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Do fuel treatments reduce fire severity? Evaluating treatment effectiveness in the 2006 Tripod Complex fires


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Do fuel treatments reduce fire severity? Evaluating treatment effectiveness in the 2006 Tripod Complex fires

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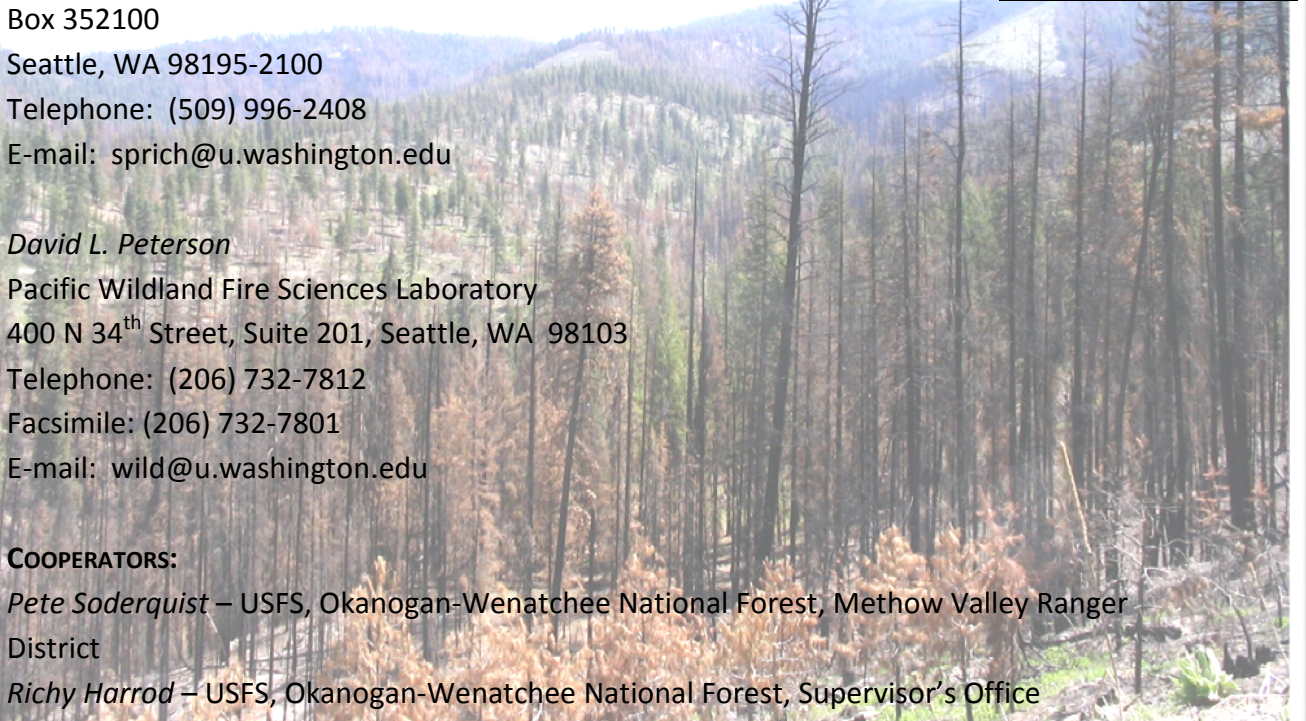
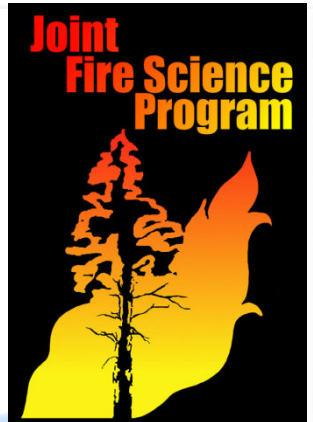
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ABSTRACT:

The 2006 Tripod Complex fires burned over 70,000 ha of dry mixed conifer forests in north-central Washington State. Recent fuel treatments burned in the wildfire offered an opportunity to quantitatively evaluate if fuel treatment effectively mitigated fire severity. We quantified the relative effect of two common fuel treatments: mechanical thinning only (thin) and mechanical thinning followed by prescribed burning (thinRx). Fire severity was markedly different between the two treatments. Over 57% of trees survived in thinRx units versus 19% in thin and 14% in control units. Considering only large-diameter trees (> 20 cm dbh), 73% survived in thinRx units versus 36% in thin and 29% in control units. Logistic regression models demonstrate significant reductions in the log-odds probability of tree mortality under both treatments with a much greater reduction in thinRx units. They also suggest that three years following the fire, large-diameter trees are at greater risk of mortality in either thin or control units than in thinRx units. Other severity measures, including maximum bole char, percentage crown scorch, and burn severity index, are significantly lower in thinRx units than thin and control units. There were no significant differences in fire severity measures between thin and control units.

This study provides strong quantitative evidence that without treatment of surface fuels, thinning alone is not a viable surrogate for prescribed fire in these dry, mixed conifer forests. In contrast, thinning followed by prescribed burning to reduce surface fuels appears to be an effective strategy for mitigating wildfire severity. Given the similar findings to other studies, our results should be applicable to many dry forests with low to mixed-severity fire regimes in the western United States.

BACKGROUND AND PURPOSE:

With a legacy of fire suppression and exclusion, millions of hectares of dry forests in western North America have fuel accumulations that are considerably higher than prior to the 20th century (Covington 2003, Hessburg et al. 2005). Wildfire frequency and area burned have increased over the past 50 years, and this trend is expected to continue under global warming scenarios (Gillett et al. 2004, McKenzie et al. 2004, Westerling et al. 2006). A variety of fuel treatments are being applied to dry forests throughout the interior West (see Agee and Skinner 2005 and Peterson et al. 2005 for reviews). Because regular prescribed burning generally reduces surface fuels, it is one of the more promising approaches to fire hazard reduction (Fernandes and Botelho 2003, Agee and Skinner 2005, Finney et al. 2005, Johnson et al. 2007, Schwilk et al. 2009). However, prescribed burn windows generally are short due to potential smoke impacts and fire hazard (Riebau and Fox 2001, Stephens and Ruth 2005). In most Western forests, the area treated with fire remains low compared to the millions of hectares that could benefit from treatment (Stephens and Ruth 2005). Surrogate treatments involving forest thinning and biomass removal are being implemented in many dry forests (Graham et al. 1999, Peterson et al. 2005).

