

silviculture

Establishment of a Long-Term Fire Salvage Study in an Interior Ponderosa Pine Forest

Martin W. Ritchie and Eric E. Knapp

An experiment designed to evaluate the treatment effects of salvaging merchantable fire-killed trees on surface fuels and regeneration was established after a wildfire in northeastern California. The study was then monitored for 10 years. Surface fuel accumulations were rapid, corresponding with a high rate of snag decay and subsequent breakage or windthrow. Pine snags retained exhibited the fastest rates of breakage and transition to surface fuels, while white fir and incense-cedar were much more stable for the duration of this study. Natural regeneration observed following salvage was scarce and did not appear to be related to treatment. Similarly, artificial regeneration, although highly variable between treatment units, both in terms of growth and survival, was not related to salvage treatment.

Keywords: biomass, snag dynamics, regeneration

Postfire salvaging of merchantable fire-killed trees is gathering increasing scrutiny in recent years. While the economic benefit of postfire salvage is well understood, the effect on other aspects of forest health is not. Unfortunately, little is really known from well-designed experiments. McIver and Starr (2001) noted that most studies of fire salvage are based on observational studies and are often unreplicated. The problem with observational studies comparing salvaged and unsalvaged areas is that the reasons for leaving some areas of a burn untreated are typically related to important confounding factors of a practical nature such as slope, road access, species composition, fire severity, and merchantable volume. The presence of such confounding factors renders results from observational studies of fire salvage subject to question.

Although it is possible to conceptualize a designed experiment for the study of fire salvage it is not generally done because of the time involved and complications involved with the demands of the National Environmental Policy Act (National Environmental Policy Act of 1969 [NEPA]) on federally funded projects. Establishment of such a study on federal land requires close cooperation between both researchers and forest managers. This is further complicated by the time-sensitive nature of fire salvage itself.

Because of the onset of rapid decay in burned forests, any timber salvage must be done quickly, before value is lost among material considered to be of sufficient size to pay its way out of the woods. For this reason timber companies, unencumbered by NEPA, will generally salvage stands immediately after the fire if weather permits and

equipment is available. On federal land, NEPA may be expedited to some degree, but even then a period of many months to a year, or more, is often required.

The timing required to complete both a fire-salvage timber sale concurrent with a study design implementing salvage treatments requires close collaboration and particularly the willingness of the National Forest to expedite the NEPA documentation and other presale activity such as establishment of boundaries and completing marking. The inclusion of a study imbedded in a timber sale necessitates loss of revenue and increased costs of operation. The inclusion of control plots in what may otherwise be prime timber can make this a difficult pill to swallow. There are inevitable questions about favoring the placement of experimental controls in areas that are for some reason not well suited to salvage. This desire must be rebuffed to maintain a strong study.

The desire to meet management goals of reduced surface fuels while also meeting needs for wildlife habitat can cause some conflict. Recently burned areas may provide habitat for cavity-nesting birds (Nappi and Drapeau 2009), and forest managers are increasingly managing for retention of such habitat. Managers are also concerned with risk associated with elevated fuel levels. The development of surface fuel loading is of

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Affiliations: Martin W. Ritchie (mritchie@fs.fed.us), USDA Forest Service, Pacific Southwest Research Station, Redding, CA. Eric E. Knapp (eknapp@fs.fed.us), USDA Forest Service, Pacific Southwest Research Station.

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Figure 1. Wildfire severity in the area of the Cone Fire where research plots were established.

particular interest because of the relation to fire effects and behavior (Agee 1993, Skinner and Taylor 2006).

A wildfire on Blacks Mountain Experimental Forest in northeastern California afforded the opportunity to evaluate fire salvage effects on surface fuel accumulation, snag dynamics, and regeneration. By establishing a designed experiment with varying levels of fire salvage we were able to evaluate these responses over the last decade.

Methods

In September of 2002, the Cone Fire on the Blacks Mountain Experimental Forest in California provided an opportunity to explore the possibility of establishing a designed experiment of the effects of fire salvage. The fire burned a total of just over 2,000 acres, 1,600 of which were on the Experimental Forest. Fire severity throughout much of the burn was of uniformly high severity (Figure 1 photo showing wildfire severity). Elevations at Blacks Mountain range from 5,600 to 6,900 ft and forests are dominated by ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and include a mix of white fir (*Abies concolor* (Gord. & Glend.) Lindl. Ex Hildebr.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and Jeffrey pine (*Pinus jeffreyi* Balf.) in some areas. Precipitation levels are typically low at Blacks Mountain with the historic mean of about

20 in. per year, falling primarily as snow in the winter months.

