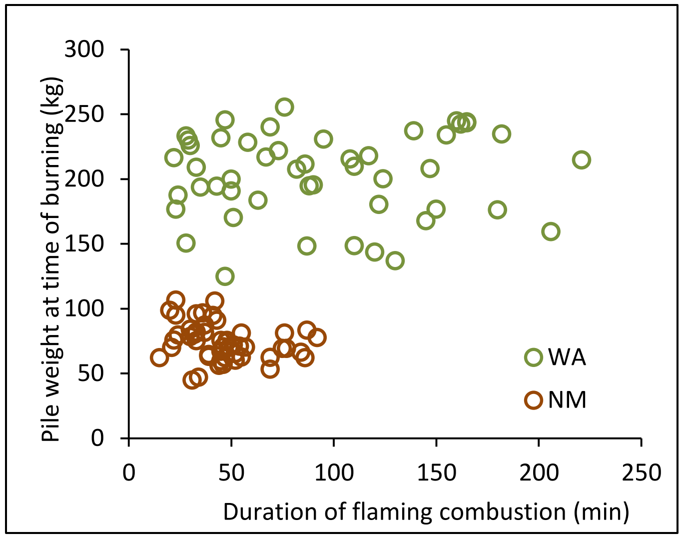

Figure 9. Duration of flaming combustion as a function of pile weight for heavier piles in Washington with large woody material and piles in New Mexico without large woody material. All piles were 1.2 m radius, 1.2 m tall half-spheroids and half-paraboloids when constructed.

- Heavier piles with larger woody material have a more variable flaming combustion duration, which is dependent on day-of-burn fuel moisture and weather conditions (Figure 9). We also observed longer flaming duration times for older piles at the New Mexico site, where piles did not include any large woody material. Inclusion of large woody material in the piles led to much more variable flaming duration as the piles aged (Figure 10). Pile age and pile weight may have some utility for predicting flaming combustion duration, an important variable when attempting to assess combustion and smoke emissions rates.

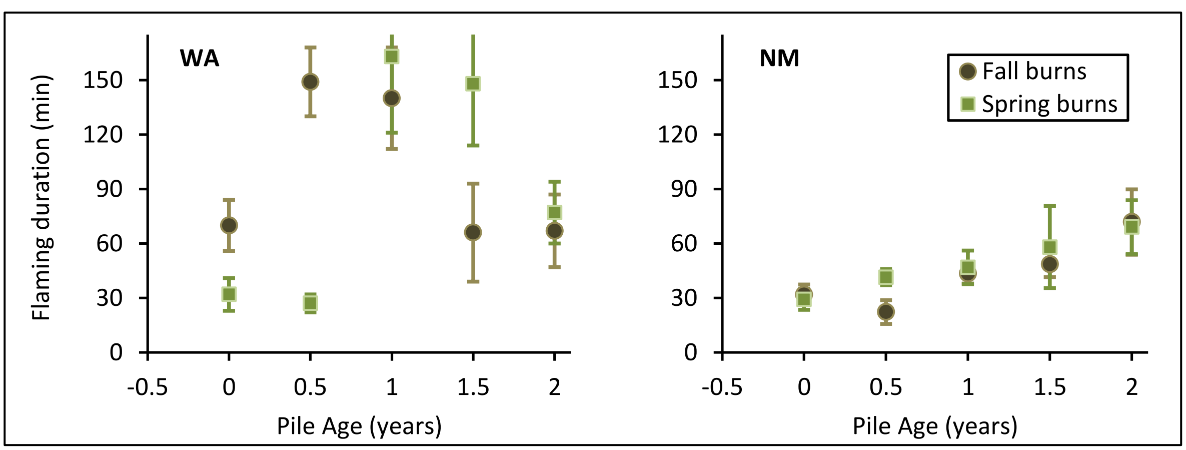

Figure 10. Duration of flaming combustion as a function of pile age and season of burn for piles in Washington with large woody material and piles in New Mexico without large woody material. All piles were 1.2 m radius, 1.2 m tall half-spheroids and half-paraboloids when constructed.

- Larger logs are slower to lose moisture to the atmosphere as weather conditions become drier by virtue of their lower ratio of surface area-to-volume. This phenomenon appears to have affected combustion dynamics, as burning under higher moisture content conditions yielded lower peak flame height (Figure 11). Burning under moisture conditions that depress flame height could be used as a strategy to minimize crown scorch and torching in cases where piles are being burned in an intact stand under a live canopy.

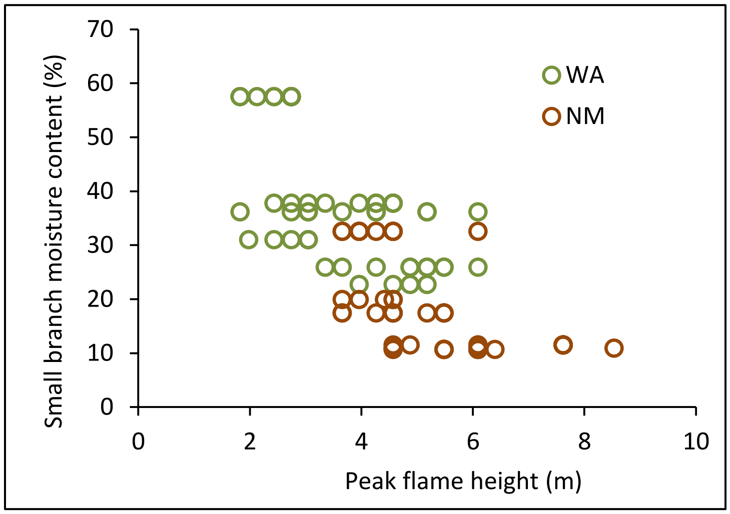

Figure 11. Flame height as a function of pile weight for piles in Washington and New Mexico. The moisture content of small branches on the day of burn was a significant predictor of flame height ($p < 0.001$; $R^2 = 0.55$).

- Fuel consumption, as a percentage of pre-burn biomass, was universally high for the hand piles burned in this study. Individual pile consumption ranged from 77 to 99 percent of pre-burn biomass, with a mean of 95 percent for all piles at the Washington site and 90 percent for all piles at the New Mexico site. This mean difference of 5 percent although significant ($t = 6.54$; $P<0.001$), but may be a function of different burning procedures (i.e., degree of pile tending during burning) moreso than differences in fuel characteristics, environmental conditions, and/or combustion dynamics. For hand pile burning, fuel consumption estimates of 90-95 percent are reasonable as an input for determining likely emissions quantities.

- Charcoal is a relatively inert form of carbon that contributes to long-term C sequestration (DeLuca and Aplet 2008, Finkral and Evans 2012), so quantifying the size of the charcoal pool is of interest from a fuel, fire, and carbon management standpoint. Of the biomass remaining after burning, approximately 31 percent on average (Washington = 30.8 percent; New Mexico = 30.4 percent) was in the form of charcoal on the forest floor. This is equivalent to 1.2 percent (Washington) and 2.8 percent (New Mexico) of pre-burn pile biomass being left onsite post-burn (Figure 12). Given a pile density of 90 and 50 ha^{-1} for the Washington and New Mexico sites, respectively, this sums to 222.3 and 97.0 kg ha^{-1} of charcoal or 177.8 and 77.6 kg C ha^{-1} (assuming charcoal is 80 percent C)

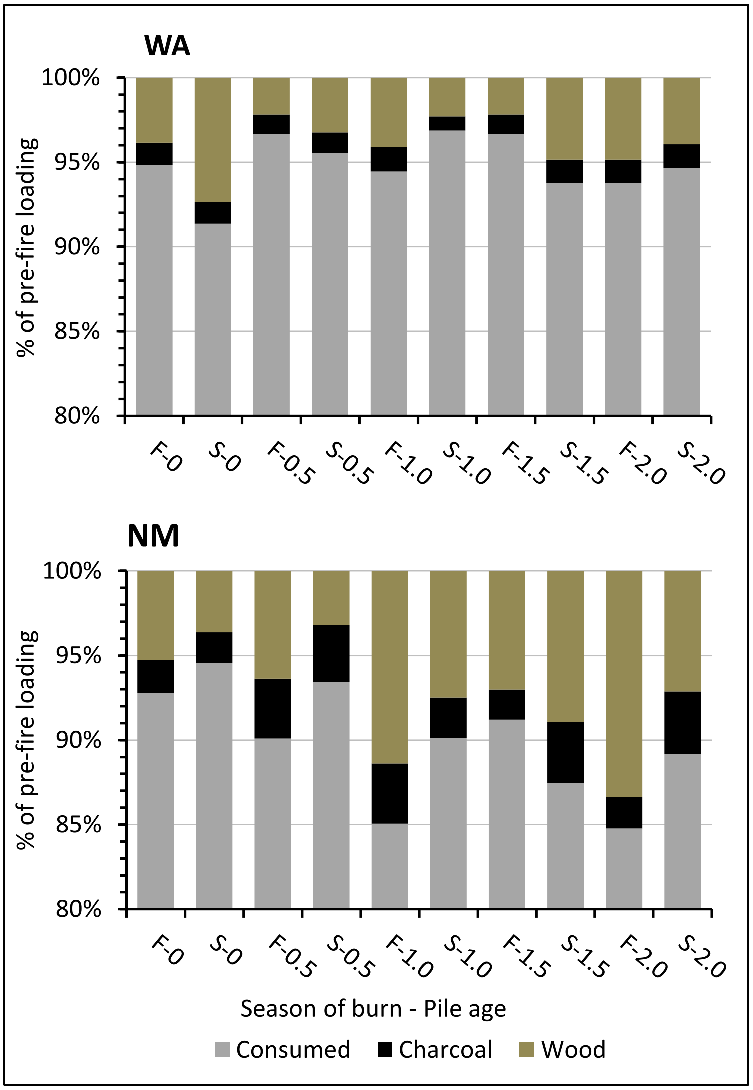

Figure 12. Average fuel consumption and charcoal fraction for piles of different ages burned in the fall and spring at study sites in Washington (WA) and New Mexico (NM).

