FUEL SUCCESSION, POST-FIRE LOGGING, AND FUTURE FIRE BEHAVIOR: ADDRESSING THE "REBURN PROBLEM."

Final Report to the Joint Fire Sciences Program

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ABSTRACT

Debates over post-fire logging typically focus on economic salvage (timber utilization) versus biological conservation (terrestrial and aquatic habitat preservation). Often overlooked in the debate over post-fire logging is the risk of ecological damage to soils, vegetation, and aquatic ecosystems from subsequent high severity fires – “re-burns” – that may result if fire-killed trees are left to decay onsite. Forest managers in dry forest ecosystems who are concerned about managing future fuels and fire behavior may propose post-fire logging as a fuel treatment, with timber values covering costs. Opponents of post-fire logging have argued that post-fire logging is not a valid fuel treatment and may, in fact, increase fire hazards. To better inform this debate, we examined patterns of snag decay and surface fuel accumulations, with and without post-fire logging, across a chronosequence of 68 stand-replacing wildfires that burned between 1970 and 2007 in dry coniferous forests of Eastern Washington and Oregon.

Without post-fire logging, surface woody fuels accumulated for an average of 15-20 years following wildfire, as surface fuel deposition from decaying and falling snags exceeded decomposition of surface woody debris. Pre-fire stand structure (particularly stand basal area) influenced maximum surface fuel loadings, while species composition and stand size structure influenced rates of snag decay and fuel deposition. Small-diameter snags fell before large-diameter snags and ponderosa pine snags fell before Douglas-fir and true fir snags, on average. The majority of large downed woody debris (> 7.5 cm diameter) reached a rotten, soft-log state within 25-30 years, increasing potential for longer fire residence times and more complete fuel consumption. Cavity nesting species used a variety of snag species and snag diameters over 30 cm diameter, but most cavities occurred in snags with broken tops.

Post-fire logging initially increased surface fuels loads relative to unlogged areas by accelerating surface deposition of branches and tops from fire-killed trees. However, fuel loads on unlogged sites surpassed fuel loads on logged sites within 10 years after wildfire and remained higher until at least 35 years following wildfire, as fuel deposition from broken and fallen snags exceeded that from logging residue. Differences in fuel loadings were particularly notable in the larger fuel sizes, due to bole removal during logging. There was no evidence that post-fire logging hindered tree regeneration, as logged stands were somewhat more likely than unlogged stands to support saplings or small trees (individuals > 1.37 m height) and be fully stocked (at least 500 trees per ha).

BACKGROUND AND PURPOSE

Dry coniferous forests dominated by fire resistant tree species like ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), are found in areas with extended summer seasonal drought that historically supported fire regimes with frequent fires (Agee 1993). High fire frequencies maintained generally low fuel loadings, so most fires were of low or mixed intensity and severity (Agee 1993). Reductions in fire frequency over the past century have led to greater surface fuel accumulations, establishment and growth of understory trees that serve as ladder fuels, and increasing occurrence of uncharacteristically severe wildfires that kill high proportions of overstory trees and often also damage soils through excessive heating (Peterson et al. 2005).

It is often assumed that these uncharacteristically severe wildfires – while unfortunate in terms of their immediate effects on soils, vegetation, wildlife habitat, and water resources – serve to restore natural fire regimes to dry forest ecosystems, negating the need for active post-fire restoration. Unfortunately, this is not true. Uncharacteristically severe wildfires in dry coniferous forests do consume litter, surface woody fuels, and some live fuels, but also produce large pulses of fire-killed trees that are uncharacteristic with respect to historic fire regimes. The "re-burn hypothesis" asserts that this pulse of dead wood produced by one wildfire can contribute significantly to future fire behavior and fire effects, leading to uncharacteristically severe effects on vegetation and soils.

As fire-killed trees (hereafter snags) decompose and vegetation recovers over time after fire, forest fuel characteristics change considerably, producing changes in potential fire behavior. We refer to this process as fuel succession. Surface woody fuels accumulate as snags decay, break, and finally fall. Wood decomposition also changes fuel properties and fire behavior. Sound (hard) logs typically contribute little to fire spread rates or local fire severity. As logs decompose, however, they may become more fractured and flammable, increasing the duration of flaming and smoldering combustion, and increasing tree mortality and soil heating (Monsanto and Agee 2008).

After stand-replacing wildfires, there is often considerable conflict when post-fire (or salvage) logging is proposed. Harvesting fire-killed trees immediately after wildfire can provide economic benefits to local communities and may reduce risks of insect and disease outbreaks that can kill additional trees (Brown et al. 2003). However, there is concern that the ecological costs of post-fire logging may outweigh the economic benefits (McIver and Starr 2001). Specifically, opponents argue that post-fire logging may compound fire effects on soil physical and chemical properties; increase precipitation runoff and soil erosion; harm water quality and aquatic habitats; reduce site productivity and slow future forest development; degrade wildlife habitat for species dependent on snags and coarse woody debris; facilitate the spread of noxious weeds; and alter plant community structure and diversity (Beschta et al. 2004).