In the aftermath of the Cone Fire, personnel from the Lassen National Forest and Pacific Southwest Research Station Redding Laboratory began to investigate the possibility of designing and implementing a study that would allow researchers to consider a number of different response metrics.

Working with district personnel, a study plan was established and included in the planning documentation for a larger salvage and fuels treatment project. While the study area included only 75 acres, to develop a marketable timber sale this acreage was embedded in a larger salvage sale covering approximately 638 acres and an additional 727 acres of green thinning (fuel reduction) treatments on the Experimental Forest.

Fifteen, 5-acre plots were established

during the spring of 2003 and varying levels of fire salvage treatment were randomly assigned to each plot (Figure 2). This design included three replicates of control (no salvage and no equipment allowed on the plot); three replicates of complete removal of all fire-killed trees, regardless of size; and 12 plots with intermediate levels of salvage with targeted snag basal area for retention. Our intermediate salvage levels were planned for approximate retentions of 25, 50, and 75% by basal area. These were obtained by thinning from below, that is, removing mostly smaller diameter snags to reach the basal area target (Table 1). Our targeted 75% retention levels came out somewhat below the original plan.

The distribution of trees in the burned forest was heavily weighted toward the smaller size material. The control (untreated) plots had only about 21 trees per acre between 12 and 18 in. dbh and only 8 trees per acre larger than 18 in. (Table 2).

The project was sold in late summer of 2003 with harvest operations beginning in September of the same year. Fire salvage treatments were completed, with the exception of chipping of decked submerchantable material, by November 2003. The area was planted with ponderosa pine at 12 × 12 ft spacing in the spring of 2004.

A grid of 25 permanent 0.05-acre plots was established in each treatment unit, wherein each snag was measured for height and dbh and the species was also recorded. Since Jeffrey pine, a minor component of these stands, and ponderosa pine are difficult to distinguish after fire, these two species were lumped together as ponderosa pine. The initial measurements were taken in 2004 and every 2 years since continuing through 2012. Additionally, four planar intercept fuels transects (Brown 1974) were established in each treatment unit to document accumulation of surface fuels over time. Regeneration (both natural and artifi-

Management and Policy Implications

Evaluating the effects of fire salvage demands rigorous experimental design and time. We observed a rapid accumulation of surface fuels over time exceeding historic levels for typical interior pine forests in areas without any salvage harvest. Thus, one potential benefit for fire salvage is in reducing the risk of severe fire behavior over time. White fir and incense-cedar snags appear to be a better choice than pine for retention because of their relative stability. Because of the scarcity of seed trees, natural regeneration rates were quite low. Planted seedling growth and mortality were unaffected by salvage treatment. Many factors that were fixed for this experiment such as species mix, slope, and precipitation may exert a substantial influence on the results, suggesting the need for more study of these processes.



Figure 2. Layout of variable retention fire-salvage plots; photo taken July 2005.

Table 1. Average total number of snags and number of snags greater than 12-in. dbh and basal area retention, across five levels of salvage treatments replicated three times.

Snag retention level	Total snags acre ⁻¹	Snags > 12 in acre ⁻¹	Basal area ft ² acre ⁻¹
None (3 plots)	0	0	0
Low-medium (3 plots)	18	11	21
Medium (3 plots)	38	13	40
Medium high (3 plots)	52	23	43
Untreated control (3 plots)	682	29	148

Table 2. Mean trees per acre and basal area per acre (with standard errors) across four dbh classes.

	Diameter class (in.)			
	1–6	6–12	12–18	18 +
Trees acre ⁻¹	481 (35)	177 (12)	21 (3)	8 (1.6)
Basal area, ft ² acre ⁻¹	36.5 (2.4)	65.6 (4.7)	23.0 (2.9)	22.6 (5.5)

cial) was sampled on 25 0.01 acre plots per treatment unit. We sampled over 3,100 snags with a distribution of 65% pine, 19% white fir, and 16% incense-cedar.