produced and stored on site for the respective sites. No clear patterns related to pile age or season of burn were noted for either study site. This study measured comparable amounts of charcoal to examples cited in DeLuca and Aplet (2008) for broadcast prescribed fires. Pile burning, however, leads to a patchy spatial distribution of charcoal within a stand, as it causes charcoal to be concentrated in scattered, high-abundance patches (i.e., mostly within the pile footprint) amid a matrix of unburned ground. As the charred wood and charcoal fragments weather and erode into smaller pieces, this material will be integrated into the soil layer, where it is especially long-lived (i.e., 3-12,000 years) and has been shown to benefit stand productivity by enhancing cation exchange, soil structure, and moisture retention (DeLuca and Aplet 2008).

3. Soil heating is concentrated under the center of the pile, is elevated with heavier piles, and is affected by soil moisture

    - Soil heating, even with relatively small (i.e., <1.2 m tall) hand piles was intense and of long duration: maximum temperatures exceeded 400°C and temperatures in excess of 60°C – a point above which plant tissue depth is thought to occur when exposure is in excess of 1 minute – lasted for many hours. High temperatures and long duration, however, only occurred in the top 15 cm of the soil layer and only within approximately 0.7 m of the pile center, thus only one-third to one-half of the pile footprint experiences lethal heating at or near the surface.

- Heavier piles (i.e., piles with large woody material) take longer to burn to completion, and tend to produce a longer and deeper heat pulse into the soil. Busse et al. (2013) noted similar patterns in the Lake Tahoe Basin suggesting that the contents of the pile are an important factor when assessing the likely effects of pile burning. Encouraging utilization of the large woody material, such as through firewood cutting, could be an effective management strategy for reducing the amount of large woody material that must be disposed of by piling following a fuel treatment such as thinning from below. If there are specific concerns about soil or root damage, piles should be kept small and as light as possible. It is worth noting, however, that our results to not raise concerns about soil or root impacts from burning hand piles with modest size and loading.

- Soil heating does appear to be affected by soil moisture levels, with increased heating associated with drier conditions (Figure 13). This is in agreement with the findings of Busse et al. (2010) and suggests that pile burning during wetter periods of the year could be important for mitigating the elevated intensity and heating duration associated with pile burning.

- Our study noted no significant damage to overstory trees, likely due to the relatively shallow depth of soil heating and the wide spacing of overstory trees relative to the flame heights achieved during pile burning. Since the main mass of ponderosa pine roots extend 60 cm below the surface (Oliver and Ryker 1990), burning piles with similar combustion characteristics to those in this study are unlikely to damage more than the top quarter of these roots over a relatively small areal extent. Maximum flame heights (3.7 m and 5.3 m on average for Washington and New Mexico, respectively) were shorter than the distance from pile center to nearest tree (7.1 m in both sites) in the majority of cases.

- Flame height tended to decrease as piles aged, while flaming duration tended to increase. Leaving piles on site for multiple years is likely to minimize negative impacts from high flame heights (i.e., crown scorch and tree torching), but increase potential impacts from longer duration flaming combustion (i.e., impacts from deeper and more sustained soil heating). Similarly, burning with higher fuel moistures will likely reduce the flame height from pile burning. Although a common sense suggestion, it should be explicitly noted that placing relatively small piles as far distant from the remaining trees in a thinned stand as practically possible will minimize potentially negative impacts on the remaining overstory.

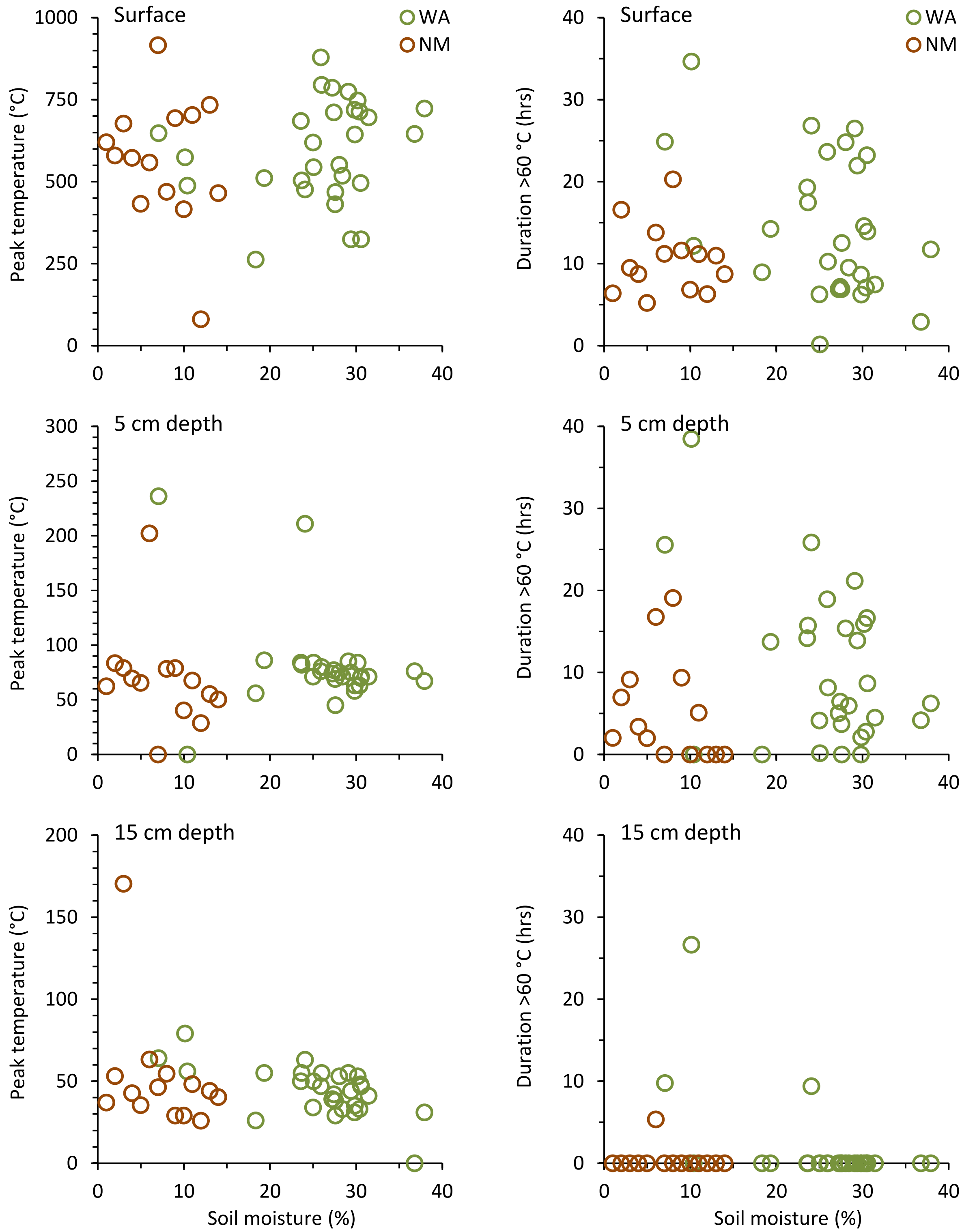

Figure 13. Peak temperature and duration of heating above 60 °C as a function of soil moisture at the soil surface, 5 cm depth and 15 cm depth near the center of the pile for study sites in Washington (WA) and New Mexico (NM). Temperature attenuates rapidly with depth.

