Project Title: Variable Intensity Salvage Logging After Fire: Effects on Fuel Accumulation, Regeneration and Understory Diversity.

Final Report JFSP Project ID: 07-2-2-09

PI: Martin Ritchie, Research Statistician, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding CA 96003, Phone: 530-226-2551, Fax: 530-226-5091, email: mritchie@fs.fed.us

Co-PI: Eric E. Knapp, Research Forester, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding CA 96002, Phone: 530-226-2555, Fax: 530-226-5091, email: eknapp@fs.fed.us

Co-PI: Carl Skinner, Research Geographer, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding CA 96002, Phone: 530-226-2554, Fax: 530-226-5091, email: cskinner@fs.fed.us

This project was funded by the Joint Fire Science Program. For additional information go to www.firescience.gov

I. Abstract

After the 2002 Cone Fire at Blacks Mountain Experimental Forest, an experiment was established to investigate the impacts of varying levels of fire salvage on subsequent vegetation and fuel dynamics. Varying levels of fire salvage, with retention of dead trees ranging from 0 to 100 percent (by basal area) were installed in a completely randomized design with three replications. Five-acre plots with varying levels of fire salvage were established and measured 2, 4, 6, and 8 years after the fire. Snag retention was observed and surface fuel loads were calculated for each time period. Snag retention for all levels of retention in the Cone Fire was brief; eight years after the fire 80 percent of the retained biomass had transitioned to surface fuels and this appeared to be unaffected by the amount of material retained (not harvested). Number of snags per unit area has also declined, although the amount is related to both snag diameter and species. Snag retention was lowest among smaller diameter (12-18 inch) retained pines, with only 39 percent still maintaining a height of at least 6 feet at year 8. Fir retention was considerably better with 75 percent retention of 12 – 18 inch snags at year 8. While invasive species such as cheatgrass and bull thistle have increased in abundance since the fire, we could not detect any impact of salvage logging on these species; the impact of the fire itself appears to overwhelm any salvage issues in this regard. Neither did we observe changes in species richness of native plants in response to salvage logging over the 8 years of study. Regeneration, both planted and natural, was unaffected by salvage harvesting. Natural regeneration was driven by temporal and spatial proximity to a seed source rather than salvage activity. Planted tree survival was also unaffected by salvage harvesting. Damage to planted seedlings from falling snags is low, regardless of the level of salvage. Planted tree dynamics at Blacks Mountain was influenced primarily by local site variation and competing vegetation.

II. Background

Though fuels management has long been advocated (Show and Kotok 1925, 1929; Weaver 1943; Biswell 1989), implementation has been inconsistent both spatially and temporally. Recently, the effects of fire salvage has received greater scrutiny (Peterson et al. 2009). McIver and Starr (2000) concluded that very little research had been done on salvage logging effects and that much of the cited literature presented observations at a single point in time shortly after treatment and many were unreplicated. McIver and Starr (2000) further found that no studies had focused on the effects of salvage logging on fuel distribution and future fire risk.

Very little work has been conducted on stand regeneration after salvage logging. Roy (1956) concluded that salvage logging reduced seedling survival but also that these losses could be mitigated through judicious timing of the logging activity. In an observational study, Donato et al (2006) concluded that salvage logging reduced seedling survival. However these results were observed very early in stand establishment (one year after logging), and thus give no indication on longer-term effects on stocking. Furthermore, a close examination of Roy's (1956) findings showed that salvage logging had no effect on adequate stocking through natural regeneration, as currently defined; both treated and untreated stands were adequately stocked by today's standards. In our study area, seed production was generally poor for all conifer species in the years immediately after the Cone Fire, and may help explain the generally low density of natural reproduction observed.