Results

Initial standing bole biomass expressed as 1,000-hour and 10,000-hour time lag dead fuels (roundwood 3 in. diameter and larger) was closely related to the basal area removed, ranging from zero to a maximum of approximately 30 tons acre⁻¹ in untreated units (Figure 3).

Surface Fuel Accumulation

The retained standing biomass in snags transitioned to surface fuel quickly in this

study. Ten years after the Cone Fire, we found that surface fuels accumulated in all plots where snags were retained and the relationship between the 1,000-hour and larger surface fuels and the snag retention level improved over time as snags fell or snapped off (Figure 4). The R^2 was 0.921 10 years after the fire. All of the control plots exceeded the historic range of variability for surface fuels (Brown et al. 2003) 6 years after the fire. Modeled 10-year surface fuels were within the historic range of variability for retention between 25 and 50 ft² of basal area. The 95% confidence intervals suggest that retention levels above about 60 ft² acre⁻¹ basal area will produce surface fuel

loads in excess of the historic range by year 10 at Blacks Mountain.

Snag Dynamics

The dynamics of individual snags are of interest to managers; one justification for leaving standing snags is for cavity-nesting bird habitat for both foraging and nesting. However, we found that for all but the largest trees (over 18 in. dbh), this was probably a short-term benefit at Blacks Mountain. This was most notable for ponderosa pine, where snags between 12- and 18-in. dbh that remained standing had a mean height below 20 ft 10 years after the fire (Figure 5). Perhaps more importantly, only 10% of the retained pine snags in this diameter class were standing 10 years after the fire, the remaining 90% either fell over or snapped off below 5 ft in height.

White fir on the other hand displayed a different dynamic. Although remaining white fir snags in this same diameter class were about the same height, about 42% were still standing 10 years after the fire. There was also a substantial difference between white fir and pine in the larger diameter class (over 18 in. dbh) where 86% of white fir snags remained standing 10 years after fire in contrast to only 25% of the pines. Incense-cedar snags were essentially stable for the entire 10-year period; all of the largest trees remain standing and there has been little or no breakage.

Regeneration

Regeneration performance can be an indicator of the ability for burned areas to regenerate naturally and the growth and survival of planted seedlings may be an indicator of the effects of salvage harvesting on subsequent productivity. Because of the severity of the burn in the Cone Fire, there were very few surviving trees to produce seed. Accordingly, our natural regeneration levels have been low throughout the 10 years we have monitored this study. The maximum seedling density was less than 70 trees per acre (for one of the control plots) and all of the remaining plots were below 30 trees per acre. Plots with distance to seed source exceeding 200 ft all had natural regeneration densities < 10 trees acre⁻¹. Coincidentally, the one control plot with the highest amount of natural regeneration was also the only plot with a few surviving trees. When we attempted to model natural regeneration with a quadratic model including distance to

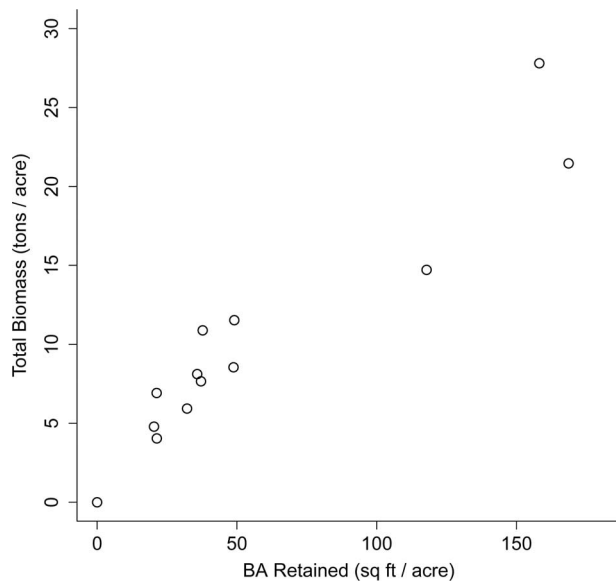


Figure 3. Relationship between standing 1,000-hour and 10,000-hour (3 in. and larger) fuel and basal area retained for treated plots at establishment in 2004.