4. Vegetation recovery is slow within the pile footprint, but invasive species colonization was minimal for our study sites

- Vegetation recovery began within the duration of the study (up to four growing seasons post burn for the earliest burn treatment), but full recovery will take longer. Very little understory vegetation regrowth occurred in the first growing season following burning. On average, the area within the pile footprint had returned to approximately one-third of the pre-burn coverage levels after 45 months of recovery (Figure 14). During the recovery period, while bare ground is still predominant, burn scars are potentially susceptible to erosion from extreme rain events, colonization by invasive species for several years post-burn, and reduced tree regeneration (Hubbert et al. 2015, Korb et al. 2004, Rhoades and Fornwalt 2015).

- Understory species richness (i.e., the number of unique species per unit area) was modest at both study sites, averaging 4.7 and 1.5 spp pile^{-1} at the Washington

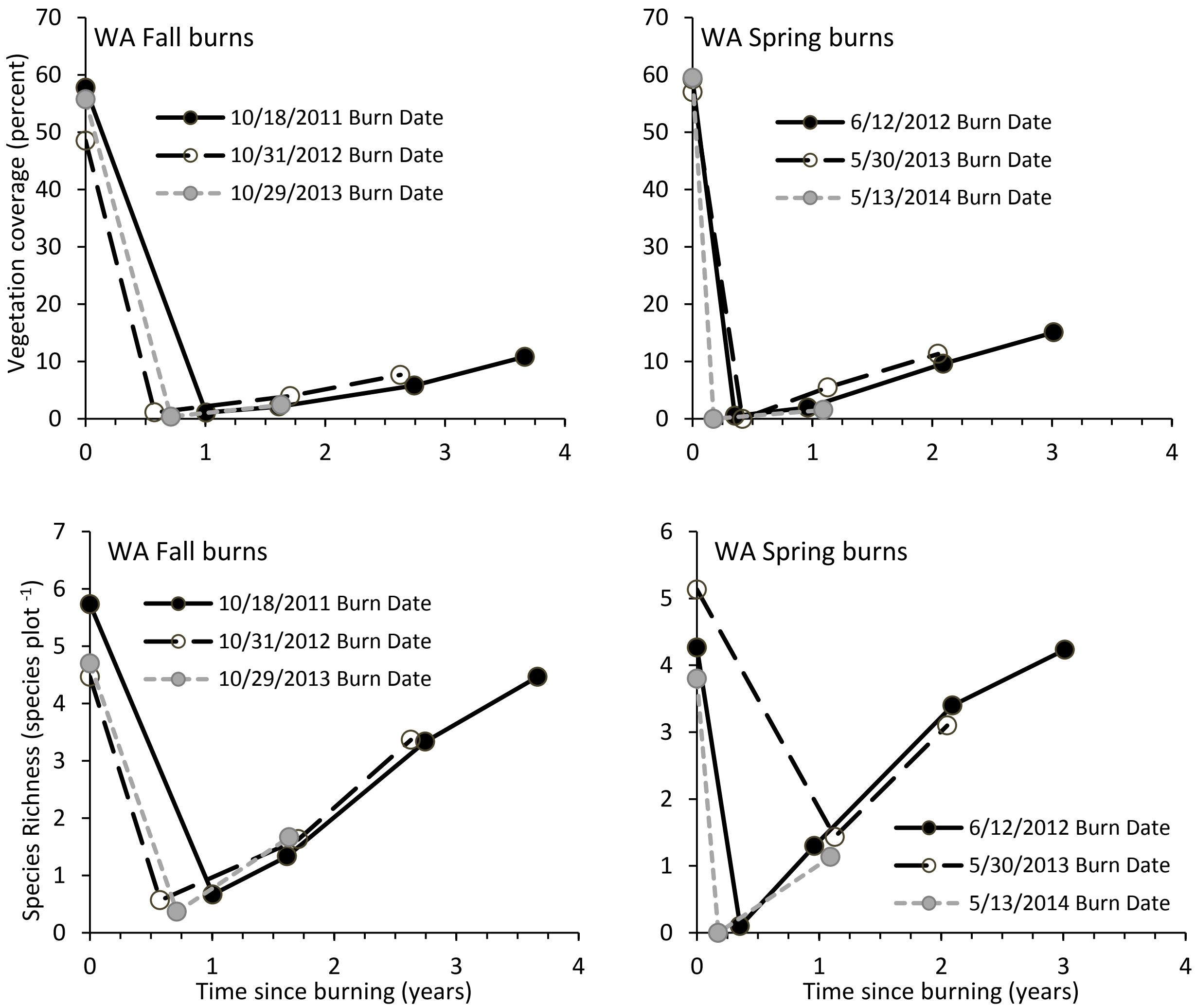

Figure 14. Coverage of vascualr plants and species richness within the pile footprint at the Washington study site. Data are grouped such that all piles burned on the same date are tracked through time.

and New Mexico sites, respectively. Site-wide, 47 and 29 unique species of vascular plants were identified from among all of the vegetation plots at the Washington and New Mexico sites, respectively. Recovery of richness appears to occur more quickly than recovery of ground coverage. On average, the area within the pile footprint had returned to approximately three-quarter of the pre-burn richness levels after 45 months of recovery at the Washington site (Figure 14).

- Despite slow understory vegetation recovery, the sites included in this study experienced only minimal colonization by invasive species. Both study sites, however, started with invasive species in low abundance so this finding may be specific to these sites and not more broadly generalizable. Mangers responsible for pile burn sites with heavy encroachment by invasive species should carefully monitor post-burn vegetation response to minimize the chance for further colonization and spread, and consider amending burn scars with native seed and living soil (i.e., soil containing micro-organisms and mycorrhizal fungi) to facilitate and accelerate re-establishment of the native flora (*sensu* Korb et al. 2004).

5. Hand pile burning does not dramatically affect soil properties

- Soil hydrophobicity has been observed following fires, and hydrophobic soils tend to be more susceptible to elevated levels of run-off and surface erosion during rain events (DeBano 1981, Doerr et al. 2000, Scott and van Wyk 1990). Given that a soil's physical properties can be altered by fire, understanding the degree to which hand pile burning affects infiltration rates is an important consideration, particularly on sloped sites and adjacent to riparian and lacustrine zones. Simple water drop penetration tests showed little to no evidence of hydrophobic conditions following hand pile burning at our study sites. Burning larger hand piles, hand piles with an abundance of large woody material, or those created with heavy machinery during logging operations, however, may have more pronounced effects on soil physical properties owing to the longer duration of burning, higher temperatures, and larger footprints (Busse et al. 2013). Additional research to determine how pile characteristics (i.e., size, composition, age) affect post-burn soil properties – including creation of hydrophobic soil conditions – is warranted, particularly in locations where sediment and nutrient transport to water bodies during rain events is of concern.

- Effects on soil chemistry and the soil biota are either minimal or recovery is sufficiently rapid that we did not observe signficant differences among treatments (i.e., different pile ages or burns in different seasons). Under our modestly sized hand piles, soil properties appear to have recovered to levels observed in unburned control piles when examined one year following the conclusion of the study. The two study sites were initially similar in several key soil characteristics, including soil organic matter and soil texture, and appear to have responded similarly to burning. We observed no effect of pile age or season of burn on most soil properties. Preliminary analyses of ectomycorrhizal communities on the roots of seedlings grown in the greenhouse also suggest that recovery of the soil biota has occurred at both sites, irrespective of pile age at the time of burning.

RELATIONSHIP TO OTHER RECENT FINDINGS AND ONGOING WORK ON THIS TOPIC:

Our results corroborate Busse and colleagues' (2013) results from piles burning in the Lake Tahoe Basin. They found that pile composition was a more important driver of soil heating than pile size with regards to hand-piled fuels. Piles with large pieces of wood generated heat about 100°C for over 60 hours in some cases (Busse et al. 2013). Related work on the long-term effects of pile burning on ecosystem processes and productivity by Rhoades and Fornwalt (2015) examined post-fire recovery over a 50-year time horizon and noted long-lasting effects on stand structure, composition, and spatial patterns as a result of the burning of piled logging debris in lodgepole pine clearcuts, although they did note that herbaceous vegetation coverage was high in the canopy openings that persisted in the old pile burn scars. The works by Rhoades and Fornwalt (2015) and Busse et al. (2013) suggest two important lines of additional inquiry: (1) determine consistencies, similarities, and differences associated with burning relatively small hand piles, as we studied, and much larger, heavier, machine-constructed piles; and (2) develop a better understanding of long-term post-fire vegetation dynamics and resulting ecological (i.e., stand dynamics) and hydrological effects (i.e., increased run-off and erosion owing to persistent post-fire reductions in vegetation coverage).

Hubbert et al. (2015) measured similar soil temperature profiles to those we observed for this study. Their assessment of the manner in which pile burning affects soil structure and water repellency was comparable to our findings of minimal impact from burning small, relatively light hand piles.