A central principle underlying most fuel reduction programs is that they will mitigate the occurrence of high-severity fire events in areas with historic high-frequency, low and mixed severity fire regimes (Fernandes and Botelho 2003, Agee and Skinner 2005). Although many fuel treatment programs are being implemented, there have been relatively few opportunities to quantitatively evaluate treatment efficacy in wildfires. Existing studies generally agree that mechanical thinning followed by prescribed burning is the most effective at mitigating wildfire severity (Pollet and Omi 2002, Omi and Martinson 2004, Finney et al. 2005, Strom and Fulé 2007, Ritchie et al. 2007). The effectiveness of fuel reduction programs, particularly that of prescribed burning, is also supported by fire behavior and effects modeling (Stephens and Moghaddas 2005, Johnson et al. 2007). Better representation of forest types and climatic regimes is needed to assist managers in planning and prioritizing fuel treatments. More definitive evidence and guidelines on the relative effectiveness of different types of fuel treatments are also needed to provide the scientific basis for fuel treatment planning in the West. As more data on fuel treatment efficacy become available, resource managers will be able to use this information as the scientific basis for fuel reduction plans and to educate the public on the value of managing hazardous fuels.

The 2006 Tripod Complex fires burned over 70,000 ha of mixed conifer forest in the Okanogan-Wenatchee National Forest in north-central Washington, USA. The 2006 Tripod Complex fire was one of the largest fire events for Washington State in the past 50 years. It was preceded by hot dry weather and an ongoing mountain pine beetle (*Dendroctonus ponderosae*) outbreak in mid- to high-elevation forests. The fires initiated as two lightning strikes and quickly converged under strong gusty winds and extreme fire weather conditions, spreading as a mixture of crown fires and variable-intensity surface fires. Over 60% of the area burned was classified as moderate to high severity (Tripod Salvage Environmental Impact Statement 2008, Methow Valley Ranger District).

Of the many fuel treatments the Methow Valley Ranger District implemented over the past decade, several were used as defensible space for burnout operations to combat the wildfires outside the town of Winthrop, Washington. An additional 19 thinned units and 10 thinned and prescribed-burned units were burned by the wildfire. The serendipitous involvement of so many fuel treatments in a wildfire and the availability of pre-wildfire data provided a rare opportunity to study the efficacy of fuel treatments in reducing fire severity and fighting wildfires.

We conducted an opportunistic study to determine the relative success of recent fuel treatments in mitigating wildland fire severity, as represented by tree mortality, tree damage, and changes in fuel structure. Our main objective was to evaluate differences in wildfire severity in units with thin treatments (thin), thin and prescribed burning treatments (thinRx), and no treatment (control) within the Tripod Complex fires.

STUDY DESCRIPTION AND LOCATION:

Study area

Treatment units are located within the southwestern section of the Tripod Complex fires, approximately 10 km north of Winthrop, Washington (Fig. 1). The study area is located in the Methow Valley Ranger District of the Okanogan-Wenatchee National Forest. Study units are located in low- to mid-elevation forests primarily composed of multi-aged stands of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and lodgepole pine (*Pinus contorta* var. *latifolia*). Grand fir (*Abies grandis*) and western larch (*Larix occidentalis*) are less common stand associates.

Of the 19 treatment units potentially available for this study, several were excluded because they were located along the wildfire perimeter or were surrounded by unburned forest. We also limited treatment units to those that had been harvested or prescribed burned within the past 15 years. Units adjacent to known burnout operations were also excluded from the study, but with increasing distance from where burnouts initiated, it was unclear whether units burned as a result of the wildfire or fires ignited in burnout operations. For a balanced study design, sample size was constrained by the availability of thinRx units that met selection requirements. Eight thinned units and 8 thinRx units were selected for this study (Table 1).

Eight control areas with no record of harvesting or burning were randomly selected within the matrix of treatment units. Control selection was buffered 0.4 km from the Tripod perimeter and within 0.8 km of roads. A standard area of 8 ha was delineated for each control unit. A 2007 Burned Area Reflectance Classification image was used to confirm that selected controls were not surrounded by unburned forest and were burned by the wildfire.

Mechanical thinning prescriptions included both thin-from-below harvests that targeted small diameter and understory trees and shelterwood harvests that removed both understory and overstory trees. All timber harvests were completed 8 to 15 years prior to the wildfire and were mostly whole-tree harvested by tractor. Four thin units were helicopter logged, and tree crowns left on site. Most thin units were scheduled for prescribed burning and had recent estimates of woody fuel loading. Prescribed burns were conducted on thinRx units between 0 and 6 years prior to the wildfire event. Hand lines were constructed around each unit, and units were hand or helicopter ignited. Burning took place either in the spring or fall, and all burns were recorded as successful in accomplishing fuel reduction objectives.

An additional paired sampling design was used to evaluate differences in fire severity between treated units and adjacent untreated control units that had similar topography and likely experienced similar fire weather at the time of the wildfire. Adjacent areas were excluded if they were upslope of the treated unit, across a major road or perennial stream from the treatment, and/or had distinctly different topography (i.e., greater than 30% slope gradient and/or greater than 90° difference in aspect). Not all thin and thinRx units had suitable adjacent controls. A total of six thin and six thinRx units were paired with adjacent controls (Table 1).

Units were sampled with circular plots along systematic grids. We used a nested plot sampling design to accommodate variable tree densities. Treated units (e.g., thin and thinRx) were sampled using 0.2-ha plots. Control units were sampled using 0.08-ha plots to account for generally much higher tree densities in all size classes. In units with tree densities < 30 trees per plot irrespective of size class, all trees were tallied within the largest radius plot. In denser units, smaller tree size classes were sampled in subplots: trees between 10 and 20 cm dbh were sampled in 25.4-m radius subplots, and trees < 10 cm dbh were sampled in 5.1-m radius subplots. A minimum of 10% of each unit was surveyed.

Plots were marked with a permanent center stake and numbered metal tag. At each plot, we collected general plot information including site description, aspect, slope gradient, and slope position (i.e., lower slope, mid slope, upper slope, ridgetop). The following measurements were collected for each sampled tree: diameter at breast height (dbh; cm), crown base height (m), height to live crown (m), tree height (m), maximum height of crown scorch (m), minimum and maximum bole char (m), percentage of the crown volume that was scorched (% crown scorch), and tree severity index (USDI NPS 2003). Tree burn severity classes were defined as: 1=unburned, 2 = scorched foliage, 3 = lightly burned (some foliage and small twigs burned), 4 = moderately burned (foliage and small stems consumed), and 5 = severely burned (only charred stems remain) (USDI NPS 2003). Recent downed trees that fell after the wildfire (e.g., logs with uncharred wood at severed stems) were tallied as trees. For consistency in observations, field personnel regularly compared and calibrated estimates of percentage crown scorch, site severity index, and tree severity index.

Live trees were tagged at tree bases facing plot center for sampling of tree status in subsequent years. During the summers of 2008 and 2009, plots that had live trees in 2007 were revisited to record subsequent tree mortality. Plots with 100% mortality were marked in the center but were not revisited in subsequent years.