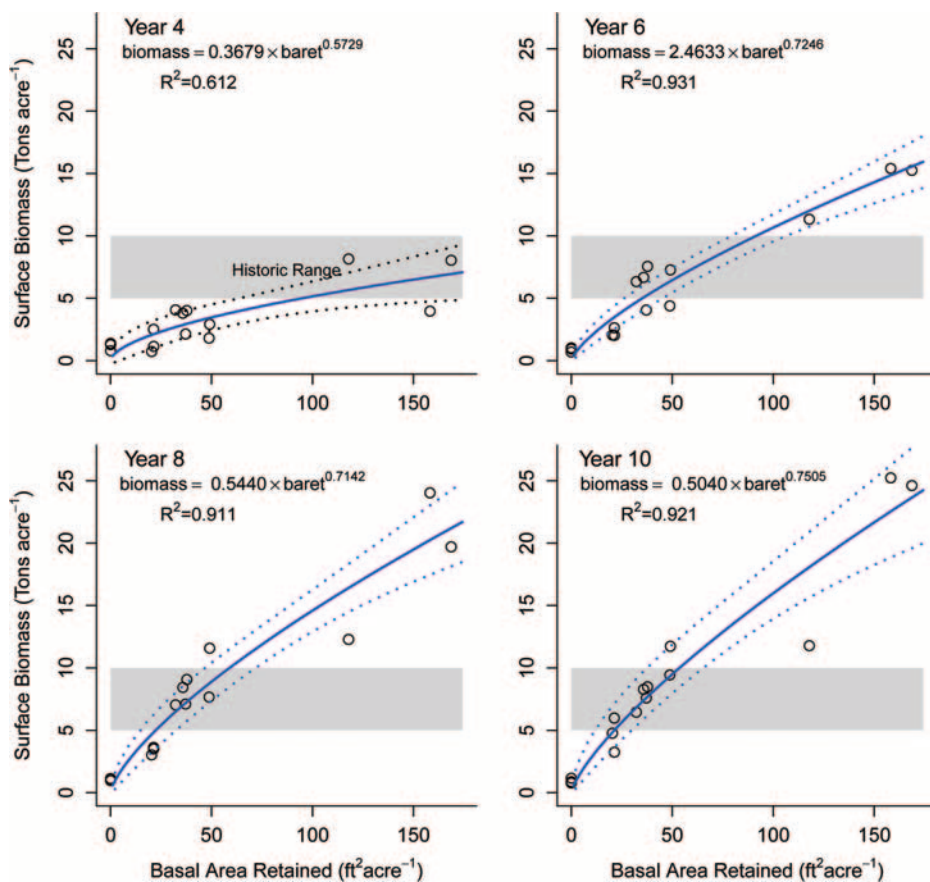


Figure 4. Surface fuel biomass accumulation (and predictive model with 95% confidence interval) over snag basal area retained for years 4, 6, 8, and 10 after the Cone Fire. Historic range of variability for interior pine forests is shown in gray (Brown et al. 2003).

seed source, our salvage treatment was not a significant contributor ($P = 0.223$).

Planted seedlings exhibited a high degree of variability both in terms of growth and survival. Mean planted seedling height

ranged from about 1.5 ft to about 5 ft after 9 growing seasons (Figure 6). Despite this high degree of variability, it had no relationship to salvage treatment ($P = 0.717$). Survival in our study area ranged from a low of