Often overlooked in the debate over post-fire logging is the risk of ecological damage to soils, vegetation, and aquatic ecosystems from subsequent high severity fires. High severity fires typically kill most trees and other vegetation; alter wildlife habitat, soil physical, and soil chemical properties; increase erosion rates; and impact aquatic ecosystems (DeBano et al. 1998). Forest managers have often suggested that post-fire logging can reduce future fire severity by removing the boles of dead trees that later contribute to surface fuels. However, there has been very little research examining the effects of post-fire logging on future fuels and fire behavior. A recent study has questioned the utility of post-fire logging as a fuel reduction treatment, concluding that post-fire logging can increase fire hazards and hinder forest regeneration (Donato et al. 2006).

To better inform this debate, we examined patterns of snag decay and surface fuel accumulations, with and without post-fire logging, across a chronosequence of 68 stand-replacing wildfires that burned between 1970 and 2007 in dry coniferous forests of Eastern Washington and Oregon. Specific research objectives included:

(1) Describe coarse woody debris dynamics and fuel succession following stand-replacing wildfires in dry coniferous forests of the Pacific Northwest.
(2) Assess the effects of post-fire logging on post-fire fuel succession and potential fire severity.
(3) Assess the effects of post-fire logging on long-term regeneration success.
(4) Describe the snag properties associated with use by primary cavity-nesters.

As part of the research program, we proposed testing the following hypotheses:

(1) Post-fire logging accelerates deposition of surface coarse woody debris (fuels) following wildfire, thereby increasing initial surface fuel loadings.
(2) Post-fire logging reduces longer-term fuel loadings and potential fire severity (compared to no logging) by removing potential large-diameter fuels.
(3) Post-fire logging reduces tree regeneration.

STUDY DESCRIPTION AND LOCATION

The study region encompasses dry coniferous forests of eastern Washington and Oregon. These forests are typically found at lower to middle elevations in the eastern Cascade Mountains, Blue Mountains, and Okanogan Highland regions of Washington and Oregon and are dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), but often contain a significant component of true firs (*Abies* spp.). A key feature of these forests is an extended summer dry period that facilitates frequent wildfires, historically producing fire regimes with low or mixed fire severities and mean fire return intervals of 3-36 years (Agee 2003, and references therein). Although we studied dry coniferous forests of the interior Pacific Northwest, comparable dry coniferous forests are common throughout western North America.

Topography and soils vary considerably among the dry forest areas of Washington and Oregon. Topography ranges from deeply dissected mountainous terrain to relatively flat plateaus. Dry forests typically occur at elevations of 400-1400 meters above sea level in eastern Washington State, but can be found at elevations up to 2000 meters, particularly in central Oregon. Soils also vary considerably, but are typically well drained, poorly developed, and usually derived from some combination of igneous or metamorphic bedrock, glacial till (or outwash sediments), pumice (particularly in Oregon), and volcanic ash.

Within the dry forest region of eastern Washington and Oregon, we identified a chronosequence of large wildfires that burned between 1970 and 2007. We looked for wildfires occurring during this period in which significant areas of dry coniferous forest burned in stand-replacing wildfire; burned dry forest stands contained a significant component of large ponderosa pine or Douglas-fir trees; and burned stands were not subject to subsequent prescribed fire or other post-fire management activities (other than post-fire logging) that would significantly alter snag or downed wood dynamics. We established a total of 255 study sites within 68 wildfires, with 96 study sites in areas that had been logged following wildfire and 159 sites in areas that had not been logged following wildfire (Fig.1).

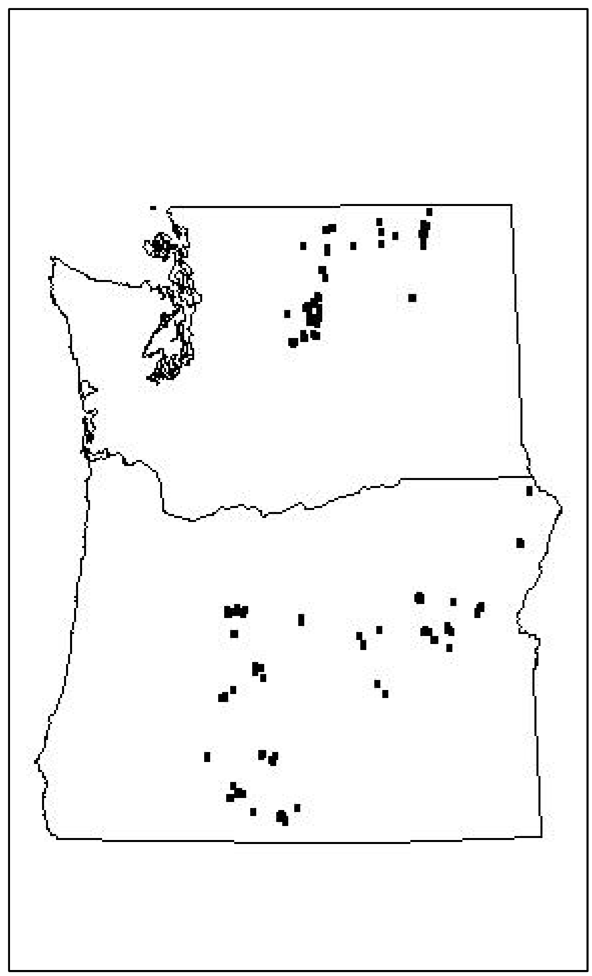

Figure 1. Study site locations in eastern Washington and Oregon.