Data analysis

Individual stand variables and fire severity measures were summarized by unit. To test for differences in tree mortality following wildfire between thin, thinRx, and controls, we conducted a 1-factor ANOVA on measures of tree fire severity for thin units, thinRx units, and controls (Sall et al. 2007). Where ANOVA indicated statistical differences between treatments (including treatments and adjacent controls), pair-wise comparisons were made using Tukey Honestly Significant Differences tests. Because tree mortality data are binary (i.e. either live or dead), we used binomial generalized linear modeling to evaluate effectiveness of treatments on tree mortality (R programming language). A logistic regression model was constructed to predict the log-odds probability of tree mortality. Treatment type and tree diameter were used as predictor variables.

With greater crown heights and thicker bark, large-diameter trees have a better likelihood of survival than small trees (Agee 1993). Small trees were more numerous in thin and control units than thinRx units. To test for differences in tree mortality and other measures of fire severity in large trees, we performed an additional set of analyses on trees greater than 20-cm dbh.

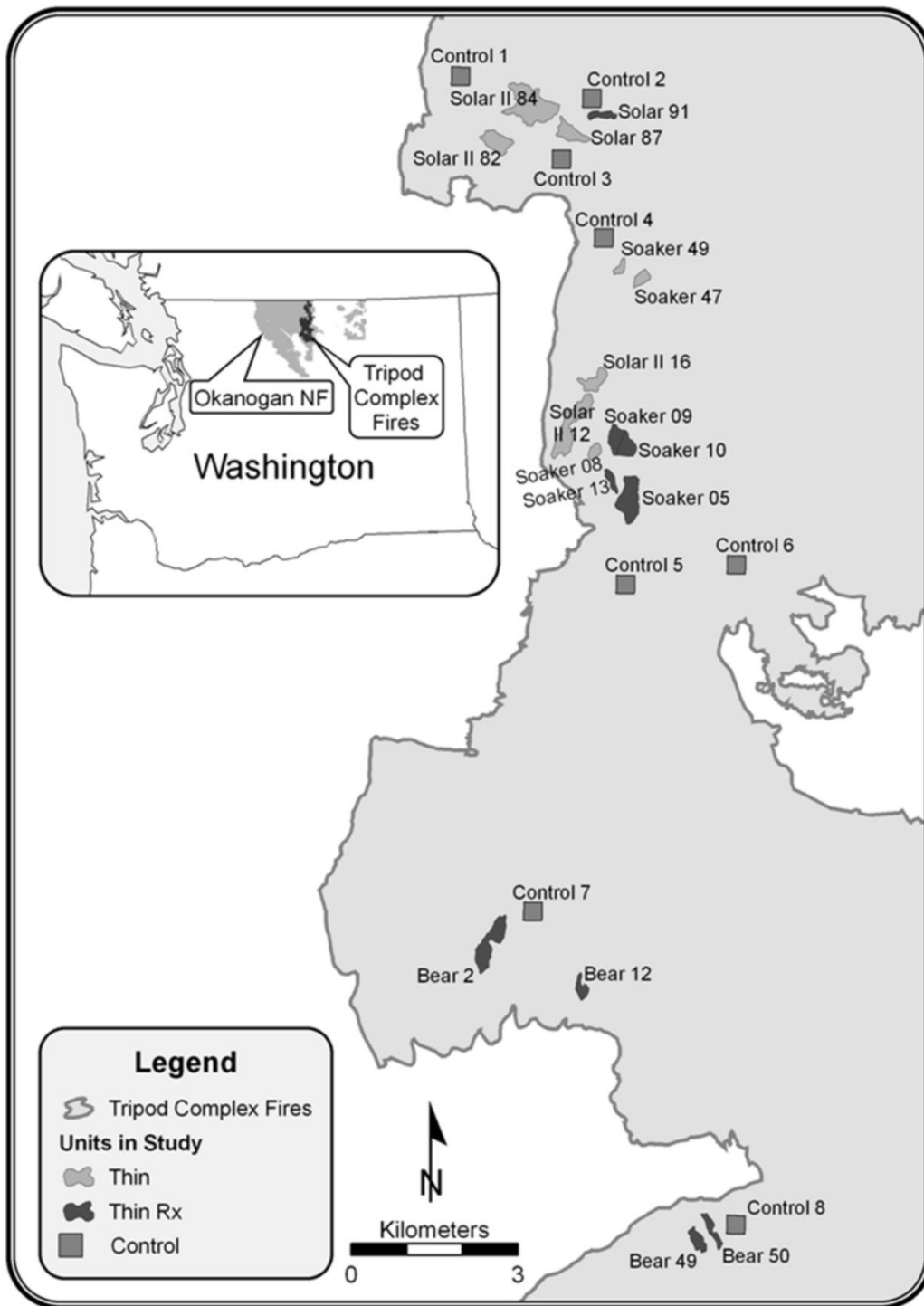


Figure 1: Study area.

Table 1: Treatment unit location, aspect, slope gradient, and elevation.

| Treatment | Unit | Area (ha) | UTM_E | UTM_N | Aspect (°) | Slope (%) | Elevation (m) |
|-----------|---------------|-----------|--------|---------|------------|-----------|---------------|
| Control | C1 | 8.2 | 712257 | 5397643 | 260 | 44 | 855 |
| | C2 | 8.2 | 714629 | 5397311 | 313 | 52 | 1409 |
| | C3 | 8.2 | 714114 | 5396203 | 323 | 45 | 1303 |
| | C4 | 8.2 | 714915 | 5394812 | 228 | 30 | 1731 |
| | C5 | 8.2 | 715484 | 5388596 | 157 | 31 | 1150 |
| | C6 | 8.2 | 717466 | 5389005 | 53 | 54 | 1266 |
| | C7 | 8.2 | 713983 | 5382667 | 97 | 21 | 1422 |
| | C8 | 8.2 | 717795 | 5377142 | 236 | 36 | 1499 |
| Thin | Soaker 8 | 4.9 | 714860 | 5390967 | 177 | 46 | 1437 |
| | Soaker 47 | 11.4 | 715619 | 5394106 | 228 | 36 | 1747 |
| | Soaker 49 | 3.3 | 715227 | 5394285 | 162 | 27 | 1787 |
| | Solar 87 | 12.2 | 714260 | 5396683 | 210 | 31 | 1362 |
| | Solar II 12 | 28.5 | 714420 | 5391410 | 222 | 44 | 1399 |
| | Solar II 16 | 11.0 | 714821 | 5392234 | 257 | 31 | 1603 |
| | Solar II 82 | 14.7 | 712940 | 5396481 | 237 | 28 | 1165 |
| | Solar II 84 | 41.9 | 713540 | 5397157 | 237 | 23 | 1294 |
| ThinRx | Bear 2 | 22.4 | 713227 | 5382066 | 117 | 30 | 1430 |
| | Bear 12 | 5.7 | 714898 | 5381307 | 86 | 21 | 1495 |
| | Bear 49 | 7.3 | 717113 | 5376841 | 329 | 52 | 1450 |
| | Bear 50 | 6.5 | 717370 | 5377041 | 286 | 47 | 1437 |
| | Soaker 5 | 8.1 | 715509 | 5390125 | 134 | 27 | 1390 |
| | Soaker 9/10 | 19.1 | 715330 | 5391140 | 107 | 18 | 1432 |
| | Soaker 13 | 4.5 | 715175 | 5390460 | 226 | 26 | 1346 |
| | Solar 91 | 5.3 | 714816 | 5397017 | 211 | 26 | 1523 |
| C_thin | Soaker 8 C | - | 714900 | 5390712 | 178 | 46 | 1394 |
| | Soaker 47 C | - | 715546 | 5394260 | 219 | 33 | 1754 |
| | Soaker 49 C | - | 715205 | 5394210 | 162 | 22 | 1768 |
| | Solar 87 C | - | 714088 | 5396708 | 179 | 33 | 1313 |
| | Solar II 82 C | - | 712844 | 5396575 | 239 | 35 | 1098 |
| | Solar II 84 C | - | 713451 | 5431010 | 237 | 33 | 1247 |
| C_thinRx | Bear 2 C | - | 713468 | 5381954 | 81 | 42 | 1377 |
| | Bear 12 C | - | 714807 | 5381261 | 154 | 19 | 1501 |
| | Bear 49 C | - | 717435 | 5377162 | 332 | 45 | 1428 |
| | Bear 50 C | - | 716919 | 5376747 | 296 | 52 | 1484 |
| | Soaker 9/10 C | - | 715534 | 5391189 | 80 | 35 | 1385 |
| | Soaker 13 C | - | 715115 | 5390397 | 234 | 46 | 1308 |