Persistence of unvegetated patches and subsequent invasion by non-native species is a concern in many ecosystems where pile burning is employed to dispose of excess woody debris. Halpern et al. (2014), in studying the response of vegetation to pile burning in a montane meadow being invaded by lodgepole pine and grand fir in Oregon, noted similar spatial patterns of fire intensity and vegetation recovery. As with our study, they noted that highest fire intensity was concentrated in the center of the pile and declined with distance from the pile center. At their site in Oregon, total vegetation coverage approached unburned levels seven years post-fire – a longer monitoring period than was possible for our study – but was still significantly less for clonal, forest, and sedge species groups. Seven years post-fire, grasses, forbs, and meadow species coverage was not different from unburned vegetation adjacent to each pile. Further monitoring at our study sites would be necessary to determine whether our dry forest types are responding in a manner similar to the tree-invaded meadow site of Halpern et al. (2014). As with our sites, which contained invasive species in relatively low abundance, Halpern et al. (2014) also did observe an increase in invasive species post-fire, although they also note that managers should take into account prevalence of exotic species before pile burning to avoid undesirable outcomes.

Korb et al. (2004) observed that introduction of mycorrhizal propagules (as well as native seeds) to the burn scar facilitated vegetation recovery and succession following pile burning in Arizona. Documenting the manner in which an addition to the system (in the form of mycorrhizal fungi and native seeds, in the case of Korb et al. (2004)) affects post-burn ecosystem dynamics is interesting and informative for developing strategies and methods for mitigating potentially negative impacts of pile burning. We noted that a concentrated charcoal addition occurs when hand piles are burned, but, that we know of, no studies are currently investigating whether or how this pulse of highly stable carbon effects carbon pools and fluxes, vegetation response, or other ecological effects over time.

FUTURE WORK NEEDED:

Although our work answers a number of important questions about the ecological impacts of pile burning, other questions remain:

- This project sought to understand how physical properties change as piles age, and how those changes influence combustion dynamics and fire effects. The study was limited, however, to hand piles. Further work is needed to determine whether the conclusions of this study are relevant and applicable for larger piles and piles constructed with heavy machinery. Likewise, further study of large piles could document whether new impacts emerge.

- The two sites selected for this study were typical of dry western U.S. forest and were dominated by ponderosa pine exclusively, or in a mixture with dry, mixed-conifer associates, such as Douglas-fir, western larch, and grand fir. Piling and burning occurs in other ecosystem types and in other geographic locations, however as noted by Creech et al. (2012), for longleaf pine (*Pinus palustris*) forests in the southeast of the country; broader geographic study is warranted to determine whether finding from typical western U.S. dry forest types are more broadly generalizable.

- Although we were able to document the initial stages of vegetation recovery following hand pile burning, the time required for full recovery, and whether full recovery is even possible, is longer than the timespan of this project and is, therefore, still an open question. Further monitoring of understory vegetation abundance and composition is necessary to understand how hand piling and burning generally, and burning piles of different age and under different seasons specifically, affects vegetation dynamics in these dry forest types. As a point of reference, Rhoades and Fornwalt (2015) noted that the effects on vegetation from pile burning following clearcutting and burning can persist for at least five decades.

- This study introduced location as a blocking factor in the experimental design; however, the potential effect of location was confounded by the compositional differences among the piles at the two sites. Inclusion of large woody material at the Washington site led to burns with longer duration and deeper soil heating. Further investigation into the manner in which pile properties (i.e., loading, bulk density, moisture content) and location affect both combustion dynamics (i.e., burning intensity and duration) and post-burn vegetation recovery is warranted.

- Charcoal, sometimes referred to as black carbon or biochar, is a by-product of biomass burning resulting from incomplete combustion. Because it is essentially inert in detrital pathways, charcoal represents a form of long-term carbon storage. Charcoal also possesses qualities that are beneficial physically and biochemically in soils. Further research is necessary to refine estimates of post-burn charcoal quantities following pile burning and to determine whether addition of charcoal from pile burning serves as a beneficial soil amendment.

- Smoke from prescribed burning operations, including pile burning, is an important consideration for safe and effective fire and fuel management. That we know of, no experimental measurements have been made of combustion and emissions rates or emissions factors (i.e., quantity of an emissions species per quantity of fuel consumed) from burning hand piled fuels (Hardy et al. 2001). Hand piles have different physical properties than the machine piles for which these rates and factors have been documented. Measuring fuel consumption and smoke emissions rates was beyond the scope of this study, but is necessary to refine empirical models for predicting fuel consumption and smoke emissions.

SCIENCE DELIVERY AND APPLICATION:

The Season and Age of Pile Burn study was proposed as a 3-year project; a one-year extension was granted bringing the total duration to 4 years. We have completed field data collection and the proposed analyses; results are summarized in this final report and included in manuscripts attached to the JFSP web site and intended for the *International Journal of Wildland Fire, Forest Ecology and Management*, *Geoderma,* and *Fire Management Today.* Results from this study have been presented orally at two international conferences, at one local fire management workshop, and in poster form at multiple local, regional, national, and international gatherings of fire management and fire science professionals (Table 4, Appendix B). Data gathered for this work will be archived on the U.S. Forest Service Research Data Archive upon publication of research results.

Table 2. Deliverables crosswalk table. Proposed and delivered products for Season and Age of Pile Burn study.

Proposed	Delivered	Status
Refereed publications	Evans, A.M.; Wright C.S.; Haubensak, K.A. in prep. Effects of burning hand-piled slash. *Forest Ecology and Management.* Wright, C.S.; Evans, A.M.; Haubensak, K.A. in prep. Fuelbed properties, fuel consumption, and carbon dynamics during hand pile burning. *International Journal of Wildland Fire.* Haubensak, K.A.; Evans, A.M.; Wright, C.S. in prep. Hand pile burning and soil processes: effects of pile age and timing of burn. *Geoderma.*	Completed; Drafts in review
Non-refereed publication	Evans, A.M; Wright C.S. in press. Unplanned wildfire in areas with slash piles. *Fire Management Today.*	Completed; in press
Invited paper/ presentation	Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2013. Pile Age and Fire Effects. 4th Fire Behavior and Fuels Conference. February 19-21, 2013. Raleigh, NC: International Association of Wildland Fire.	Completed
Poster	Evans, A.M.; Wright, C.S.; Haubensak, K.A.; Vihnanek, R.E. 2011. Science at Santa Clara: measuring the effects of slash pile burning and how fire effects change as piles age. Technology Transfer and Education Opportunity. November 4, 2011. Española, NM: Santa Clara Pueblo Forestry Department.	Completed
Field tour/ site visit	Visits to field study sites and presentations of research findings to fire management staff at the collaborating locations.	Completed

Table 2. Deliverables crosswalk table. Proposed and delivered products for Season and Age of Pile Burn study.

Proposed	Delivered	Status
Website	Webpage documenting study on the Fire and Environmental Research Applications team webpage: www.fs.fed.us/pnw/fera/research/smoke/piles/aging_piles.shtml).	Completed
Computer model	The online Piled Fuels Biomass and Emissions Calculator (http://depts.washington.edu/nwfire/piles/) is being updated to report residual charcoal biomass for hand piled fuels.	In progress, completion expected Dec. 2015
Dataset	Pile, vegetation, fuel consumption, carbon dynamics, soil heating, weather, and soils data will be archived on the U.S. Forest Service Research Data Archive (www.fs.usda.gov/rds/archive/) upon publication of results.	Will be posted following publication
Annual reports	JFSP annual report of interim research progress and findings in 2011, 2012, 2013, and 2014.	Completed
Final report	JFSP final report documenting research findings and management implications.	Completed

ADDITIONAL DELIVERABLES:

In addition to the proposed data collection and science delivery products, we were also able to collect data that were beyond the scope of the original proposal; one additional year of vegetation response data and pile decomposition data were collected. Presentations and posters in addition to the proposed number were also completed.

Table 3. Delivered products that were not part of the original proposal.

Deliverable	Status
Additional presentation: Evans, A.M. 2014. Measuring the effects of slash pile burning: collaborative science to inform management. Northern New Mexico College. April 2014.	Completed in April 2014
Additional presentation: Evans, A.M.; Wright, C.S.; Haubensak, K.A. 2014. Measuring the effects of slash pile burning. 2014 SAF National Convention. October 8-12, 2014. Salt Lake City, UT: Society of American Foresters.	Completed in October 2014
Additional poster: Wright, C.S.; Evans, A.M.; Haubensak, K.A.; Vihnanek, R.E. 2012. Measuring the effects of slash pile burning and how fire effects change as piles age. 1st Annual Washington Prescribed Fire Council Meeting. March 6, 2012. Wenatchee, WA: Washington Prescribed Fire Council.	Competed in March 2012

Table 3. Delivered products that were not part of the original proposal.