At each site, we established a randomly-placed study plot on which we surveyed pre-fire stand structure, snag and log conditions, and surface woody fuel loadings. By surveying all standing and fallen snags and cut stumps within a fixed-radius plot, we were able to reconstruct pre-fire stand basal area, density, and species composition. For each snag on the fixed-radius plot and additional snags in an expanded variable-radius plot, we recorded the species, diameter, current status (standing, fallen, or cut), decay class, and the presence or absence of wildlife cavities (on standing snags only). We also surveyed surface woody fuels, by size class, on 3-7 Brown fuel transects at each study site.

We described post-fire snag and downed woody debris dynamics over time using a series of mixed-effects logistic regression models. We first developed a model describing the transition from standing snag to fallen log as a function of time since fire. We included tree species and diameter as potential tree-level fixed effects; time since fire, elevation, and pre-fire stand basal area (and their interactions) as potential stand-level fixed effects and plot as a random effect. We then removed nonsignificant ($P > 0.05$) effects from the model using a backward elimination process to arrive at a final model. For subsequent models, we split the data into standing and fallen snag subsets and used the same process to develop a series of conditional probability models describing changes in decay classes, snag breakage, and wildlife cavity presence as a function of time since fire, given the snag status (standing or fallen). Finally, we developed joint probability models describing the probability a snag would be standing (or fallen) and also be in a particular condition (e.g., standing and broken, standing with a wildlife cavity, fallen and in decay class 2, etc) as a function of time since fire.

We analyzed changes in surface fuel loadings and downed coarse woody debris with time since fire using linear mixed-effects models. We analyzed surface fuel loadings by size class using fuel estimates averaged from 3-7 fuel estimates (transects) per plot. Full initial models included time since fire, post-fire logging treatment, pre-fire stand basal area, and elevation as plot-level fixed effects and fire as a random effect. We used log-linear regression after preliminary analysis indicated strong non-normality of model residuals without transformation. Finally we again used logistic regression to describe changes in the proportion rotten/sound large fuels over time since fire.

KEY FINDINGS

I. Without logging, fuel deposition from decaying and falling snags begins shortly after wildfire and produces maximum total surface fuel loads within 15-30 years. Surface fuel loads remain high on many sites for 40 years or more, a period that exceeds historical mean fire return intervals in most dry coniferous forests of the Pacific Northwest.

Snag decay and surface fuel deposition begins within a year or two after wildfire as small-diameter snags begin to fall and larger snags begin to shed branches and tops. Most small to medium diameter snags and half of large diameter snags fell within 25-35 years, leaving residuals stumps less than 2 meters tall. More than 50% of standing snags had broken tops within 15 years, and virtually all had broken tops within 25 years (Fig. 2). Along with broken tops, most snags also deposited a large proportion of fine and medium branches during the first 15 years.

As snags decayed, surface woody fuel loads increased in unlogged stands for 15-30 years following wildfire. Loadings of small and medium diameter fuels generally peaked within 15 years, after which fuel losses to wood decay apparently exceeded fuel deposition rates. Large woody fuels continued to increase for up to 30 years following wildfire before declining (Fig. 3).

II. Total potential fuel deposition after fire is positively associated with stand basal area killed, while stand species composition and size structure influence snag decay and fuel deposition rates.

Surface fuel loadings were positively correlated with reconstructed pre-fire stand basal area for all woody fuel diameter classes. The greater the amount of stand basal area killed by fire, the greater the potential surface fuel loadings are. Pre-fire stand basal area had a particularly strong influence on large woody fuels (Fig. 3), as large woody fuel loads in stands in the 90^{th} percentile for basal area were more than double those in stands in the 10^{th} percentile for basal area.

Snag fall rates varied with tree size and species. Large diameter trees remained standing longer than small diameter trees. Similarly, true firs and Douglas-firs remained standing longer than ponderosa pines of comparable size. About half of the small ponderosa pines (20 cm dbh) fell within 10 years, while half of the small Douglas-fir and true firs fell within 15 years. Few large ponderosa pines (60 cm dbh) remained standing for 35 years, while about 30% of the large true firs and Douglas-firs remained standing for at least 35 years (Fig. 3). True fir fall rates were very similar to Douglas-fir.