KEY FINDINGS:

What type of fuel treatment effectively mitigated wildfire severity?

This study provides strong quantitative evidence that thinning alone is not a viable surrogate for prescribed fire in these dry, mixed conifer forests. In contrast, thinning followed by prescribed burning to reduce surface fuels appears to be an effective strategy for mitigating wildfire severity. Figure 2 includes representative photographs from the three treatment types in this study.

Three years post fire, over 57% of trees survived in thinRx units versus 19% in thin and 14% in control units (Figure 3). Other severity measures, including maximum bole char, percent crown scorch, and burn severity index, are significantly lower in thinRx units than thin and control units. In sharp contrast, there are no significant differences in fire severity measures between thin and control units. Unit size does not appear to be a factor in treatment effectiveness. Even small thinRx units (4 to 5 ha in size) had low fire severity, suggesting that unit size is not as important as treatment type in predicting fire severity. However, statistical analysis of the effect of unit area was not possible due to our small number of units.



Figure 2. Representative photos of a) control unit, b) thin unit, and c) thin and prescribed burn unit.

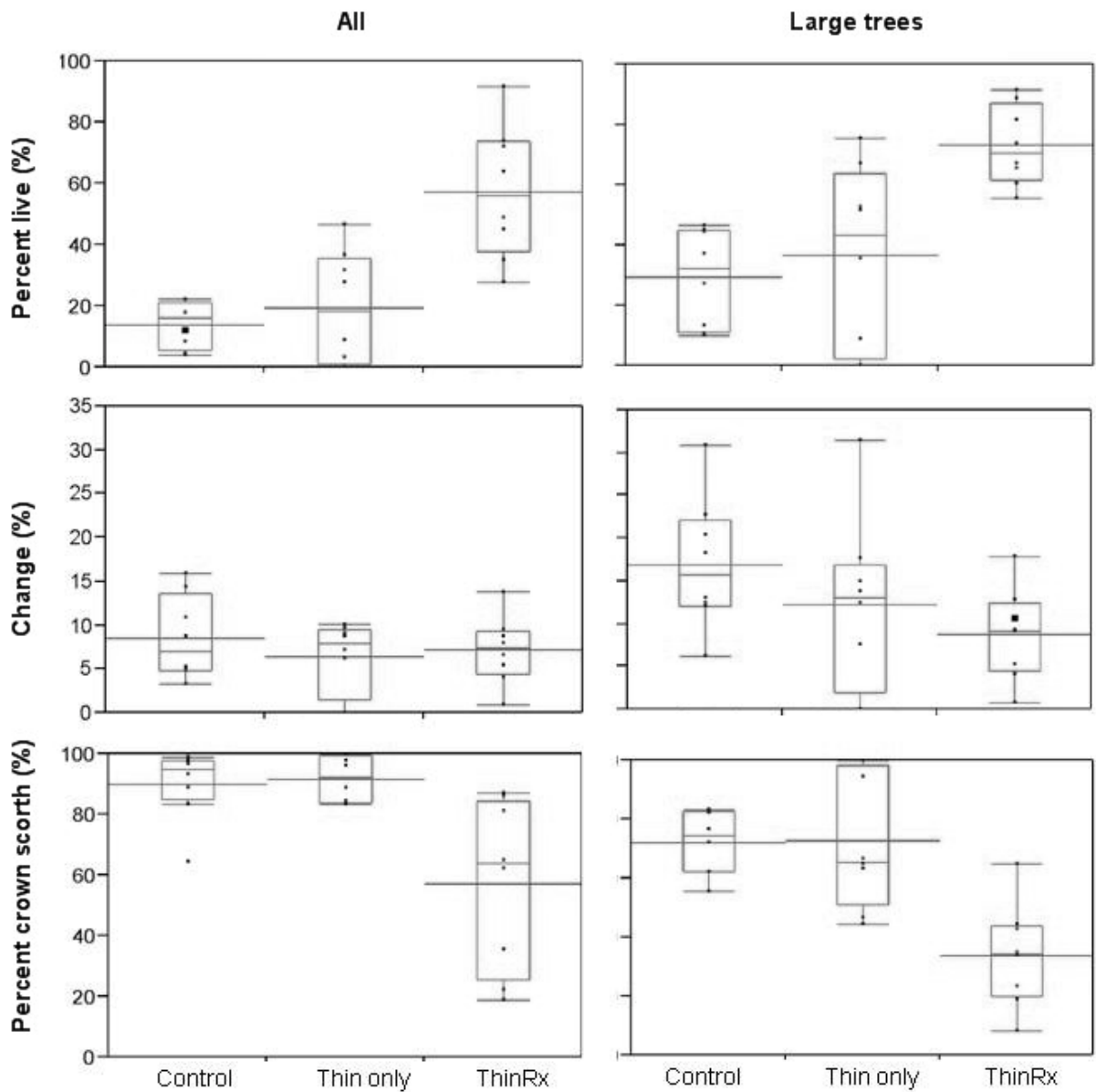


Figure 3: (a) Percentage of live trees by treatment for all trees and large diameter trees (> 20 cm dbh), (b) percentage change in mortality 1 year and 2 years post fire, and (c) percentage crown scorch by treatment for all trees and large diameter trees. Box plots represent minimum, 25% quantile, median, 75% quantile, and maximum values, from lower to upper. Horizontal lines represent the statistical mean of all units within each treatment.