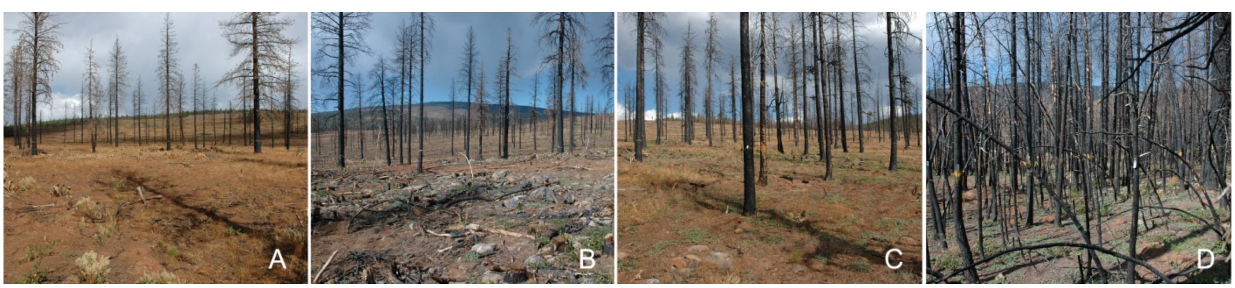
McIver and Starr (2000) also found little research conducted on understory species composition in response to salvage. There is some concern that salvage logging might inhibit recovery of native understory vegetation (Stuart et al. 1993, van Nieuwstadt et al. 2001, Greene et al. 2006) and facilitate the invasion by exotic species (McIver and Starr 2001, Beschta et al. 2004). Because weedy non-native species invasions generally build slowly over time (Keeley et al. 2003), it was expected that long-term results might differ from short term observations. In this study, we observed fuel accumulation, regeneration, species composition and nest cavity excavation in response to salvage intensity over an 8 year period, post-fire.

III. Study Design and Location

In 2002, the Cone Fire burned 2006 acres in northeastern California (Skinner et al. 2005, Ritchie et al. 2007); 1,487 acres were on Blacks Mountain Experimental Forest. Blacks Mountain Experimental Forest is located in the southern Cascades. It was a stand replacing event. Elevations range from 5700 to 6900 feet and annual precipitation averages 20 inches, falling mostly as snow. The Cone Fire led to the establishment of several new studies, among these is a variable retention salvage study designed to investigate varying levels of salvage harvest intensity and the effects on fuels and vegetation.

After the Cone Fire and prior to salvage harvest, 15 five-acre treatment plots were surveyed and geo-referenced within the burn. These plots all experienced a high severity burn and all but one had no surviving trees. Salvage intensities were then randomly assigned to these plots. Initially we targeted approximately 0, 25, 50, 75 and 100 percent retention but achieving these targeted retention levels with precision varied, particularly with regard to 50 and 75 percent. All salvage harvests targeted small trees. That is, a partial salvage involved removing trees from the lower diameter ranges and retaining the largest trees in the plot. Essentially this was like a thinning from below. There were three plots with zero retention: all snags removed from the plot, and three controls (no salvage activity whatsoever). The remaining plots had intermediate salvage levels (Figure 1).

Figure 1. Four of the variable retention plots photographed in 2004, shortly after treatment with (A) 20 ft^2 $acre^{-1}$, (B) 38 ft^2 $acre^{-1}$, (C) 49 ft^2 $acre^{-1}$, and control (D) 158 ft^2 $acre^{-1}$ retention.



IV. Key Findings

A. *Surface fuels and snag retention*

Surface fuels increased rapidly in proportion to the amount of material left standing after the completion of salvage harvests. By year 8, 80 percent of the retained standing biomass had transitioned to surface fuels.

Snag retention, defined as the number of standing snags > 12 inches breast-height diameter and > 6 feet in height, also declined quickly for pine and fir. Eight years after the fire, standing snag mean retention was 27 percent with a range from 2 to 54 percent. Differences existed among species;

Incense-cedar snags remained remarkably stable and eight years after the fire, few of the incense-cedar snags have been uprooted or snapped off. However within the burn area most of these incense-cedar snags are < 18 inches diameter and we find no evidence of excavation by cavity nesting birds in incense-cedar regardless of size; evidently fir and pine are preferred for excavation. Thus, for providing structures for wildlife nesting, retention of cedar appears to be unwarranted within the 8 years of this study. Smaller pine and fir snags tend to be uprooted while larger snags came down in stages by breaking off, resulting in decreasing snag height over time. Among 12 to 18 inch diameter ponderosa pine snags, 39 percent were retained in year 8. In contrast, retention of larger (>18 inch dbh) pine snags was 67 percent in year 8. Snag retention of white fir was considerably higher: 75 percent and 93 percent for these two size classes, respectively. Cavity excavation appeared to be more frequent in fir than pine among trees > 12 inches in diameter.