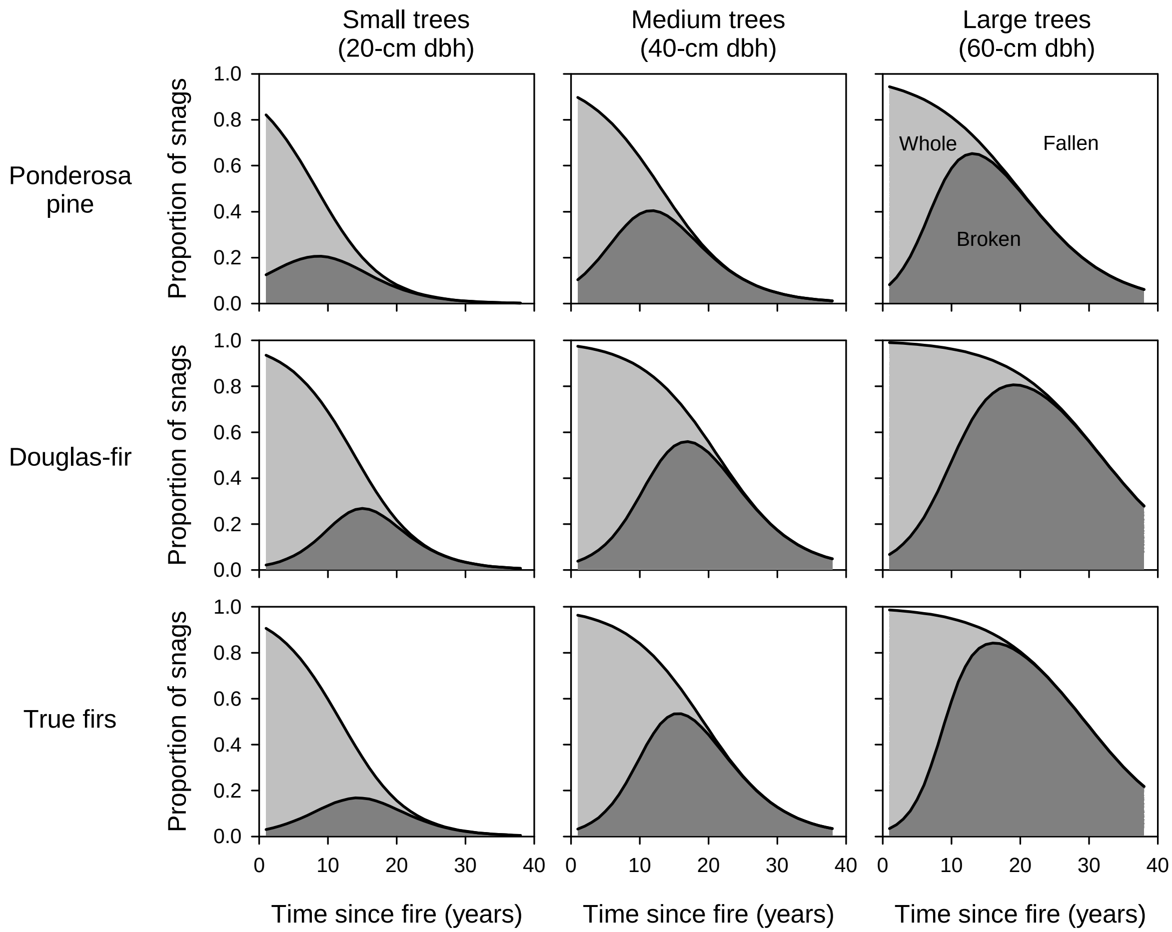

Figure 2. Snag break and fall rates for three sizes of each species.

III. Rotten woody fuels increased with time since fire as a proportion of total large woody fuels. More than 50% of large woody fuels were rotten within 30 years.

Coarse woody debris on the ground began to transition from sound to rotten condition after about 15 years with most of the coarse woody debris reaching the rotten condition within 30-35 years. Given historic fire return intervals of 3-36 years in these forests (Agee 1993) it is likely that woody surface fuels created by decay of the fire-killed trees will influence future fire behavior. Re-burns are unlikely until enough flashy and fine fuels have accumulated to carry the fire. After enough fuels have accumulated, fire hazard likely increases with time as fuels accumulate and coarse woody debris rots, increasing its flammability (Monsanto and Agee 2008).