How did results from the standard analysis compare to the paired analysis?

Wildfires can be extremely variable in fire spread and intensity due changeable environmental conditions such as fire weather and topography. When we designed this study, we added an additional analysis of adjacent controls to test for differences between treatments in areas that presumably experienced similar fire weather and behavior as the wildfire burned into the control and treated units. Our analysis of the adjacent controls demonstrated very similar results to our balanced ANOVA design. Fire severity measures do not significantly differ between thin units and adjacent controls whereas measures such as bole char height, percentage crown scorch and burn severity index are significantly lower in thinRx units than adjacent controls. Although both thin and thinRx treatments reduced the log-odds probably of tree mortality, thinRx treatments had much greater reductions than thin treatments.

How did large-diameter trees fare relative to small diameter trees?

With greater crown heights and thicker bark, large-diameter trees have a better likelihood of survival than small trees (Agee 1993). Even considering only large-diameter trees (>8 inches dbh), thinRx units were more effective at mitigating wildfire effects on tree mortality. Three years post-fire, over 73% of large-diameter trees survived in thinRx units versus 36% in thin and 29% in control units (Figure 2). All measures of large-diameter tree severity in thinRx units are significantly lower than thin and control units. Considering only large-diameter trees, there still are no significant differences in fire severity measures between thin and control units.

Logistic regression models of the log-odds probability of tree mortality reveals influences of tree diameter class and sampling year (Figure 4). Overall, the log-odds probability of mortality is considerably lower in thinRx units than thin and control units. Across all treatment types, small diameter tree are much more likely to die than larger trees. Log odds mortality in 2008 is still higher in smaller diameter trees. In 2009, the probably if mortality is low for all trees but larger diameter trees are actually somewhat more likely to die than smaller diameter trees in control and thin units. In contrast, for large trees in thinRx units, log odds mortality is near 0 across all years. Two factors likely contributed to these findings. First, small-diameter trees are more vulnerable to direct and immediate mortality by fire than large-diameter trees. Second, older, large-diameter trees may be more vulnerable to secondary mortality agents including bark beetles and drought-stress than young trees. Tree mortality associated with bark beetles was observed in the units in 2008 and 2009. Overall, large-diameter trees in

control and thin units that survived the wildfire were likely exposed to higher intensity fires, which in turn may have increased their vulnerability to secondary mortality agents such as drought stress and bark beetle outbreaks.

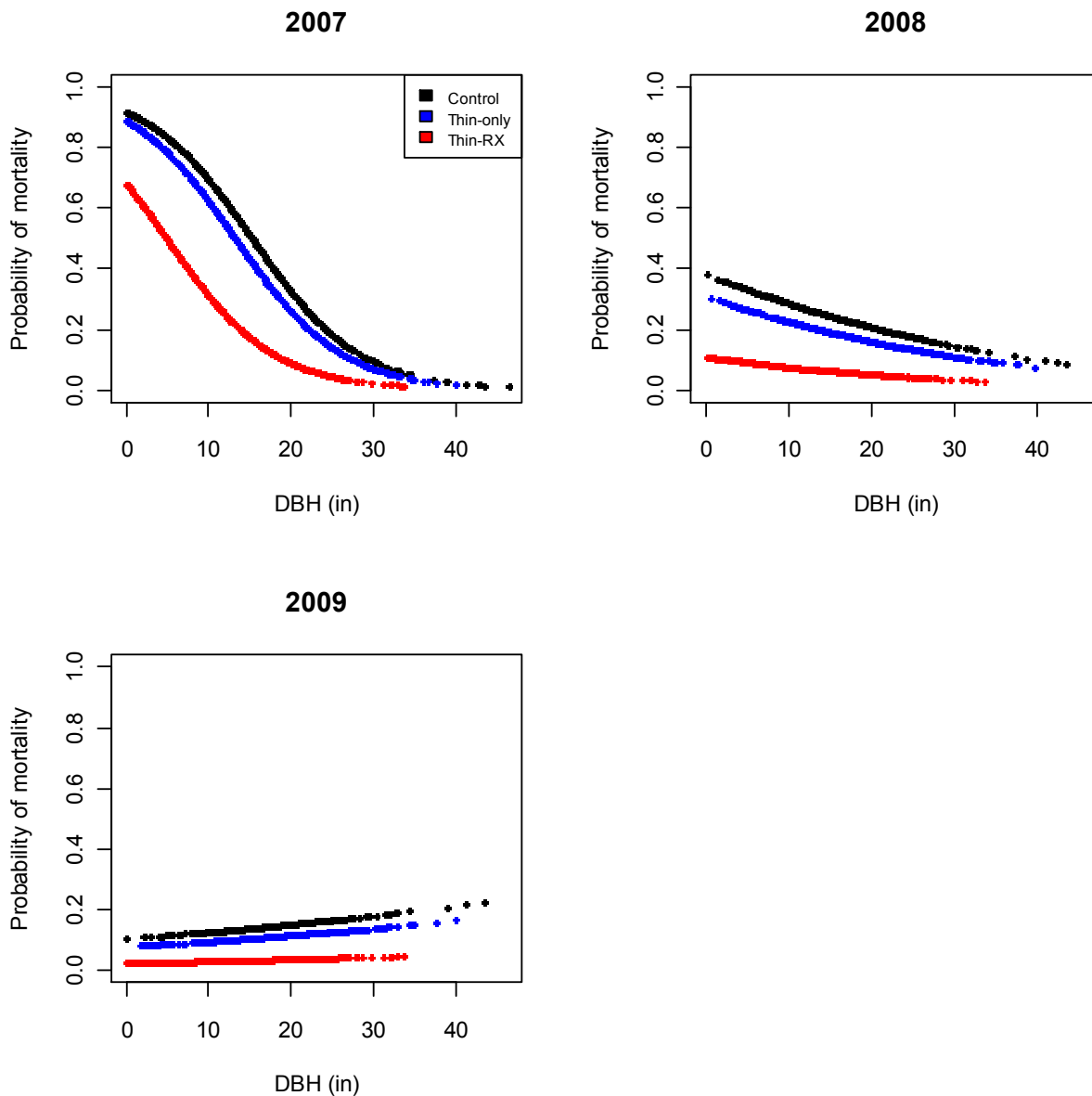


Figure 4: Log-odds probability (0-1) of tree mortality in 2007, 2008, and 2009 modeled by treatment type and tree diameter.

Did tree mortality differ by tree species?

Tree mortality was surveyed for three years following the wildfire event. Following the initial survey in 2007, an additional 18% of trees subsequently died in 2008 and 7% of trees died in 2009 (Figure 5). Percent change in tree mortality between 2007 and 2009 does not significantly differ by treatment (Figure 2). Tree mortality markedly differs by species (Figure 4) with the lowest mortality for western larch (21%) and ponderosa pine (39%) and highest mortality for lodgepole pine (91%) and Engelmann spruce (88%). Overall mortality for Douglas-fir is 66%.