B. Vegetation response

If exotic species are promoted by the degree of soil disturbance and propagules of these species are spread by logging machinery, we would have expected a gradient of increasing exotic species cover from the no salvage to 100 percent salvage treatments. While the cover of exotic species increased over the course of this study (from 0.7 percent in 2006 to 2.6 percent in 2010), there was no relationship to salvage intensity. Results for the number (richness) of exotic species was similar, with the mean number per $2m^2$ plot increasing from 0.27 in 2006 to 0.61 in 2010, and also showed no significant relationship with the level of salvage. It therefore appears that spread is dictated more by the disturbance of the fire itself, and perhaps proximity to exotic species seed sources. Cheatgrass (*Bromus tectorum*) cover is increasing in all treatments, while cover of bull thistle (*Cirsium vulgare*) actually declined from 2006 to 2010.

The number of native species was also unrelated to the level of salvage. However, a gradient in native species cover was observed, with the lowest cover (43 percent) in the unsalvaged treatment, and the highest cover (55 percent) in the 100 percent salvaged treatment. This result could possibly be explained by the cover of fallen logs inhibiting native species.

C. Regeneration response

Planted seedlings were unaffected by salvage harvests. Planted seedling survival at age 6 ranged from a low of 37 percent to a high of 96 percent. However this substantial level of variability had nothing to do with salvage retention; a linear model relating survival to snag basal area retention had a p-value of 0.935. Similarly, growth of planted seedlings was not significantly affected by treatment; if anything salvage harvesting improved growth. A linear model relating height growth to basal area retained actually had a negative slope, suggesting a detrimental effect of snag retention of about 2 cm per year, although with a the p-value of 0.71, this is not statistically significant. The only strong relationship observed was a distinct linkage between growth and survival. Growth and survival appeared the greatest where rock content of soil was relatively low. Thus, variation in site factors (rock content and soil depth) at Blacks Mountain appeared to overwhelm any potential influence of salvage harvesting. The one encouraging sign with regard to retained snags and plantation development is that damage to seedlings from falling material was relatively light, regardless of the level of retained snags.

We attempted to evaluate soil compaction with a penetrometer at Blacks Mountain but found that the instrument generally indicated the depth to the nearest large rock, rather than any indication of soil strength. Thus, the only indications of a soil effect that we can observe are indirect: the influence on growth and survival as well as changes in species.

Natural regeneration rates were generally low throughout the Cone Fire. Few surviving trees remained within the burn and ponderosa pine did not exhibit a good seed crop within the first 3 years after the fire. In the salvage units, all but three currently contain less than 20 natural seedlings per ha (8 trees per acre). Numbers of naturally established seedlings within the cone fire appear to have more to do with the proximity to seed source (i.e. live trees that survived the fire) than the level of salvage. For example, the three units with > 8 naturally established seedlings per acre were all located in areas where live survivors were growing < 100 feet away.

D. LiDAR Estimation of Coarse Woody Debris

Although not originally part of the proposed research, the acquisition of LiDAR data for Blacks Mountain in 2009 allowed us to evaluate the applicability of these data for estimation of surface fuel loading and snag density. Surface fuel estimation presents a difficult problem in many cases, because the Browns (1974) method commonly used is very time consuming and often imprecise.

We found that using the Fusion Cover procedure was ineffective at locating standing snags. However, we had some limited success identifying surface fuels (>8 inches in diameter). The effectiveness of LiDAR in fuel estimation is probably further limited by canopy density and ineffective in estimating 100 and 1000 hour fuels (those < 8 inches dbh).