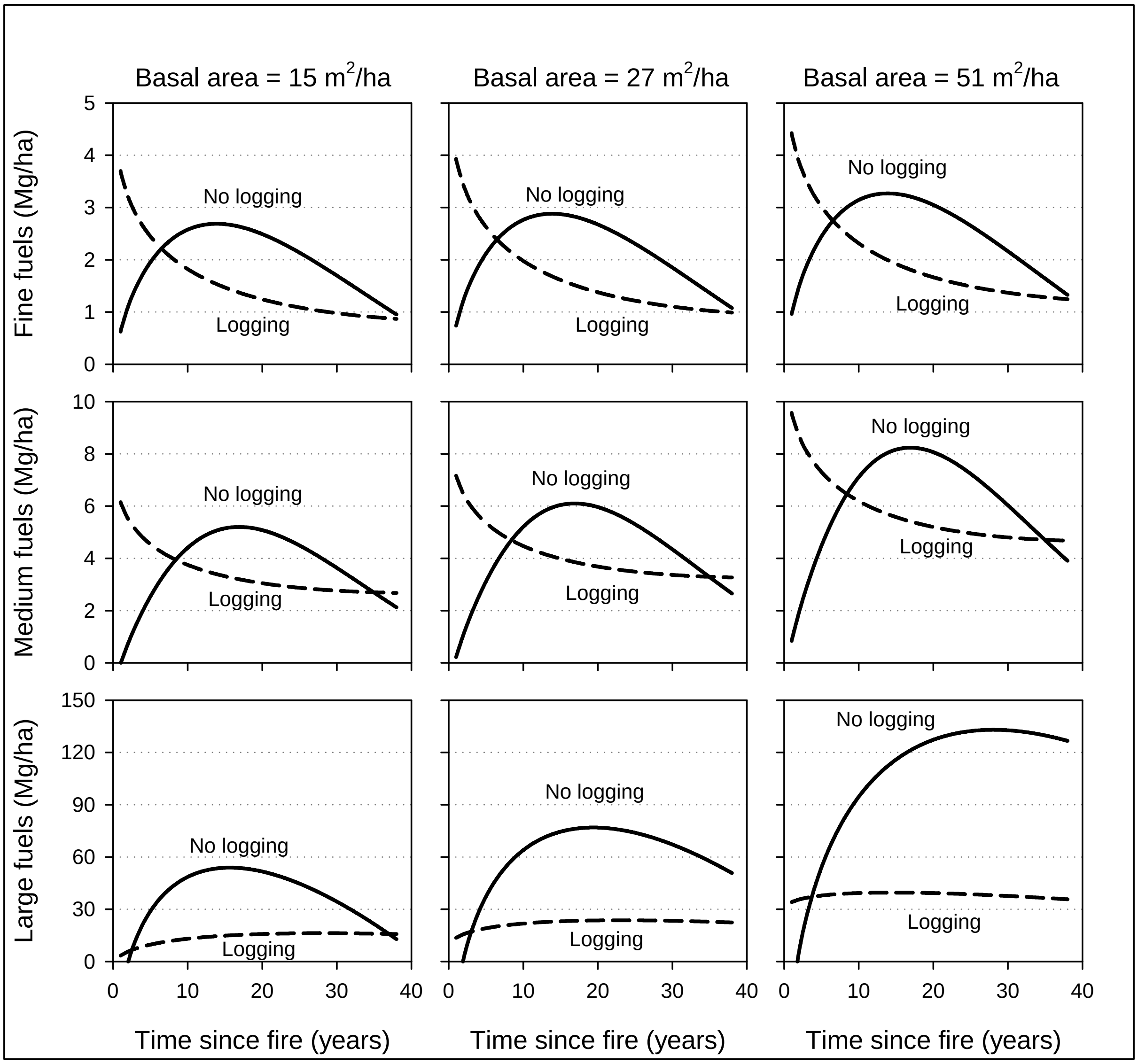

Figure 3. Changes in surface fuel loadings over time since wildfire, with and without post-fire logging. Rows of graphs show temporal patterns for fine (1-hour and 10-hour), medium (100-hour), and large (1000-hour and larger) fuels. Columns of graphs display expected fuel levels for three levels of pre-fire stand basal area: 10th percentile (15 m^2/ha), 50th percentile (27 m^2/ha), and 90th percentile (51 m^2/ha).

IV. Post-fire logging reduced surface fuels of all sizes after a short-lived period of elevated fuels.

Post-fire logging initially increased average surface fuel loads relative to unlogged stands. However, the average total woody fuel load on unlogged stands exceeded that on logged stands within 5-10 years. Fine and medium woody fuels then remained higher in unlogged stands until about 35-40 years after wildfire, when levels converged with logged stands (Fig. 3). Beyond the first few years, large woody fuel loadings in unlogged stands remained higher than those in logged stands through at least 35 years after wildfire. Differences in fuel loadings between logged and unlogged stands was especially pronounced for stands with large trees and moderate to high pre-fire stand basal areas (Fig. 3). This is important as such stands are most likely to be considered as candidates for post-fire logging.

V. Cavity nesting species use a variety of species and size classes over time. Broken tops and decay condition are important predictors of usage along with tree size.

Cavities were found almost exclusively in trees with broken tops, showing the importance of decay to cavity excavation. Ponderosa pines were used for cavities earlier in post-fire succession than Douglas-firs and true firs and small/medium trees were used earlier than large trees. Large trees were most likely to persist and eventually contain a cavity, but were relatively rare on the landscape. Intermediate-diameter snags trees (30-60 cm dbh) supported the greatest number of sampled cavities (Fig. 4). Small trees were very common, but most fell very quickly and had very little chance of having a cavity (Fig. 4).

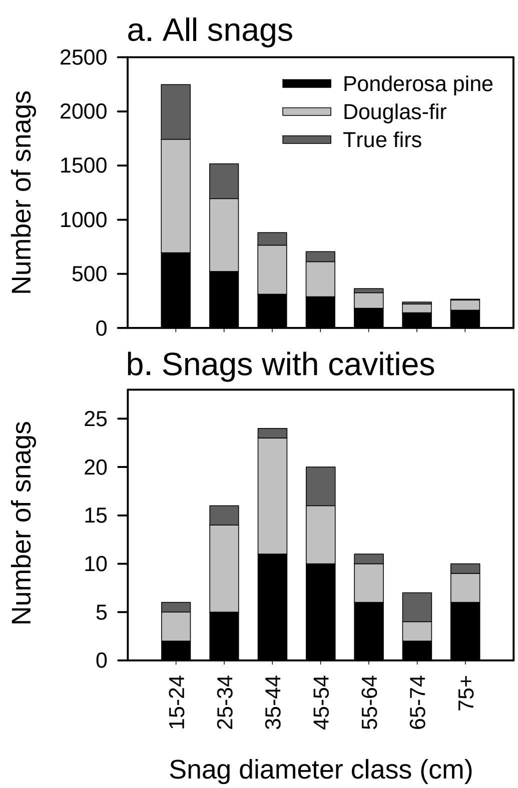

Figure 4. Snag size and species distributions for a) all snags surveyed within fixed-radius plots, and b) standing snags containing a wildlife cavity.