Deliverable	Status
Additional poster: Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2012. Measuring the effects of slash pile burning and how fire effects change as piles age. 5th International Fire Ecology and Management Congress. December 3-7, 2012. Portland, OR: Association for Fire Ecology.	Completed in December 2012
Additional poster: Restaino, J.R.; Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2015. Pile age and season of burning influence combustion and fire effects. 6th International Fire Ecology and Management Congress. November 16-20, 2015. San Antonio, TX: Association for Fire Ecology.	To be completed in November 2015
Additional data: Fourth year repeat measurement of pile decomposition rate. Data will be archived on the U.S. Forest Service Research Data Archive (www.fs.usda.gov/rds/archive/) upon publication of results.	Will be added to primary database and posted following publication
Additional data: One additional year repeat measurement of post-burn vegetation composition. Data will be archived on the U.S. Forest Service Research Data Archive (www.fs.usda.gov/rds/archive/) upon publication of results.	Will be added to primary database and posted following publication

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APPENDIX A

STUDY LOCATIONS:

The effects of pile burning were evaluated at the following locations in the western United States. Two sites, one each in central Washington (N46° 39' 25.9"; W121° 09' 26.6") and north-central New Mexico (N36° 0' 56.4"; W106° 16' 59.9") were established in the summer of 2011. Pre-treatment vegetation assessments (overstory structure and composition, understory composition), soil temperature probe installation, and pile construction for 50% of the piles occurred during the summer of 2011. The remaining 50% of piles were built in the spring of 2012. Piles were burned during the fall of 2011, 2012, and 2013, and during the spring of 2012, 2013, and 2014. Vegetation recovery was monitored annually from 2012 to 2015.

Naches Ranger District, Okanogan-Wenatchee National Forest, WA

The sample site occupied the southwest corner of the Russell Ridge #20 unit that was thinned and hand piled during the spring and summer of 2011. Random existing piles were selected, deconstructed, weighed on site, and re-built over a spot in which understory vegetation composition had been measured and soil temperature probes had been installed.

Table A1. Information for pile study on the Okanogan-Wenatchee National Forest, WA. Piles built in the fall of 2011 (F…) and spring of 2012 (S…) were burned at approximately 0.5-year intervals. Pile ages (0, 0.5, 1.0, 1.5, and 2.0) are calculated based on the date of piling. Thus, treatment F0.5 indicates a pile built in the fall of 2011 and burned in the spring of 2012.

Treatment-replicate	Burn season	Tag no.	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3	Post-burn date 4
F0-1	Fall	607	8/23/2011	10/18/2011	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0-2	Fall	608	8/23/2011	10/18/2011	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0-3	Fall	609	8/23/2011	10/18/2011	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0-4	Fall	610	8/23/2011	10/18/2011	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0-5	Fall	611	8/24/2011	10/18/2011	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0.5-1	Spring	591	8/8/2011	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0.5-2	Spring	592	8/17/2011	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0.5-3	Spring	593	8/17/2011	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0.5-4	Spring	594	8/17/2011	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F0.5-5	Spring	595	8/17/2011	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/17/2015
F1.0-1	Fall	605	8/18/2011	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
F1.0-2	Fall	606	8/18/2011	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
F1.0-3	Fall	642	8/25/2011	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
F1.0-4	Fall	643	8/25/2011	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
F1.0-5	Fall	644	8/31/2011	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
F1.5-1	Spring	596	8/17/2011	5/30/2013	7/16/2014	6/17/2015		
F1.5-2	Spring	601	8/18/2011	5/30/2013	7/16/2014	6/17/2015		
F1.5-3	Spring	602	9/20/2011	5/30/2013	7/16/2014	6/17/2015		
F1.5-4	Spring	603	9/20/2011	5/30/2013	7/16/2014	6/17/2015		
F1.5-5	Spring	604	9/20/2011	5/30/2013	7/16/2014	6/17/2015		
F2.0-1	Fall	612	8/24/2011	10/29/2013	7/16/2014	6/17/2015		

Table A1. Information for pile study on the Okanogan-Wenatchee National Forest, WA. Piles built in the fall of 2011 (F…) and spring of 2012 (S…) were burned at approximately 0.5-year intervals. Pile ages (0, 0.5, 1.0, 1.5, and 2.0) are calculated based on the date of piling. Thus, treatment F0.5 indicates a pile built in the fall of 2011 and burned in the spring of 2012.

Treatment-replicate	Burn season	Tag no.	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3	Post-burn date 4
F2.0-2	Fall	613	8/24/2011	10/29/2013	7/16/2014	6/17/2015		
F2.0-3	Fall	614	8/24/2011	10/29/2013	7/16/2014	6/17/2015		
F2.0-4	Fall	615	8/25/2011	10/29/2013	7/16/2014	6/17/2015		
F2.0-5	Fall	616	8/25/2011	10/29/2013	7/16/2014	6/17/2015		
S0-1	Spring	617	5/22/2012	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/16/2015
S0-2	Spring	618	5/22/2012	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/16/2015
S0-3	Spring	619	5/22/2012	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/16/2015
S0-4	Spring	620	5/22/2012	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/16/2015
S0-5	Spring	621	5/23/2012	6/12/2012	10/19/2012	5/29/2013	7/16/2014	6/16/2015
S0.5-1	Fall	632	5/24/2012	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
S0.5-2	Fall	633	5/24/2012	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
S0.5-3	Fall	634	5/24/2012	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
S0.5-4	Fall	635	5/23/2012	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
S0.5-5	Fall	636	5/23/2012	10/31/2012	5/29/2013	7/16/2014	6/17/2015	
S1.0-1	Spring	622	6/13/2012	5/30/2013	7/16/2014	6/17/2015		
S1.0-2	Spring	623	6/13/2012	5/30/2013	7/16/2014	6/17/2015		
S1.0-3	Spring	624	6/12/2012	5/30/2013	7/16/2014	6/17/2015		
S1.0-4	Spring	625	6/12/2012	5/30/2013	7/16/2014	6/17/2015		
S1.0-5	Spring	626	6/12/2012	5/30/2013	7/16/2014	6/17/2015		
S1.5-1	Fall	637	6/13/2012	10/29/2013	7/16/2014	6/17/2015		
S1.5-2	Fall	638	6/13/2012	10/29/2013	7/16/2014	6/17/2015		
S1.5-3	Fall	639	6/13/2012	10/29/2013	7/16/2014	6/17/2015		
S1.5-4	Fall	640	6/13/2012	10/29/2013	7/16/2014	6/17/2015		
S1.5-5	Fall	641	6/13/2012	10/29/2013	7/16/2014	6/17/2015		
S2.0-1	Spring	627	6/12/2012	5/13/2014	7/16/2014	6/17/2015		
S2.0-2	Spring	628	6/12/2012	--[a]				
S2.0-3	Spring	629	6/12/2012	5/13/2014	7/16/2014	6/17/2015		
S2.0-4	Spring	630	6/12/2012	5/13/2014	7/16/2014	6/17/2015		
S2.0-5	Spring	631	6/12/2012	5/13/2014	7/16/2014	6/17/2015		

[a] pile inadvertently burned during land management operations; pile not used in data analyses

Table A2. Information for decomposition pile study on the Okanogan-Wenatchee National Forest, WA. Decomposition piles were built on chain-link panels in the fall of 2011 and not burned during the study. Decomposition piles were re-weighed intact at approximately 6-month intervals to monitor pile mass loss rate; site-specific mass loss rates were used to account for mass loss that occurred between the time of experimental burn pile creation and the burn date.

			Re-measurement date						
Pile ID	Tag no.	Date built	Fall 2011	Spring 2012	Fall 2012	Spring 2013	Fall 2013	Summer 2014	Summer 2015
D-1	459	8/9/2011	10/19/2011	6/12/2012	10/31/2012	5/30/2013	10/29/2013	7/16/2014	6/17/2015
D-2	598	8/16/2011	10/19/2011	6/12/2012	10/31/2012	5/30/2013	10/29/2013	7/16/2014	6/17/2015
D-3	599	8/16/2011	10/19/2011	6/12/2012	10/31/2012	5/30/2013	10/29/2013	7/16/2014	6/17/2015
D-4	600	8/16/2011	10/19/2011	6/12/2012	10/31/2012	5/30/2013	10/29/2013	7/16/2014	6/17/2015
D-5	597	8/17/2011	10/19/2011	6/12/2012	10/31/2012	5/30/2013	10/29/2013	7/16/2014	6/17/2015

Santa Clara Pueblo, NM

The sample site occupied the Turkey Flats unit that was thinned and piled during the spring and summer of 2011. Random existing piles were selected, deconstructed, weighed on site, and re-built over a spot in which understory vegetation composition had been measured and soil temperature probes had been installed.