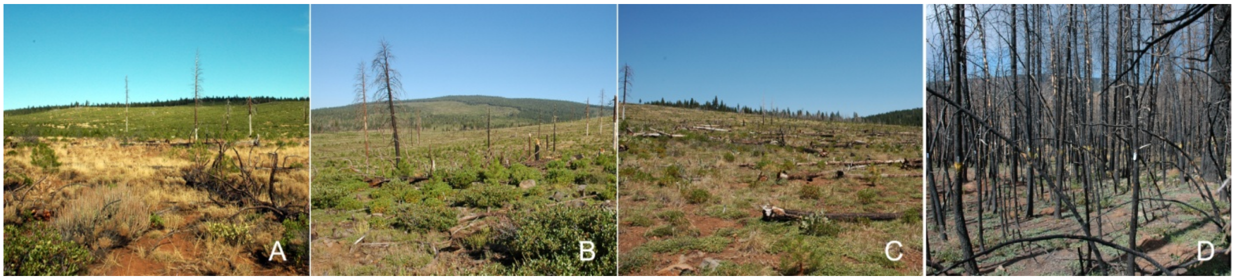
V. Management Implications

Stands that burned with high severity in a pine-dominated forest with a mix of fir and cedar produced significant surface fuel loading in a short time span (within 8 years), while also providing opportunities for cavity excavation. The degree to which this fuel accumulation threatens future stand development is directly linked to how much standing biomass is left. We estimate it will take another 100-140 years to grow a new stand of trees large enough to provide habitat for any cavity nesting species at this site. The benefit of retained snags is therefore relatively brief and the penalty (of elevated fuel levels) is enduring. Decay rates in these dry forests are relatively low, so surface fuels will likely remain a concern for some time.

Given the observed fall rates and the preference of most species for larger snags, retention of pine below 18 inches in diameter for cavity nesters appears ineffective. If trees are to be retained, large fir trees (> 18 inches in diameter) should be favored since they had the best 8-year retention and the higher cavity excavation rates at Blacks Mountain. The total number retained should be guided by desired coarse woody debris levels since retained trees break-up quickly and even though most of the large fir snags are still intact (at least 6 feet tall) most of their biomass is on the forest floor.

Fall rates have continued to be fairly high since our last measurement and on some of our plots all standing snags retained are now on the forest floor 8 after the fire (Figure 2).

Figure 2. Four of the variable retention plots photographed in 2010, shortly after treatment with (A) 20 ft^2 $acre^{-1}$, (B) 38 ft^2 $acre^{-1}$, (C) 49 ft^2 $acre^{-1}$, and control (D) 158 ft^2 $acre^{-1}$ retention (Compare with Fig 1).



If snag retention is to be considered and salvage logging either reduced in scope or eliminated, managers should understand that retained ponderosa pine and white fir snags, particularly those less than 45 cm in diameter will endure on the landscape. In this study 80 percent of the 1000 hour biomass retained was on the forest floor within 8 years after the fire, so one could estimate the amount of surface fuel biomass eight years after a burn by simply multiplying the standing dead biomass by 0.8. If the stand is very heavy to pine this estimate will tend to be low and if it is heavy to fir this estimate will be a little high. Currently, the unsalvaged units range from 12 to 23 tons of surface fuel per acre (27-51 metric tons/hectare), and the prospect for tree survival in any subsequent fire is not favorable. A retention level of 22-44 ft^2/acre (5-10 m^2/ha) corresponds to retained surface fuels somewhere in the “optimum” range of 5-20 tons/acre suggested by Brown et al. (2003), with the lower limit (22 ft^2/acre or 5 m^2/ha) providing something near probable historic levels (5-10 tons/acre) of surface fuels in the dry interior forest type (Figure 3).