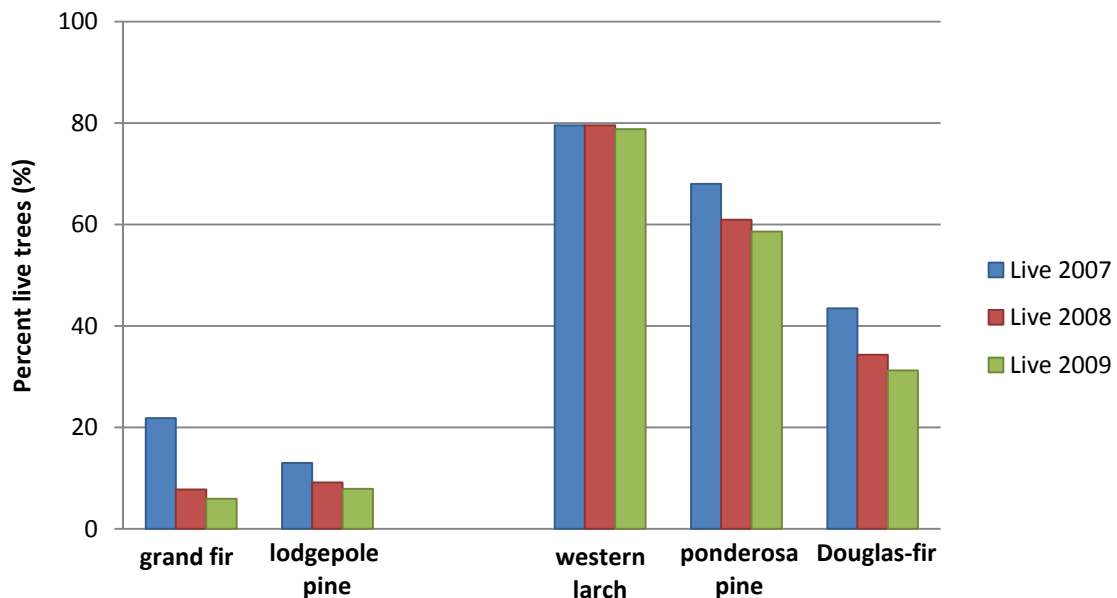


Figure 5: Trends in mortality over the 3-year study by species.

Summary of key findings:

- Tree mortality and other fire severity measures are significantly different between thinRx units and other treatments (thin-only units and Controls).
- Results are significant even when comparing large-diameter trees.
- There is no significant difference in tree mortality and other severity measures between thin units and control units.
- Unit size does not appear to be a factor in treatment effectiveness.

MANAGEMENT IMPLICATIONS:

Why did thin units not mitigate wildfire severity?

With lower tree densities and fewer understory trees than unmanaged controls, thin units likely were effective at reducing crown fire but not tree mortality. We did not observe evidence of crown fire in thin units; in the first two years following the wildfire, red needles were retained on most dead trees (Figure 2). In contrast, control units comprised a mixture of scorched patches of trees and areas where crowns were consumed by fire. High tree mortality in thin units likely was associated with cambial heating and crown scorch from intense surface fires. Bole char and crown scorch height both were highest in thin units, suggesting high flame lengths and particularly intense surface fires in those units.

Dispersed logging slash combined with extreme fire weather likely contributed to intense surface fire behavior and high tree mortality in thin units. Piling and burning of logging slash may have mitigated wildfire severity (Strom and Fulé 2007, Safford et al. 2009) but was not done on any thin units. Because this was an opportunistic study, we have limited information about pre-fire surface fuel conditions. In all thin units, logging slash was characterized by forest managers as surface fire behavior fuel model 11 (moderate logging slash with 10 to 13 Mg ha⁻¹ of fine woody fuels < 20.3 cm in diameter, U.S. Fire Behavior Prediction System) (Anderson 1982). Litter accumulations were low, with depths < 2 cm. Pre-fire shrub cover was not recorded, but shrub cover is low in these dry forests and probably did not contribute to surface fire behavior. Pre-wildfire surface fuel data are not available on thinRx units, but prescribed burns were reported as successful in all units, with a reduction of > 90% of fine surface fuels. Treatment of fine, downed woody debris and litter accumulations likely limited surface fire intensity, flame lengths, and convective and radiative heating in thinRx units and lowered post-wildfire tree mortality and other fire severity measures.

How do our findings relate to management of large-diameter trees in dry forest landscapes?

A stated goal of the 2009 Dry Forest Strategy of Okanogan-Wenatchee National Forest is to recruit and retain old, large-diameter trees (>50 cm dbh) on forested landscapes (USFS 2009). A key management issue is how to increase survival of old, large trees in future wildfires. Our findings suggest that thinning followed by prescribed burning is viable management tool to protect large-diameter trees in wildfire events. Based on our logistic regression models, the probability of mortality for large-diameter trees is near zero in thinRx units.

Thinning alone, without treatment of surface fuels, will not protect large trees from future wildfires. The probability of mortality is considerably higher in thin and control units than thinRx units. Three years post fire, large-diameter trees are actually somewhat more likely to die than smaller diameter trees in thin and control units. Increased risk of mortality in large-diameter trees may be associated with exposure to higher intensity fires; weakened trees were likely more vulnerable to secondary mortality agents such as drought-stress and bark beetle attack.

How applicable are these results to other dry forest types?

Given the similar findings to other studies, our results should be applicable to many dry forests with low to mixed-severity fire regimes in the western United States. However, they may *not* apply to forests with flammable shrub and/or grassland understories. Both thinning and prescribed burning can increase shrub dominance by creating gaps in the forest canopy (Bailey and Tappeiner 1998).

For forest types in which flammable understory shrub growth could be accelerated by fuel treatments, the efficacy and longevity of treatments could be reduced compared to the dry forests of our study area. For example, in a landscape analysis of fire severity in the 2002 Biscuit fire in southwestern Oregon, Thompson and Spies (2009) report that shrub cover was one of the most important predictors of fire severity. Plantations and other clearings involved in the Biscuit fire experienced the highest incidence of fire severity and were associated with a flammable shrub stratum.

Potential influence of fuel treatments on fire spread

Although individual fuel treatments may be effective at reducing fire severity, they may do little to alter fire spread across landscapes unless they are strategically placed (Agee et al. 2000, Agee and Skinner 2005, Finney et al. 2005). Strategic placement of fuel treatments can be difficult to implement across complex terrain and management units (e.g., wildlife reserves, riparian corridors) (Peterson and Johnson 2007), but may be necessary to suppress and or alter the course of fire spread (Finney 2007).