Table A3. Information for pile study on the Santa Clara Pueblo, NM. Piles built in the fall of 2011 (F…) and spring of 2012 (S…) were burned at approximately 0.5-year intervals. Pile ages (0, 0.5, 1.0, 1.5, and 2.0) are calculated based on the date of piling. Thus, treatment F0.5 indicates a pile built in the fall of 2011 and burned in the spring of 2012.

Treatment-replicate	Burn season	Tag no.	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3
F0-1	Fall	935	10/13/2011	10/25/2011	11/21/2012	10/17/2013	6/18/2015
F0-2	Fall	953	10/13/2011	10/25/2011	11/21/2012	10/17/2013	6/18/2015
F0-3	Fall	933	10/13/2011	10/25/2011	11/21/2012	10/17/2013	6/18/2015
F0-4	Fall	932	9/23/2011	10/25/2011	11/21/2012	10/17/2013	6/18/2015
F0-5	Fall	931	9/23/2011	10/25/2011	11/21/2012	10/17/2013	6/18/2015
F0.5-1	Spring	940	10/13/2011	4/10/2012	11/21/2012	10/17/2013	6/18/2015
F0.5-2	Spring	934	10/13/2011	4/10/2012	11/21/2012	10/17/2013	6/18/2015
F0.5-3	Spring	938	10/13/2011	4/10/2012	11/21/2012	10/17/2013	6/18/2015
F0.5-4	Spring	949	10/13/2011	4/10/2012	11/21/2012	10/17/2013	6/18/2015
F0.5-5	Spring	954	10/13/2011	4/10/2012	11/21/2012	10/17/2013	6/18/2015
F1.0-1	Fall	942	10/13/2011	11/15/2012	10/17/2013	6/18/2015	
F1.0-2	Fall	945	10/13/2011	11/15/2012	10/17/2013	6/18/2015	
F1.0-3	Fall	946	10/17/2011	11/15/2012	10/17/2013	6/18/2015	
F1.0-4	Fall	939	10/17/2011	11/15/2012	10/17/2013	6/18/2015	
F1.0-5	Fall	951	10/17/2011	11/15/2012	10/17/2013	6/18/2015	
F1.5-1	Spring	958	10/20/2011	3/12/2013	6/18/2015		
F1.5-2	Spring	959	10/17/2011	3/12/2013	6/18/2015		
F1.5-3	Spring	963	10/17/2011	3/12/2013	6/18/2015		
F1.5-4	Spring	961	10/24/2011	3/12/2013	7/23/2015		
F1.5-5	Spring	956	10/24/2011	3/12/2013	6/18/2015		
F2.0-1	Fall	964	10/20/2011	10/17/2013	7/23/2015		
F2.0-2	Fall	965	10/20/2011	10/17/2013	6/18/2015		
F2.0-3	Fall	962	10/20/2011	10/17/2013	6/18/2015		
F2.0-4	Fall	957	10/20/2011	10/17/2013	7/23/2015		
F2.0-5	Fall	960	10/20/2011	10/17/2013	6/18/2015		
S0-1	Spring	937	4/9/2012	4/10/2012	11/21/2012	10/17/2013	6/18/2015
S0-2	Spring	952	4/9/2012	4/10/2012	11/21/2012	10/17/2013	6/18/2015
S0-3	Spring	947	4/9/2012	4/10/2012	11/21/2012	10/17/2013	6/18/2015
S0-4	Spring	948	4/9/2012	4/10/2012	11/21/2012	10/17/2013	6/18/2015
S0-5	Spring	944	4/9/2012	4/10/2012	11/21/2012	10/17/2013	6/18/2015
S0.5-1	Fall	950	4/16/2012	11/15/2012	10/17/2013	6/18/2015	
S0.5-2	Fall	955	4/9/2012	11/15/2012	10/17/2013	6/18/2015	
S0.5-3	Fall	936	4/9/2012	11/15/2012	10/17/2013	6/18/2015	
S0.5-4	Fall	986	4/16/2012	11/15/2012	10/17/2013	6/18/2015	
S0.5-5	Fall	982	4/16/2012	11/15/2012	10/17/2013	6/18/2015	
S1.0-1	Spring	974	4/16/2012	3/12/2013	6/18/2015		
S1.0-2	Spring	967	4/9/2012	3/12/2013	7/23/2015		
S1.0-3	Spring	971	4/16/2012	3/12/2013	6/18/2015		

Table A3. Information for pile study on the Santa Clara Pueblo, NM. Piles built in the fall of 2011 (F…) and spring of 2012 (S…) were burned at approximately 0.5-year intervals. Pile ages (0, 0.5, 1.0, 1.5, and 2.0) are calculated based on the date of piling. Thus, treatment F0.5 indicates a pile built in the fall of 2011 and burned in the spring of 2012.

Treatment-replicate	Burn season	Tag no.	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3
S1.0-4	Spring	985	4/16/2012	3/12/2013	6/18/2015		
S1.0-5	Spring	984	4/16/2012	3/12/2013	6/18/2015		
S1.5-1	Fall	972	4/30/2012	10/17/2013	6/18/2015		
S1.5-2	Fall	975	4/30/2012	10/17/2013	6/18/2015		
S1.5-3	Fall	969	4/30/2012	10/17/2013	6/18/2015		
S1.5-4	Fall	977	4/30/2012	10/17/2013	6/18/2015		
S1.5-5	Fall	979	4/30/2012	10/17/2013	6/18/2015		
S2.0-1	Spring	978	4/16/2012	2/6/2014	6/18/2015		
S2.0-2	Spring	970	4/16/2012	2/6/2014	6/18/2015		
S2.0-3	Spring	968	4/30/2012	2/6/2014	6/18/2015		
S2.0-4	Spring	981	4/30/2012	2/6/2014	6/18/2015		
S2.0-5	Spring	983	4/30/2012	2/6/2014	6/18/2015		

Table A4. Information for decomposition pile study on the Santa Clara Pueblo, NM. Decomposition piles were built on chain-link panels in the fall of 2011 and not burned during the study. Decomposition piles were re-weighed intact at approximately 6-month intervals to monitor pile mass loss rate; site-specific mass loss rates were used to account for mass loss that occurred between the time of experimental burn pile creation and the burn date.

			Re-measurement date						
Pile ID	Tag no.	Date built	Fall 2011	Spring 2012	Fall 2012	Spring 2013	Fall 2013	Spring 2014	Summer 2015
D-1	941	10/24/2011	10/25/2011	4/10/2012	11/15/2012	3/12/2013	10/17/2013	2/6/2014	7/23/2015
D-2	976	10/24/2011	10/25/2011	4/10/2012	11/15/2012	3/12/2013	10/17/2013	2/6/2014	7/23/2015
D-3	966	10/31/2011	10/25/2011	4/10/2012	11/15/2012	3/12/2013	10/17/2013	2/6/2014	7/23/2015
D-4	973	10/31/2011	10/25/2011	4/10/2012	11/15/2012	3/12/2013	10/17/2013	2/6/2014	7/23/2015
D-5	943	10/31/2011	10/25/2011	4/10/2012	11/15/2012	3/12/2013	10/17/2013	2/6/2014	7/23/2015

Appendix B

Proposed Deliverables:

The primary deliverables proposed for this project included four refereed publications, one non-refereed publication, two posters or presentations, a website, an updated computer model, a database of fuel and vegetation characteristics, fire behavior, and environmental measurements, an online training session, and a field tour for collaborating institutions. With the exception of an online training and revisions to the computer model, all deliverables have been fulfilled and are detailed below; topics for two of the four originally envisioned refereed publications have been combined, yielding a net number of three refereed publications.

Refereed publications:

Evans, A.M; Wright C.S.; Haubensak, K.A. *in prep.* Effects of burning hand-piled slash. *Forest Ecology and Management.*

Attached to the JFSP website: Pile_burning - fire effects.pdf

Wright, C.S.; Evans, A.M; Haubensak, K.A. *in prep.* Fuelbed properties, fuel consumption, and carbon dynamics during hand pile burning. *International Journal of Wildland Fire.*

To be attached to the JFSP website: Pile_burning - fuel and C.pdf

Haubensak, K.A.; Evans, A.M.; Wright, C.S. *in prep.* Hand pile burning and soil processes: effects of pile age and timing of burn. *Geoderma.*

To be attached to the JFSP website: Pile_burning - soils.pdf

Non-refereed publication:

Evans, A.M; Wright C.S. *in press.* Unplanned wildfire in areas with slash piles. *Fire Management Today.*

Attached at Appendix D, and to the JFSP website: FMT_Wildfire_in_slash_piles.pdf

Presentations:

Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2013. Pile Age and Fire Effects. 4th Fire Behavior and Fuels Conference. February 19-21, 2013. Raleigh, NC: International Association of Wildland Fire.