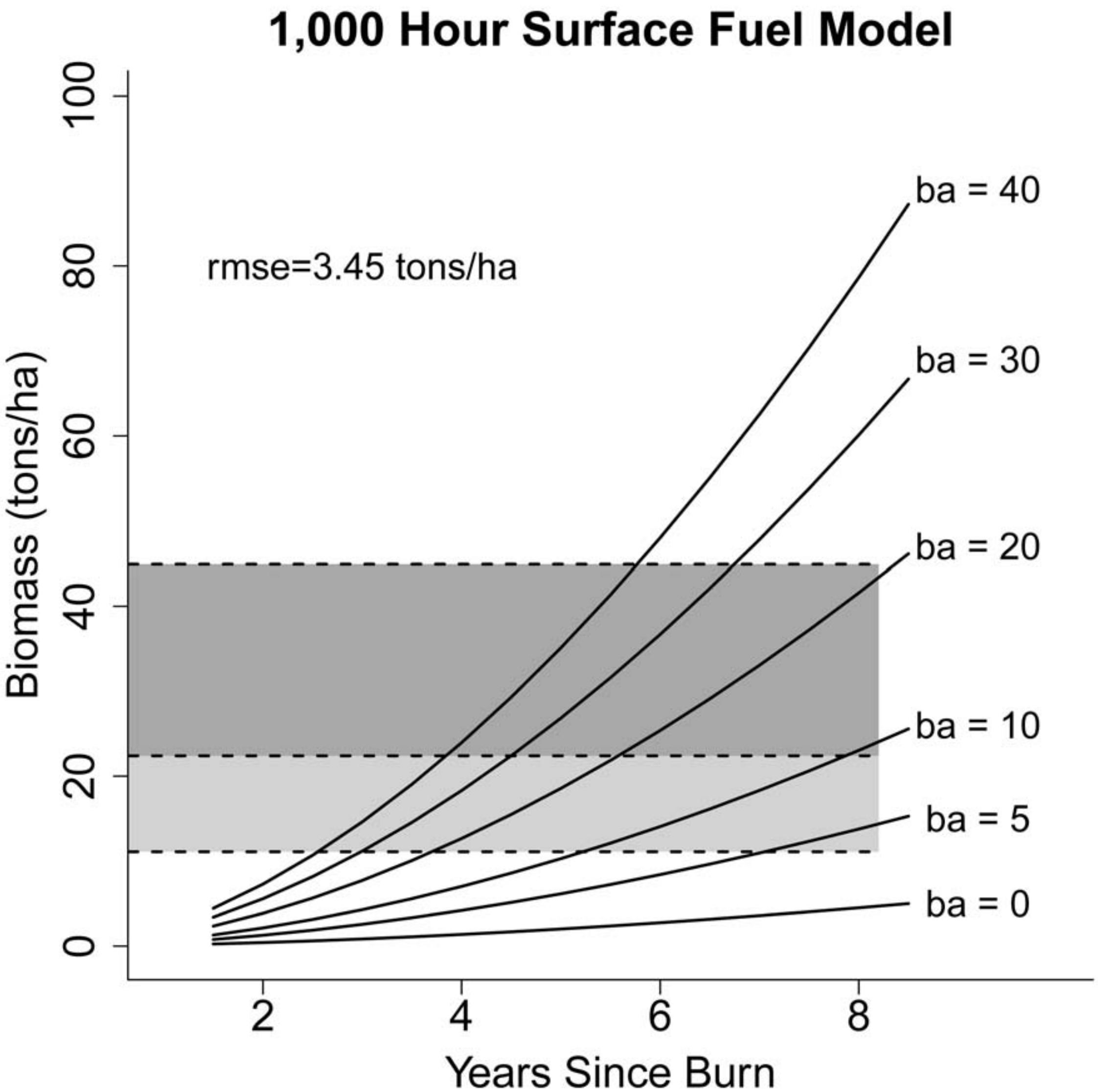
An elevated risk to planted trees from subsequent wildfires makes planting in unsalvaged areas unwarranted. Natural seedling establishment is infrequent and poorly distributed in the Cone Fire. Without planting the Cone Fire appears would likely revert to a brush field. Abundant shrubs established from seed after the fire are now common throughout the burn.

The level of post-fire salvage did not appear to affect cover and richness of exotic species. Cover of exotics continues to increase in all treatments 8 years after the fire. Soil disturbance caused by the fire may be overwhelming other factors influencing exotic species. If we wish to minimize invasive species at Blacks Mountain, it would be best to avoid events like the Cone Fire.

Rather than be negatively affected by salvage logging, the cover of native species was higher in the more heavily salvaged treatments. It is possible that logs covering portions of the forest floor in unsalvaged and partially salvaged treatments may be limiting growth of native plants. The level of soil disturbance in this area resulting from salvage logging does not appear to be a concern.

It should be noted that results of this study (as with all such studies) are influenced by such unique factors as the timing of burn, fire severity, species mix and topography. Additional studies are needed to evaluate the long-term response to salvage in other forested environments.

Figure 3. Modeled fuel accumulation from a mixed-model for material > 7.6 cm (3 inches) in diameter as a function of basal area removed, ranging from 0 to 40 m^2ha^{-1}(0 to 174 ft^2/acre); Brown et al. (2003) range for optimum is shaded and the range for historic surface fuels is light gray.