VI. Post-fire logging did not delay forest regeneration or prevent full stocking.

There was no evidence that post-fire logging reduced or delayed forest regeneration based on surveys of sapling- and larger-sized trees. Regenerating trees reached sapling size (> 1.35 meters height) somewhat earlier in logged stands than in unlogged stands. Logged stands were also more likely to be fully stocked (at least 500 trees per ha) than unlogged stands for any given time since fire (Fig. 5). While it is possible that forest regeneration is generally faster and more successful when fire-killed trees are logged than when they are retained on-site (presumably due to management requirements to ensure successful regeneration), at the very least there is no evidence for widespread reductions in forest regeneration caused by post-fire logging.

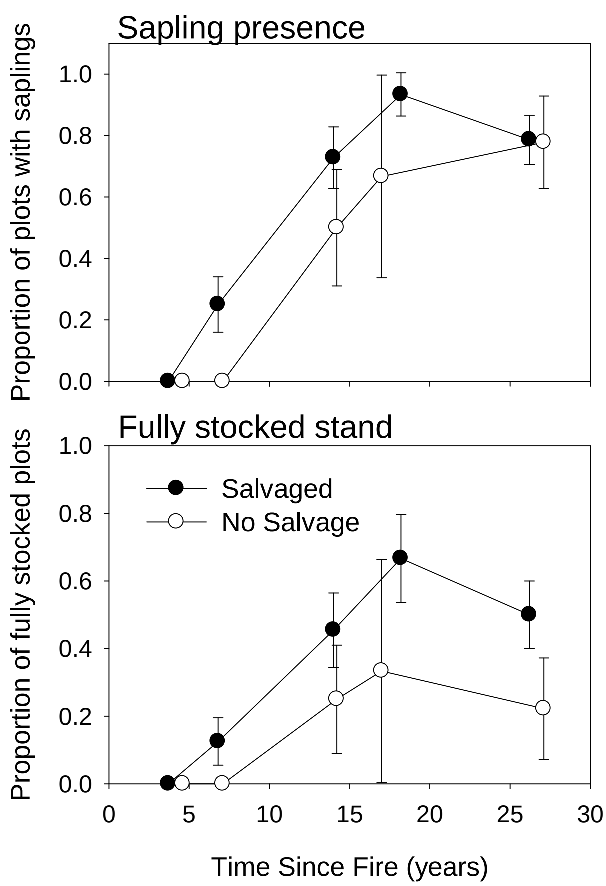

Figure 5: Mean (plus or minus one standard error) for proportion of plots with saplings and fully stocked (at least 500 saplings per ha) with and without post-fire logging over time.

Management Implications

I. Time matters. Fuel succession processes following wildfire produce significant changes in surface woody fuel beds over time in both logged and unlogged stands that can strongly influence potential fire behavior and fire severity.

Evaluating the effectiveness of post-fire logging as a fuel treatment requires evaluating treatment effects over time and considering multiple components of fuel succession, including woody fuel deposition and decomposition and post-fire vegetation growth and succession (live fuels).

Shortly after wildfire and post-fire logging, surface woody fuels are likely to be higher in logged stands than in unlogged stands, as logging accelerates deposition of branch and top materials from fire-killed trees. These higher woody fuels in logged stands may increase wildfire hazards if there is sufficient spatial continuity of fine fuels to carry a wildfire. However, fire severity may be limited by the flammability of recently deposited fuels and the degree to which understory vegetation and forest regeneration have developed.

Within 10 years after wildfire, surface woody fuel loadings in unlogged stands exceed those of logged stands on average (controlling for pre-fire stand structure and composition). These higher surface fuel loadings are likely to produce higher wildfire intensity and severity in unlogged than in logged stands. Differences in fire severity are likely to become especially acute 25-30 years following wildfire and logging, as large woody fuels become rotten and more flammable, increasing potential fire residence times and heating effects on soils and vegetation (Monsanto and Agee 2008).

II. Without active post-fire fuel reduction treatments, fuel succession processes create high potential for subsequent high severity wildfire 20-40 years following wildfire in dry coniferous forests.

Historically, dry coniferous forests in the Pacific Northwest supported frequent, low severity fire regimes with mean fire return intervals of 3-36 years (Agee 1993). Mean fire return intervals in these forests are generally longer now due to active fire suppression and reduced landscape permeability for fire spread (e.g., roads, residential clearings), but wildfire threats are still very real. The fuel succession patterns we describe produce high surface woody fuel loadings 10-40 years (or more) following wildfire, a period that still corresponds with high likelihood of wildfire occurrence. Since most of the large woody fuels are in the more flammable rotten stage 30-40+ years after wildfire, re-burns during this time could be very severe. For example, the Deer Point Fire of 2002 in north-central Washington State re-burned a watershed that had burned in stand-replacing wildfire in 1970. High surface fuel loads and extended smoldering times produced severe effects on soils and vegetation (Fig. 6).