Attached to the JFSP website: Pile_burning - IAWF Conference presentation - Feb2013.pdf

Posters:

Evans, A.M.; Wright, C.S.; Haubensak, K.A.; Vihnanek, R.E. 2011. Science at Santa Clara: measuring the effects of slash pile burning and how fire effects change as piles age. Technology Transfer and Education Opportunity. November 4, 2011. Española, NM: Santa Clara Pueblo Forestry Department.

Attached to the JFSP website: Pile_burning - SCP poster - Nov2011.pdf

Website:

http://www.fs.fed.us/pnw/fera/research/smoke/piles/aging_piles.shtml

Computer model:

The online Piled Fuels Biomass and Emissions Calculator (http://depts.washington.edu/nwfire/piles/) is being updated to report residual charcoal biomass for hand piled fuels. This update is ongoing; completion is expected in December 2015.

Database:

Wright, C.S.; Evans, A.M; Haubensak, K.A.; Restaino, J.R. Piled biomass, burning, and fire effects data for sites in Washington and New Mexico.

Upon publication of research results, this database will be made available publically through the U.S. Forest Service Research Data Archive (http://www.fs.usda.gov/rds/archive/) and posted on the Fire and Environmental Research Application Team's website (http://www.fs.fed.us/pnw/fera/).

Field tour:

Collaborating staff at the Naches Ranger District and the Santa Clara Pueblo were briefed on research findings while visiting the study sites at various times during the course of the project. Additional outreach will be conducted with collaborators upon publication of research findings.

Appendix C

Additional Deliverables:

In addition to the proposed data collection and science delivery products, we were also able to collect data that were beyond the scope of the original proposal; one additional year of vegetation response data and one additional year of pile decomposition data were collected. Presentations and posters in addition to the proposed number were also completed.

Additional presentations:

Evans, A.M. 2014. Measuring the effects of slash pile burning: collaborative science to inform management. Northern New Mexico College. April 2014.

Attached to the JFSP website: Pile_burning - N NM College presentation - Apr2014.pdf

Evans, A.M.; Wright, C.S.; Haubensak, K.A. 2014. Measuring the effects of slash pile burning. 2014 SAF National Convention. October 2014. Salt Lake City, UT: Society of American Foresters.

Attached to the JFSP website: Pile_burning - SAF presentation - Oct2014.pdf

Additional posters:

Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2012. Measuring the effects of slash pile burning and how fire effects change as piles age. 5th International Fire Ecology and Management Congress. December 3-7, 2012. Portland, OR: Association for Fire Ecology.

Attached to the JFSP website: Pile_burning - AFE Conference poster - Dec2012.pdf

Wright, C.S.; Evans, A.M.; Haubensak, K.A.; Vihnanek, R.E. 2012. Measuring the effects of slash pile burning and how fire effects change as piles age. 1st Annual Washington Prescribed Fire Council Meeting. March 2012. Wenatchee, WA: Washington Prescribed Fire Council.

Attached to the JFSP website: Pile_burning - WA Rx Fire Council poster - Mar2012.pdf

Restaino, J.R.; Wright, C.S.; Evans, A.M.; Haubensak, K.A. 2015. Pile age and season of burning influence combustion and fire effects. 6th International Fire Ecology and Management Congress. November 16-20, 2015. San Antonio, TX: Association for Fire Ecology.

Attached to the JFSP website: Pile_burning - AFE Conference poster - Nov2015.pdf

Additional data:

Wright, C.S.; Evans, A.M; Haubensak, K.A.; Restaino, J.R. Piled biomass, burning, and fire effects data for sites in Washington and New Mexico.

One additional year of post-burn vegetation composition measurements and one additional year of pile decomposition measurements were collected and appended to the primary database, which, upon publication of research results, will be made available publically through the U.S. Forest Service Research Data Archive (http://www.fs.usda.gov/rds/archive/) and posted on the Fire and Environmental Research Application Team's website (http://www.fs.fed.us/pnw/fera/).

APPENDIX D

Article in press with *Fire Management Today*

Unplanned wildfire in areas with slash piles

by Alexander M. Evans and Clinton S. Wright

A review of the literature suggests that treated units with unburned slash piles and untreated units with ladder fuels will experience similar fire behavior and effects

Millions of acres of fuels reduction treatments are being implemented each year to reduce the likelihood of uncharacteristic wildfire in overstocked stands. Typical hazardous fuels reduction treatments target small-diameter trees for removal producing large amounts of unmerchantable woody material and elevating surface fuel loadings. Currently, few commercial markets for this woody material exist, so it is commonly piled by hand or with heavy machinery and burned on site. One estimate suggests that at least 15,000 piles are created each year (Hosseini et al. 2014). Occasionally, unplanned wildfires, whether natural or human-caused, burn piles before managers are able to burn them under controlled conditions.

While unplanned fires in areas with piled fuels are not common, they still present a potential risk for managers and firefighters. Little is written or documented about piles burning during wildfires, making it difficult to assess the threat posed by unburned piles on the landscape. In an effort to better understand the prevalence, causes, and impacts of unplanned burning of piles, we reviewed the available literature and interviewed managers from across the country. What follows is a first step that will hopefully call attention to the issue and help frame incisive questions for future research.

Why are there unburned piles?

Piles are built and left to dry since green wood burns poorly. For example, the U.S. Forest Service's Lake Tahoe Basin Management Unit in California states that it takes approximately 18 months for the piles generated by their fuel reduction activities to dry sufficiently for effective consumption when burned. Weather conditions are another reason to delay pile burning. Material cut in the spring or summer may be left until conditions are safe for burning. In many areas pile burning is a winter activity that is carried out when there is snow on the ground to prevent unwanted fire spread. Although winter is a popular time for pile burning, the Coalition for the Upper South Platte in Colorado was unable to burn thousands of piles during the winter of 2012-2013 because snow depth did not meet their pile burn guidelines (Steiner 2014). Institutional factors such as available labor and funding also factor into the amount of time piles may remain in the woods before managers can safely burn them. In the Lake Tahoe Basin and the Okanogan-Wenatchee National Forest in Washington, there is a backlog of unburned piles because of limitations imposed by air quality restrictions, unfavorable weather conditions, available resources, and even funding (USFS 2014; Jim Bailey, U.S. Forest Service, personal communication).

Wildfire can bring unplanned fire to piled fuels, but so too can arson. Piling and burning is common in the wildland-urban interface (WUI) where the proximity of homes makes broadcast burning more challenging. Piles in the WUI are at risk of arson until they are dry enough to burn, environmental conditions are in prescription, and qualified personnel are available to burn them. Because piles can be burned safely under some conditions, arsonists may not realize that piles lit under unfavorable weather conditions can quickly escape control. Of course this is a dangerous miscalculation and arsonist-ignited piles can easily become life- and property-threatening wildfires. For example, in a case from 2006 in a California campground, managers suspect that the arsonists may have been motivated by curiosity rather than evil intent (Ben Jacobs, National Park Service, personal communication).

Do piles affect wildfire behavior?

One of the key questions is whether or how fire behavior changes in the presence of unburned piles. From the perspective of a wildfire, unburned piles are simply redistributed fuels. In other words, boles and branches that were previously in the canopy are aggregated into piles on the surface, so the same amount of fuel is available in a different arrangement. An assessment of the 2007 Angora Fire in California stated that the convective and radiant heat output in untreated stands and stands with piles burned by wildfire would be similar because the same amount of fuel would burn (Murphy et al. 2007). However, piling fuels can change fuel moistures by converting live fuels to dead fuels, which can affect flame length, fireline intensity, burning duration, and other aspects of fire behavior. Moving biomass from standing trees to piles decreases canopy bulk density, ladder fuels, and canopy continuity, which can reduce fire intensity and severity. Thinning or harvesting and piling, however, can also elevate fine fuel loading by increasing the amount of light that reaches the forest floor and encouraging herbaceous growth. Likewise, removing trees reduces stem and canopy density, which opens the stand to higher wind speeds and potentially elevated levels of fire behavior. Unburned piles contributed to fire intensity and duration during the 2010 Fourmile Canyon Fire in Colorado (Graham et al. 2012). In the Gold Hill area, the Fourmile Canyon Fire burned more intensely through stands with piles as compared to adjacent untreated stands, because of increased wind speeds in the thinned stands (Graham et al. 2012). An experimental burn at Nenana Ridge in Alaska that mimicked wildfire conditions showed that a stand with windrowed fuels had a lower maximum temperature but longer heating time than a stand with a lop-and-scatter treatment (Butler et al. 2012).