Our study concentrated on fuel treatment effectiveness within specific treatment units and not on landscape patterns of fire spread. However, landscape fire spread did appear to be influenced previous wildfires and fuel treatments. The most striking example of this was the ca. 1000-ha 1974 Forks fire located in the center of the Tripod perimeter. The Tripod complex fires originated to the south and north of the Forks fire and wrapped around either side of the young lodgepole pine forest, burning only the edges of the regenerating trees. Similarly, a network of fuel treatments is located along the southwestern fire perimeter and was used as defensible space for back-burning to prevent fire spread toward nearby communities.

RELATIONSHIP TO OTHER RECENT FINDINGS AND ONGOING WORK:

Comparison with recent studies

Results from this study closely agree with previously published field research and fire behavior and effects modeling.

- In a field-based, retrospective study of five wildfires in the interior West, Omi and Martinson (2004) found that thinning followed by slash treatment was the most effective at reducing fire severity, whereas thin treatments failed to reduce fire severity and in some cases increased it.
- Finney et al. (2005) evaluated the efficacy of prescribed burning in the 2002 Rodeo-Chediski fire in Arizona and report significant relationships between the age, size, and frequency of past prescribed burns and lower fire severity.
- Strom and Fulé (2007) studied thinned units where slash had been piled and burned in the Rodeo-Chediski fire and found significant reductions in fire severity compared to untreated stands.
- Safford et al (2009) report significant differences in tree mortality in thinned units where slash had been piled and burned relative to untreated areas in the Angora fire, CA. In a study of fire severity following a wildfire in northern California, Ritchie et al. (2007) report highest tree survivorship in units that were thinned and prescribed burned.

The effectiveness of fuel reduction programs, prescribed burning in particular, is also supported by fire behavior and effects modeling (Raymond and Peterson 2005, Stephens and Moghaddas 2005, Johnson et al. 2007). The national Fire and Fire Surrogates study also demonstrated that prescribed burns treatments were more effective than mechanical treatments at reducing surface fuels (Schwilk et al. 2009). Table 2 provides a summary of other recent retrospective studies of fuel treatment effectiveness following large wildfire events.

Table 2: Summary of research findings from recent retrospective studies of fuel treatment effectiveness in wildfire events. Thin = mechanically thinned, SW = shelterwood harvest, Rx = prescribed burn only, ThinRx = mechanical thin followed by prescribed burn, P&B = pile and burn.

| Reference | Wildfire(s) and location(s) | Treatment types evaluated | Findings |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| This study | 2006 Tripod Complex fires, north central WA | Thin ThinRx | Fire severity was significantly lower in thinRx units than thin-only units and untreated controls. Tree mortality was slightly greater in untreated than thin sites, and there was no significant difference in other severity measures between thin and untreated controls. |
| Pollett and Omi (2002) | 1994 Webb fire, MT 1994 Tye fire, eastern WA 1994 Cottonwood fire, Sierra Mtns, CA 1996 Hochderffer fire, AZ | Rx fire ThinRx Thin (whole tree) ThinRx | Fire severity was significantly lower in treated units compared to untreated sites in three of the four fires. Results were not significant in the 1996 Hochderffer fire. |
| Finney et al. (2005) | 2002 Rodeo-Chediski fire, AZ | Rx fire | Prescribed burns reduced fire severity relative to untreated sites. Unit size and frequency of burning are negatively correlated with severity. |
| Strom and Fule (2007) | 2002 Rodeo-Chediski fire, AZ | Thin, P&B | Thin followed by pile and burning reduced burn severity relative to untreated sites. |
| Safford et al. (2009) | 2007 Angora Fire, Sierra Mountains, CA | Thin and PCT Thin, PCT and P&B | Fire severity was significantly lower in treated units than untreated units. Topography was less important to severity than pre-burn fuel loads. Fire behavior was generally reduced within 25-40 m of treatment edges. |
| Ritchie et al. (2007) | 2002 Cone Fire, northern CA | Thin ThinRx | Tree survival was low in untreated areas, slightly higher in thinned units, and markedly higher in thinRx units. |
| Raymond and Peterson (2005) | 2004 Biscuit Fire, southwest OR | Thin (n=2) ThinRx (n=2) | Increased fire severity. Reduced fire severity. |
| Wimberly et al. (2009) | Camp 32 Fire, western MT School Fire, eastern WA Warm Fire, northern Arizona | Thin, thinRx Rx fire, thin, thinRx SW, Rx fire, Thin | Thin alone increased severity while thinRx decreased severity. Prescribed burning alone had no effect. Thin and thinRx treatments both significantly reduced fire severity. Prescribed burning alone and shelterwood harvesting reduced burn severity. Thinning increased burn severity. |

Ongoing project on a landscape analysis of fuel treatments

Our current JFSP-funded study (JFSP 09-1-01-19 [Landscape analysis of fuel treatment longevity and effectiveness in the 2006 Tripod Complex Fires](#)) will extend this analysis of fuel treatment effectiveness from a field-based study involving two treatment types and control units to a large-scale analysis of all units involved in the Tripod Complex for which there are geospatial records. We have compiled geospatial harvest and prescribed burning records of 380 additional units dating back to the early 1970s that were burned in the wildfires. Past harvests include clearcuts, shelterwood cuts, and thins. Older harvests generally were conducted for reasons other than treating hazardous fuel (e.g., extracting merchantable timber and type conversion). However, many units were broadcast burned or underburned following harvest to reduce logging slash. The range of treatment types, spatial extent, and time since treatment in this dataset will allow us to address key management concerns including the type, size, and longevity of effective fuel reduction prescriptions.

Preliminary analysis of this expanded dataset suggests that prescribed burning effectively mitigated wildfire severity in a variety of harvest types and years since treatment. For example, the 1990 Coma timber sale included clearcut, shelterwood, and thinned units, most of which were broadcast burned or underburned between 1990 and 1992. Brown timber sale units were clearcut harvested in 1988, and some were broadcast burned between 1989 and 1992. In both timber sales, most units that were broadcast burned even 14-17 years before the wildfire event experienced no fire or low severity fire following the Tripod Complex fires.

A number of other factors may have influenced the extent and severity of the wildfires, including fire weather, vegetation type and structure, landform, and past disturbances. Analysis of fuel treatments across landscapes will include these other contributing factors as potential covariates.

FUTURE WORK NEEDED

Longevity of fuel treatments

This study only included fuel treatments harvested within 15 years and prescribed burned within 6 years of the wildfire event. Older treatments involved in the wildfire, including clearcut, shelterwood and thinning harvests that were broadcast burned in the 1980s and early 1990s, provide an opportunity to evaluate how long surface fuel treatments may be effective in this dry forest type. With sparse understories of grasses, shrubs, and relatively slow-growing forests, fuel succession appears to be quite slow in our study area. Quantifying the longevity of fuel treatments is one of the objectives in our latest JFSP-funded study and findings will hopefully assist local forest managers in planning future prescribed burns. We suspect that fuel treatment longevity varies considerably across different forest types and regions. To provide sound management recommendations, studies of treatment longevity will be necessary over a broad range of forest types and management situations.