Figure 6: Effects of a severe re-burn on the Poison Creek watershed following the Deer Point Fire in north-central Washington State.

III. Post-fire logging is a valid fuel treatment when applied to dry coniferous forests ecosystems, effectively reducing future woody fuel loads while maintaining sufficient coarse woody debris to support historical ecosystem functions.

Although post-fire logging initially increased fuel loads, logging reduced fuel loads significantly over the longer term. For a stand of median basal area, logged stands maintained an average of 11-25 Mg/ha of coarse woody throughout most of the 38 years study period. Even in high basal area stands the logged plots did not exceed 45 Mg/ha. This falls within the optimum range for dry coniferous forests for balancing wildlife, ecosystem productivity, historical conditions, and fire hazard (Brown et al. 2003). Unlogged stands reached maximum downed woody debris of 76 Mg/ha at the median basal area and nearly 135 Mg/ha in high basal area stands, exceeding recommended levels and accentuating fire hazards

IV. Small diameter snags are more important as future surface fuels than as potential wildlife habitat.

Past logging practices and fire exclusion have led to much higher densities of small to medium sized trees in dry coniferous forests (Covington et al. 1997), which is one factor increasing fire hazard in these forests (Peterson et al. 2005). The vast majority of these smaller snags fall within 15-20 years and, despite their abundance, very few are used by cavity nesters. Therefore, these small trees contribute more to future woody fuel loads and future fire hazards than to wildlife habitat. Post-fire logging that emphasizes removal of these smaller trees could both reduce future fire hazards without significant loss of wildlife habitat.

V. Retaining snags of varying species and size classes may provide the greatest habitat benefit for cavity-nesting species during the interval between fires.

Large-diameter trees are often considered critical for wildlife habitat. Although large snags were most likely to be used by cavity nesters in this study, they were not common across the landscape (only 10% of trees in this study were larger than 56 cm dbh). Large trees were also not widely used by wildlife for 10-20 years after wildfire, likely due to slow decay rates. Most of the cavities observed in this study occurred in intermediate-sized trees, which were more common and decayed more quickly, on average, following fire. Also, ponderosa pines were used by cavity nesters earlier than Douglas-firs and true firs, but the latter tended to stand longer and provide habitat after most ponderosa pines had fallen. Therefore, leaving a variety of tree sizes and species on the burned landscape is most likely to provide continuous habitat for primary and secondary cavity-nesters.

VI. Dry forest restoration treatments may reduce wildfire severity and basal area killed, thereby limiting future woody fuel deposition and future wildfire severity.

Dry forest restoration treatments (e.g., thinning, prescribed fire) have been shown to be effective in reducing wildfire severity (Pollet and Omi 2002). By altering overstory stand structure and treating surface fuels, restoration treatments reduce the amount of basal area killed during wildfire and thereby limit the magnitude of the subsequent pulse of surface woody fuels produced by post-fire fuel succession. This, in turn could limit future wildfire severity. Restoration treatments effects on overstory structure and canopy fuels also increase management options for subsequent treatment of surface woody fuels with prescribed fire early in the fuel succession process.

VII. Post-logging management activities influence fuel succession, forest regeneration, and re-burn hazards.

We observed a high level of variability in surface fuel loadings and regeneration densities that could not be accounted for by time since fire or pre-fire stand structure. Clearly, post-fire logging methods have varied through time and also vary within the region. Logging can generate a large pulse of surface woody debris and can also damage newly established tree seedlings (Donato et al. 2006). These logging effects could persist for a decade or more, or they can be reduced by post-logging forest management activities such as fuel treatments and tree planting. Post-logging fuel treatments, such as piling and burning, can rapidly reduce total amounts and spatial continuity of surface woody fuels, and may allow logged stands to serve as fuel-breaks in a landscape-level fire management strategy. Planting tree seedlings can offset logging activity damage to natural regeneration, but also allows managers to supplement natural seed sources. Fire-resilient species such as ponderosa pine are important components of dry coniferous, but may not regenerate well following stand-replacing wildfires due to seed source limitations (Keyser et al. 2009), particularly in areas where pre-fire logging removed canopy dominants.

RELATIONSHIP TO OTHER RECENT FINDINGS AND ONGOING WORK ON THIS TOPIC

The initial increase in fuels with post-fire logging is consistent with other recent studies in southwestern Oregon (Donato et al. 2006) the Black Hills of South Dakota (Keyser et al. 2009) and central Washington (Monsanto and Agee 2008). However, other studies also found that fuels in unlogged stands quickly surpassed those in logged stands as snags decay (Monsanto and Agee 2008; Keyser et al. 2009). Our study supports these findings from a regional perspective and provides greater detail on fuel succession in dry forests with and without post-fire logging, including the importance of pre-fire stand structure. This contrasts with modeled fuel loads in the Blue Mountain of Oregon, where modeled fine fuels on logged stands remained somewhat higher on logged stands for 20 years or more following wildfire (McIver and Ottmar 2007).