In some cases, even though the piles had not been treated when wildfires occurred, fire behavior appears to have been less active than might have been expected in an untreated stand. For example, in 2004 the Cal Hollow Fire threatened the community of Central, Utah. A fuel break had been put in place in the piñon-juniper forest above the community, but the fire occurred before the piles generated during fuelbreak installation could be burned under controlled conditions (USFS 2013). The fire approached the fuel break in the tree crowns, but dropped to the surface in the treated area, although it did burn intensely in the piles. Retardant drops and other suppression activities successfully contained the fire before it could enter the community (McAvoy 2004). Similarly, during the 2005 Camp 32 Fire in Montana, the untreated stand supported an active crown fire, but when the fire entered the stand with untreated piles it switched to a passive crown fire (Ron Hvizdak, personal communication; USFS 2006).

Wildfire in stands with unburned piles may increase spotting, as was observed when large landing piles ignited during the 2008 American Rivers Complex in California causing torching of nearby trees and spotting (Safford 2008). Similarly, during the 2013 Rail Fire on the Modoc National Forest, also in California, even though the rate of spread of the fire front decreased when the wildfire encountered a treatment where material had recently been piled, the uncured (or green) piles contributed to spotting, which ultimately made containment difficult (Kenneth Heald, U.S. Forest Service, personal communication). In contrast, during the Angora Fire, spotting distance in stands with unburned handpiles was shorter than in untreated stands. In this case, repositioning fuels from the crown to the surface reduced ember loft and correspondingly, the distance embers traveled and the manner in which the fire spread (Murphy et al. 2007).

In addition to generating embers, piles can also be receptive to embers from other sources. For example, the 2013 Andrews Creek Fire in Oregon ignited piles in a recently thinned Douglas-fir stand. The fire then spotted from pile to pile but did not spread far outside the footprint of the piles (Patrick Skrip, Douglas Forest Protective Association, personal communication).

How do burning piles affect wildfire control?

In terms of wildfire suppression or control, ease of access to the affected area may influence operational success. In cases where there is good access (i.e., proximity to roads and trails) for staging suppression activities, wildfires in piles may be easier to control than comparable untreated stands, particularly if the piling activities reduced the horizontal continuity of the surface fuel layer. However, where access is difficult, wildfires in piles may be more difficult to control than fires in untreated or lop-and-scatter treatments because of the intense heat generated by burning piles. For example, in two Lake Tahoe, California area fires where piles burned, the success of suppression activities, and ultimately control, was determined by ease of access. When the Angora Fire burned an area with piles, the fire resisted control because access was difficult, however, an area with piles that burned during the American Rivers Complex was accessible via a public road, providing suppression personnel better access for fire fighting apparatus and therefore easier control. Firefighters kept some of the large landing piles that the American Rivers Complex Fire threatened to ignite from burning by bulldozer blading and watering (Safford 2008). Similarly, safe, successful fire suppression in an area with piles on the 1999 Alder Fire in Grand Teton National Park, Wyoming was made possible by the existence of escape routes (via paved road) and ready access to plentiful water supplies (Mack McFarland, National Park Service, personal communication). The fast-moving 2008 Jack Fire burned through an area with piles of western juniper in Lava Beds National Monument in Northern California. Managers had been unable to burn the piles when scheduled the previous winter. When ignited by the wildfire the piles burned very intensely, but the fire was contained with minimum impact strategies such as use of existing roads and water rather than ground disturbing methods (Calvin Farris, National Park Service, personal communication; Augustine 2014). When the 2007 Tin Cup Fire in Montana entered treated areas it moved from a crown to a surface fire, even though not all of the piles had been burned before the fire front arrived at the piled area (Bitter Root RC&D 2014).

Do piles alter wildfire effects?

The effects of wildfires on the residual stand vary with weather, topography, forest type, fuel loadings, and other factors, potentially including whether unburned piles were present at the time of the wildfire. An area with handpiles that burned during the Angora Fire had slightly lower severity when compared to similar completely untreated stands (Murphy et al. 2007). Investigators attributed the reduced mortality to the wider crown spacing in the piled stand. The heat from the piles that burned in the Andrews Creek Fire caused approximately 40 percent mortality in the overstory even though there was little scorch (Patrick Skrip, Douglas Forest

Protective Association, personal communication). The 2011 Wallow Fire in Arizona affected both stands with a lop-and-scatter treatment and stands with piles that had yet to be burned. Although both types of treatment resulted in canopy mortality, mortality in the piled treatment was concentrated around the pile locations (particularly landing piles) while the lop-and-scatter treatment experienced complete mortality (Bostwick et al. 2011, Palmer et al. 2011). In some areas that burned in the Wallow Fire near Nutrioso, Arizona, the delayed mortality of the overstory trees near piles that burned in the wildfire appeared to be driven by the long fire residence time associated with the burning piles (Russell Bigelow, U.S. Forest Service, personal communication).

In a number of cases when wildfire encountered unburned piles, the effects were worse than in similar untreated stands. The 2007 East Zone Complex burned about 156 acres in Secesh Meadows, Idaho, where contractors had thinned and piled small trees the year before, but had not yet burned the piles. Tree mortality was higher in the areas where the wildfire burned piles than in untreated areas (Hudak et al. 2011). When the 2011 Cougar Fire in California reached accumulations of trees cut by feller bunchers and left to cure before being chipped (also called 'doodle piles') the result was higher fire severity (Calvin Farris, National Park Service, personal communication; Safford et al. 2012). Wimberly and colleagues (2009) studied unfinished fuel treatments that burned in the 2005 Camp 32 Fire and the 2006 Warm Fire in Arizona. Though their analysis did not focus specifically on the impact of unplanned fire in piled fuels, they found that thinning without treatment of the resulting slash increased burn severity. In an analysis of the 2007 Tin Cup Fire, Harrington and colleagues (2010) stated that crown burn effects were similar between partially treated units with slash piles and untreated units with ladder fuels.

Where topography drives an increase in fire intensity, fuel treatments are often overwhelmed. For example, during the 2012 Little Bear Fire in New Mexico, burnout operations sent fire uphill into a stand where hand-piled fuels had yet to be treated and the result was high levels of mortality in the residual stand (Kuhar 2012).

In one case, an unplanned ignition of piles at Mount Rushmore National Park, South Dakota in 2005, resulted in rapid and complete pile consumption, a fire effect that park staff considered beneficial (e.g., greater fuel consumption) compared to other areas where piles that were burned within prescription failed to achieved desired levels of fuel consumption (Steve Ipswich, Bureau of Indian Affairs, personal communication).

Conclusions and research needs

Based on our review of the available reports and interviews with managers, it appears that unplanned fire in areas with piles may not be especially common. Our search only uncovered about 20 examples in the last decade. Although we suspect our review of the literature and limited survey of the management community potentially reflects a significant under-estimate, the fact remains that it is three orders of magnitude smaller than the total number of wildfires that occur each year (the National Interagency Fire Center estimates an average of about 10,000 lightning and 62,000 human-caused fires each year), and therefore, still a relatively minor occurrence in the broader context. Even in cases like the East Zone Complex in Idaho, where 156 acres of piles did burn in a wildfire, another 954 acres of piles had been burned under controlled conditions before the wildfire arrived (Hudak et al. 2011) highlighting the disparity between wildfire area burned with and without piles. Piles need not always exacerbate wildfire activity and severity; there are also some cases where, either because of location (easier access) or re-arranging of the surface fuels across the larger stand (disrupting horizontal fuel continuity) unburned piles increase control opportunities and potentially reduce wildfire severity.

Piling and burning is a proven fuel treatment method for reducing fuel loading in forested systems. It is often favored in the WUI and other difficult-to-burn areas because of the added measure of control over fire behavior and emissions it affords fuel management personnel. Piles are being created more quickly than they are being burned, however, leaving a surplus of unburned piles in forested landscapes of the United States that are susceptible to burning during wildfires. Personnel and environmental limitations, along with the need to allow piles to dry means there is frequently a risk that piles could be present in areas being burned during unplanned fires (i.e., wildfires). Therefore a key question is whether the risk of unplanned fire in piles should change the management approach to fuel reduction. In other words, in areas where resources and opportunities to burn piles are limited, should management focus on alternative fuel treatments such as chipping or mastication?

We consider this report a first look at the phenomenon wherein wildfires burn areas with piled fuels. Given the dearth of information and quantitative study, we suggest that the topic warrants additional inquiry. A more in-depth investigation of the area affected could help define the scope of the potential issue. A simple inventory of the total area with piles and of the annual area with piles burned during wildfires would be a good place to start. Planned experiments and opportunistic post-fire measurements should also be undertaken to assess how the presence of piles (and the associated changes to stand structure and surface fuels that accompany fuel treatments that include pile burning) affects fire intensity and severity in ecosystem types where piling and burning occurs so that land managers can better weigh the risks and benefits associated with piling as a fuel treatment.

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