VI. Relationship to Other Recent Findings and ongoing work

McIver and Starr (2001) reviewed 21 studies worldwide on the impacts of salvage logging. Of these, only 14 had a control for comparison. Of the 14 controlled studies, only 7 were actually replicated. On closer examination it appears that none featured a study design with replicated and randomized treatment applications. The only study that may have had a sound design was that of Sexton (1998), who did not provide sufficient information to discern if the study was randomized. Thus, what we know about salvage logging is essentially derived from poorly designed or weak observational studies. There is no compelling reason that salvage harvesting effects cannot be studied in a more rigorous fashion. This study is, to our knowledge, the only of its kind, featuring a fully randomized and replicated suite of treatments across a range of treatment intensities.

The results observed in this study are consistent with those of McIver and Ottmar (2007), who found that standing structure collapses quickly, leading to rapid increases in surface fuels. We observed 80 percent of standing 1000 hour fuels on the forest floor 8 years after the fire. In the dry interior pine forests, frequent fire helped to suppress surface fuel accumulation (Skinner and Chang 1996). Brown et al. (2003) suggested "optimum" range (5 – 20 tons/acre) for 1000 hour (3 inch and larger) surface fuels. This will likely be exceeded without salvage logging and the historic range of 5 – 10 tons/acre will be exceeded by a substantial margin. Cone Fire unsalvaged units currently contain between 12 and 23 tons/acre of surface fuels > 3 inches in diameter, and this level should increase further in the next few years.

With regard to the distribution of shrubs and forbs and the potential for increase in invasive species, we were able to confirm that invasive species are increasing in the post-fire environment (Keeley et al 2003). Yet we did not observe any significant relationship between increased levels of disturbance (salvage harvesting) and either invasive species prevalence or overall species richness. In contrast, Sexton (1998) found a decrease in species richness following salvage logging in a ponderosa pine forest. Sexton (1998) also observed decreased ponderosa pine seedling growth, another finding we could not confirm. It should be noted that the Sexton only reported results for a period of 2 years immediately following salvage on six treatment units (3 salvaged and 3 unsalvaged), whereas this study features remeasurements over a six year period for 15 separate treatment units.

Cavity excavation was related to snag density; increasing numbers of snags retained resulted in increases in numbers of observed nest cavities. Other studies have noted a relationship between cavity nesting and salvage harvesting, but the relationship is complex. Primary and secondary cavity nesters may respond differently (Haggard and Gaines 2001). While Haggard and Gaines (2001) also found intermediate salvage levels were favored for most observed cavity nesters, a number of other studies suggest that most cavity nesting species are favored by eschewing salvage harvests altogether, there is no clear basis for decision making in an environment where salvage intensity may vary.

VII. Future Work

Continued monitoring of this site would allow for a more complete description of snag dynamics and fuel accumulation over time. At this time we are pursuing the possibility of developing installations across a range of forest types and fire severity within the region. This is important because responses to salvage logging will likely vary with species composition, fire severity, forest soils and topographic features. In future studies, an expansion of plot size may provide for integration of monitoring for cavity nesting birds. Installations of such studies will benefit from detailed documentation of locations of skid-trails to fully evaluate and quantify impacts on forest soils and the direct observation of the amount of nesting activity and the species involved over time.

VIII. Deliverables Table

Proposed	**Delivered**	**Status**
Initial Data Acquisition and Integration	Plots established and measured in 2004, 2006 and 2008.	Complete Nov. 2008
Cone Fire Web site with permanent photos and preliminary results	www.fs.fed.us/psw/programs/ecology_of_western_forests/projects/cone_fire/	Complete Oct. 2010 Updated Oct. 2011
Year 6 data acquisition	Plots remeasured in 2010.	Complete Nov. 2010
Influence on surface fuels	Ritchie, et al. (manuscript) *Snag Longevity and Surface Fuel Accumulation following high-severity fire in a Ponderosa Pine Dominated Forest*	Manuscript complete In Review, Submitted Int. J. Wildland Fire
Influence on understory vegetation	Knapp et al. (manuscript) Effect of fire salvage intensity on native and non-native understory species	In draft
Natural and artificial regeneration	Ritchie et al. (manuscript) *Natural and artificial regeneration in response to fire salvage intensity*.	In draft

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C. 493 p.

Brown, J.K. 1974. Handbook for inventorying downed wood material. GTR-INT-16. Ogden, UT: USDA Forest Service.

Brown, J.K., E.D. Reinhardt, K.A. Kramer. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. RMRS-GTR-105. Fort Collins, CO: USDA Forest Service.