Previous studies have suggested that fuels quickly accumulate to a peak after wildfire as snags decay and fall, then slowly decline surface fuels decay (Hall et al. 2006; Passovoy and Fulé 2006). This pattern is very similar to that documented in our study in the absence of post-fire logging. Dry forest stands in Colorado reached maximum fuel loads from 10-20 years for all size classes (Hall et al. 2006), which is very similar to the patterns found in this study, with the exception of coarse woody debris on very high basal area stands that took longer to accumulate to a peak. The coarse woody debris fuel loads found in this study were much higher than historical values for dry coniferous forests (Brown et al. 2003), matching the very high spike in fuels predicted in Passovoy and Fulé (2006). Previous work suggests that fuel loads will continue to decline until about 80 years (Hall et al. 2006).

Monsanto and Agee (2008) experimentally burned logs from various decay classes. They found that rotten logs were more flammable than sound logs. Similarly, overall fuel load matters as logs burned in groups are more likely to be consumed than logs burning in isolation (Harrington 1981) or logs surrounded by smaller fuels (Albini and Reinhardt 1995, 1997).

Previous modeling studies have found that fire hazard can be high for stands that regenerate after wildfires, whether or not post-fire logging is applied (McIver and Ottmar 2007). However, modeled fuel loads and stand densities were used to model fire effects. Modeled fuel loads were somewhat higher on logged stands than on unlogged stands, which is inconsistent with our results. Furthermore, regeneration was larger and more successful than found in our empirical data.

This study demonstrated a strong link between pre-fire stand structure and post-fire fuel accumulation. Therefore, post-fire fuel accumulation is likely a function of the species and sizes of trees killed in the wildfire. Using the decay and fall rates found for various species and size classes in this study and published biometric equations we are working on developing a calculator to estimate fuel loads at various times as a function of the trees killed and decay rates.

FUTURE WORK NEEDED

More research is needed on wood decay patterns and processes in dry coniferous forests. Coarse woody debris dynamics and decay rates have been well studied in moist temperate forests of Washington and Oregon, but have received much less attention in dry coniferous forests. This is unfortunate, given the importance of coarse woody debris to fire behavior, wildlife habitat, ecosystem carbon storage, and nutrient cycling in these forests.

The effects of large-diameter fuels on fire behavior and ecosystem effects also warrants further study. Most fire behavior and fire effects models ignore 1000-hour and larger fuels altogether, largely because they are not considered important for determining fire intensity and spread rates. However, large fuels likely contribute greatly to the smoldering combustion phase, wildfire residence times, and fire effects on soils and vegetation, and predicting such effects would be useful in making decisions about how to manage coarse woody debris and forest carbon stocks. Such information could also help managers design long-term fuel reduction programs using prescribed fire.

Despite high-profile controversies and legal conflicts, post-fire logging effects on ecosystem structure and function remain poorly studied. In fact, the lack of good studies has undoubtedly enabled conflict and hindered the development of an informed debate about the relative costs and benefits of post-fire logging. Our study addressed one aspect of post-fire logging effects, but much work remains and many of the outstanding questions will only be satisfactorily addressed through empirical studies. We believe that many questions about post-fire logging impacts could be addressed through management experiments in which elements of experimental design are incorporated into post-fire logging operations, with funding provided for periodic effects monitoring. If replicated on enough sites, such an approach could provide defensible data to address social concerns over post-fire logging at a very reasonable cost.

Deliverables Crosswalk

Proposed	Delivered	Status
Progress reports	Annual progress reports to Joint Fire Sciences Program	08/31/2007, 08/31/2008
Manuscript #1	Modeling fuel succession and fire behavior following wildfire in dry forests: can post-fire logging reduce future fire hazards?	In review
Manuscript #2	Post-fire fuel dynamics and potential wildfire behavior in dry ponderosa pine and Douglas-fir forests.	Joined with above manuscipt
Manuscript #3	Effects of post-fire logging on fuels, wildfire behavior, and management use of prescribed fire.	In progress (modeling)
Manuscript #4	Tree species and diameter effects on snag and log decomposition dynamics following wildfire.	In review
Snag calculator	Incorporate snag/log decay equations into spreadsheet (or comparable) format to allow managers to estimate future snag/log inventories based on post-fire inventories.	In Progress
Final report	Final report to the Joint Fire Sciences Program detailing accomplishments, products, impacts of research, and status of any outstanding deliverables (e.g., publications in review or in press).	Completed

Presentations

Dodson, E.K., and D.W. Peterson. 2009. Snag retention, wildlife usage, and surface fuel deposition following large stand replacing wildfires in dry coniferous forests. Northwest Scientific Association meeting. Seattle, WA. March, 2009.

Peterson, D.W., and E.K. Dodson. 2009. Tree size and species influence snag retention rates following severe wildfires in dry coniferous forests. 7th North American Forest Ecology Workshop, Logan, Utah, June 22-26, 2009.

Dodson, E.K., and D.W. Peterson. 2009. Contributions of fire-killed trees to future wildlife habitat and surface fuels in dry coniferous forests. 7th North American Forest Ecology Workshop, Logan, Utah, June 22-26, 2009.

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