How will fuel treatments perform in steep terrain or extreme fire weather?

Little is known about the effectiveness of fuel treatments in steep terrain and under extreme fire weather (Peterson *et al.* 2005). The relative influence of extreme fire weather and steep terrain may supersede the importance of fuel treatments (Bessie and Johnson 1995). Safford *et al.* (2009) evaluated the effect of topography on fire severity in the 2007 Angora fire and concluded that overall, pre-fire fuel loads were more important than topography in influencing fire severity. However, they did note that fire behavior will be more extreme on steep, south-facing sites with greater solar radiation and drying of fuels, particularly if they are located on windward locations. They recommended greater reduction of fuel loads on these sites to mitigate wildfire severity. Validation of the effects of silvicultural and fuels management techniques by studying additional wildfires using real-time fire weather and behavior records would increase confidence in using these treatments more broadly to reduce fire hazard in fire-prone landscapes.

Using fuel treatments as defensible space during wildfires

A number of treated units were used to initiate burnout operations during the Tripod Complex fires. At the height of wildfire, there were four concurrent incident response teams on the fire. In several cases, burnout operations set in treated units were so intense that these units experienced 100% tree mortality. Local managers describe overall fire severity as being more severe in burnout operations than in the actual wildfire. Given that treated units are regularly used as defensible space for firefighters, it seems imperative that we gain an understanding of fire severity in these areas and if possible, develop recommendations for the use of fuel treatments that remain effective both at reducing fire spread and mitigating local fire severity.

Implementing fuel treatment monitoring on public lands

One of the frustrations of conducting a retrospective study on fuel treatment effectiveness is the lack of pre-fire sampling design and data. A variety of fuel treatments are being implemented on public lands each year and yet with the exception of National Parks, managers often do not have the direction, time and training to adequately monitor their fuel treatments. Although a strategy to monitor fuel treatments on public lands (e.g., National Forests) would be difficult and expensive to implement, the potential benefits would be many. Pre-burn data on forest structure and surface fuel loadings in treated and untreated units would provide us with datasets necessary to rigorously evaluate treatment effectiveness following wildfires and allow us to address some of the key management questions, including:

- Treatment longevity (see above),
- Effective unit size,
- Strategic placement of fuel treatments, and
- Efficacy of surrogate fuel treatments (mastication, biomass removal) in areas where burning is not possible due to smoke or fire hazard issues.

DELIVERABLES

We completed all of the deliverables proposed for this study. A scientific manuscript was submitted to the *Canadian Journal of Forest Research* in December 2008 and is in review. We will submit the *Fire Management Today* manuscript after the scientific manuscript has been published. Other deliverables completed under this project but not included in our accepted JFSP proposal include participation in conferences, collaboration with summer interns and college students, and development of a website for project information and data distribution.

Table 3: Comparison of proposed and actual deliverables.

| Proposed | Delivered | Completion Date |
|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| JFSP progress report 1 | Progress report to JFSP for FY 2007 | November 2007 |
| JFSP progress report 2 | Progress report to JFSP for FY 2008 | November 2008 |
| Local presentation to managers | Local presentation to managers in the Okanogan and Wenatchee National Forests | June 2009 |
| | Project updates were delivered to Region 6 managers in 2008 and 2009. | October 2008 October 2009 |
| Manuscript | Scientific manuscript submitted to <i>Canadian Journal of Forest Research</i> | Submitted January 2009 |
| Article | Article in <i>Fire Management Today</i> | Draft completed February 2009 |
| JFSP Final Report | Final report to JFSP | Submitted March 2010 |
| Additional deliverables (not in original proposal) | | |
| Conference presentations | Oral presentation at the Pacific Coast Fire Conference, San Diego, CA. | December 2008 |
| | Poster presentation at the 4 th International Fire Ecology and Management Congress, Savannah, GA | December 2009 |
| Collaboration with NASA interns | Local advisor on two NASA DEVELOP summer internship projects involving the Tripod Complex fire. | Summer 2008 Summer 2009 |
| Website | Constructed a website for the Tripod complex fire research. After publication of the scientific manuscript, data, metadata, and publication links will be available at: http://www.fs.fed.us/pnw/fera/research/treatment/tripod/index.shtml | |

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ADDITIONAL REPORTING (APPENDICES AND OTHER CONTRIBUTIONS)

- A) **Scientific manuscript:** Prichard, S.J., Peterson, D.L., and Jacobsen, K. In review. Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA. Canadian Journal of Forest Research (Appendix A)
- B) **Fire management today manuscript:** Prichard, S.J., Peterson, D.L. In prep. Lessons learned from the 2006 Tripod Complex Fires: Did fuel treatments reduce wildfire severity? Fire Management Today (Appendix B)

C) Scientific meetings

Prichard, S.J. and D.L. Peterson. Oral presentation. Evaluating treatment effectiveness in the Tripod Complex fires. Pacific Coast Fire Conference, December, 2008, San Diego, CA.

Freed, T.J., Prichard, S.J., and Peterson, D.L. 2009. Landscape Analysis of Fuel Treatment Longevity and Effectiveness in the 2006 Tripod Complex Fires. Poster presentation at the 4th International Conference on Fire Ecology and Management, Savannah, GA.

D) Student projects

- 1) Susan Prichard advised two NASA DEVELOP internship projects on the Tripod Complex Fires. Poster sessions and abstract proceedings from the two summer projects are listed below:

Schiffman, B., Newcomer, M., Delgado, D., Gantenbein, C., Wang, T., Prichard, S., Schmidt, C. and Skiles, J. 2008. Burn severity assessment in the Okanogan-Wenatchee Forest using NASA satellite missions. Poster session presented at the American Geophysical Union, San Francisco, California.

Newcomer, M.; Delgado, D.; Gantenbein, C.; Wang, T.; and Schiffman, B. 2009. Burn Severity Assessment in the Okanogan-Wenatchee Forest Using NASA Satellite Missions. Proc. of ASPRS, Baltimore, Maryland.

Justice, E.; Cheung B.; Danse, W.; Myrick, K.; Willis, M.; Prichard, S.; and Skiles, J.W. 2009. Impact of Fuel Treatments on Carbon Flux During a Wildfire Using Satellite Imagery: Okanogan-Wenatchee National Forest. Poster session presented at American Geophysical Union San Francisco, California.

Justice, E.; Cheung B.; Danse, W.; Myrick, K.; and Willis, M.; 2010. Effect of Fuel Treatments on Carbon Flux During a Wildfire Using Satellite Imagery:

Okanogan-Wenatchee National Forest. Proc. of ASPRS, San Diego, California.

- 2) One of our summer field technicians, Aarin Sengsirirak, recently completed his senior project “Post-fire beetle activity in the Tripod Complex Fires” for the School of Forest Resources, University of Washington. He used data collected in 2008 and 2009 from treatment units from this study for his analysis.

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