Biswell, H.H. 1989. Prescribed burning in California wildlands vegetation management. University of California Press, Berkeley.

Beschta, R.L., J.J. Rhodes, J.B. Kauffman, R.E. Gresswell, G.W. Minshall, J.R.Karr, D.A. Perry, F.R. Hauer, C.A. Frissell. 2004. Postfire management on forested public lands of the western United States. Conservation Biology 18 (4) 957-967.

Donato, D.C., J.B. Fontaine, J.L. Campbell, W.D. Robinson, J.B. Kauffman, B.E. Law. 2006. Post wildfire logging hinders regeneration and increases fire risk. Science 311, 352.

Greene, D.F., S. Gauthier, J.Noel, M.Rousseau, Y. Bergeron. 2006. A field experiment to dertermine the effect of post-fire salvage on seedbeds and tree regeneration. Frontiers. Ecol Environ. 4:69-74.

Haggard, M. and W.L. Gaines 2001. Effects of stand replacing fire and salvage logging on a cavity-nesting bird community in eastern Cascades, Washington. Northwest Science 75:387-396.

Keeley, J.E., D. Lubin, and C.J. Fotheringham. 2003. Fire and grazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada. Ecological Applications 13:1355-1374.

MacDonald, S.E. 2007 Effects of partial postfire salvage harvesting on vegetation communities in the boreal mixedwood forest region of northeastern Alberta, Canada. Forest Ecology and Management 239:21-31.

McIver, J.D., and L. Starr (Tech. Eds.) 2000. Environmental effects of post-fire logging: literature review and annotated bibliography. General Technical Report PNW-GTR-486. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

McIver, J.D. and L. Starr. 2001. A literature review of the effects of post-fire logging. Western Journal of Applied Forestry 16:159-168

McIver, J.D. and R. Ottmar. 2007. Fuel mass and stand structure after postfire logging of a severely burned ponderosa pine forest in northeastern Oregon. Forest Ecology and Management 238:268-279.

Peterson, D.L., J.K. Agee, G.H. Aplet, D.P. Dykstra, R.T. Graham, J.F. Lehmkuhl, D.S. Pilliod, D.F. Potts, R.F. Powers and J.D. Stuart. 2009. Effects of timber harvest following wildfire in western North America. Gen. Tech. Rep. PNW-GTR-776. USDA Forest Service Pacific Northwest Research Station, Portland OR. 51 p.

Ritchie, M.W., T.A. Hamilton, and C.N. Skinner. 2007. Probability of wildfire-induced tree mortality in an interior pine forest: effects of thinning and prescribed Fire. Forest Ecology and Management. Forest Ecology and Management 247:200-208

Roy, D.F. 1956. Salvage logging may destroy Douglas-fir reproduction. Forest Research Note 107. California Forest and Range Experiment Station. Berkeley CA.

Skinner, C.N. and C. Chang. 1996. Fire regimes, past and present. *In:* Sierra Nevada Ecosystem Project, final report to congress, vol. II, Assessments and Scientific Basis for Management Options. Water Resources Center Report No. 37. Davis: University of California, Centers for Water and Wildland Resources. pp. 1167-1176.

Skinner, C.N.; Ritchie, M.W.; Hamilton, T.; and Symons, J. 2005**.** Effects of prescribed fire and thinning on wildfire severity: the Cone Fire, Blacks Mountain Experimental Forest. In: S. Cooper, editor. 25th Annual Forest Vegetation Management Conference, January 2004, Univ. of California Coop. Extension, Redding, CA.

Show, S.B., and E.I. Kotok. 1925. Fire and the forest: California pine region. Department Circular 358. US Department of Agriculture. Washington, D.C.

Show, S.B., and E.I. Kotok. 1929. Cover type and fire control in the national forests of northern California. Department Bulletin No. 1495. US Department of Agriculture, Washington, D.C.

Stuart, J.D., M.C. Grifantini, and L. Fox III. 1993. Early successional pathways following wildfire and subsequent silvicultural treatment in Douglas-fir/ hardwood forests, NW California. Forest Sci. 39:561-572.

Van Nieuwstadt, M.G., D. Shiel, and K. Kartawinata. 2001. The ecological consequences of logging in the burned forests of east Kalimantan, Indonesia. Conservation Biology 15:1183-1186.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific Slope. Journal of Forestry 41:7-14.