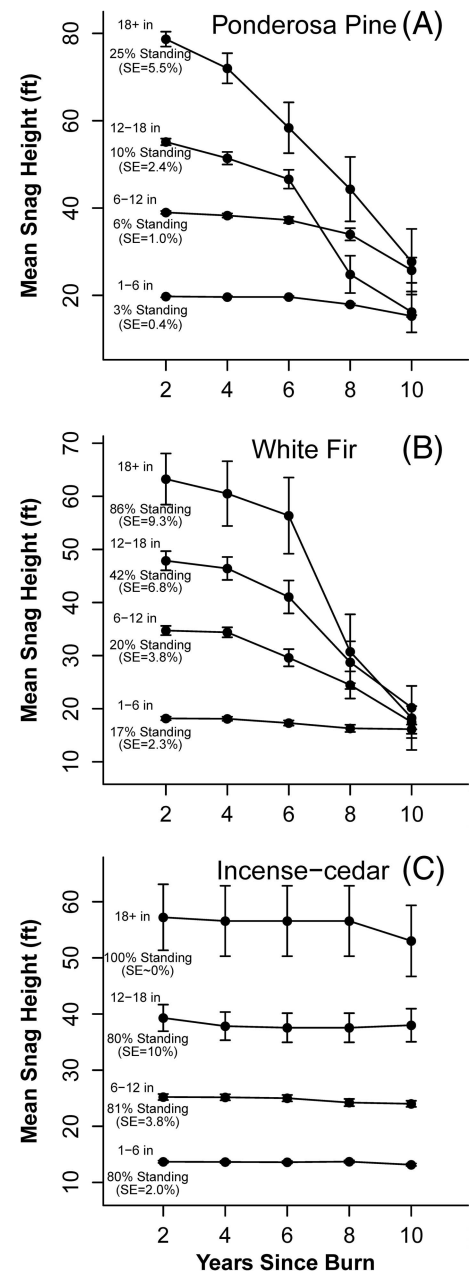


Figure 5. Snag height for sampled snags (with a 5-ft height threshold) over time by 6-in. diameter classes with % of snags still standing in year 10.

about 30% to a high of about 96% 10 years after the fire and also showed no relation to treatment ($P = 0.925$). However, survival was highly correlated with mean seedling height ($r = 0.65$, $P < 0.001$). This was indicative of site differences, primarily rock content, between treatment units.

Discussion

The rapid accumulation of surface fuels for all but the complete salvage plots is indicative of a potential problem in leaving snags on the landscape. Approximately 80%

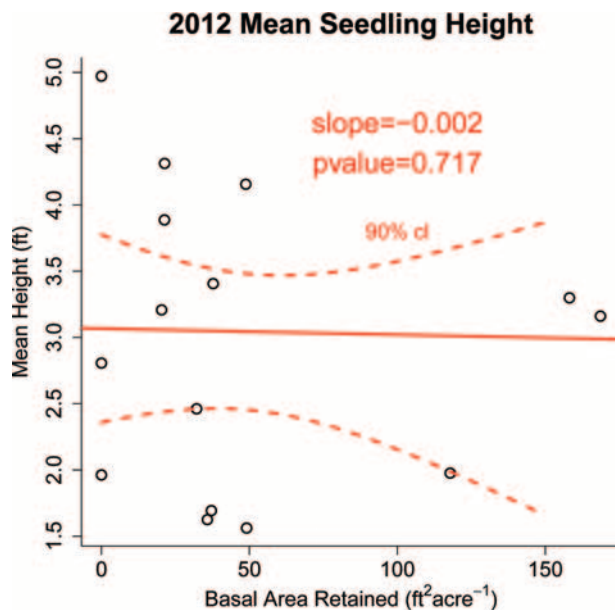


Figure 6. Relationship between mean planted seedling height and basal area retained in the summer of 2012, after nine growing seasons.

of the standing biomass retained is now on the forest floor and for untreated controls this amount is in excess of what we believe to be the historic range of variability (Brown et al. 2003). Thus, if one is managing to minimize future fuel loading, consideration should be given to the amount of standing material to be retained.

Conversely, by leaving snags in our plots we provided habitat for cavity-nesting birds. We found evidence of cavity excavation on all plots where snags were retained. However, the actual longevity of these snags was exceedingly brief. Only the largest white fir trees 18 in. dbh showed any proclivity for remaining upright. This rapid decay and fall rate may be an important consideration for key postfire cavity excavators such as the black-backed woodpecker because little is known about use beyond the 3–4 year post-fire time horizon commonly employed in past studies (e.g., Haggard and Gaines 2001, Smucker et al. 2005, Hutto and Gallo 2006, Cahall and Hayes 2009, Nappi and Drapeau 2009). Our findings with regard to the largest snags being more stable than smaller snags has been observed elsewhere (e.g., Keen 1955, Raphael and Morrison 1987).

It has been suggested that one may anticipate a slow decay and subsequent gradual accumulation of surface fuel (Donato et al. 2006). However, given the absence of any large trees (those over 30 in. dbh), and the observed rapid fall of retained trees, this was not supported at Blacks Mountain. Because this is a very dry forest type, decay of surface

fuels is slow. We, therefore, expect elevated levels of surface fuels to be maintained for some time. The stability of white fir snags relative to pine was somewhat surprising. It suggests that if trees are to be left for habitat requirements of cavity nesters, that large white fir snags may be a better choice than pine due to the limited residence time of ponderosa pine we observed. Interestingly, the incense-cedar snags showed little evidence of decay over a 10-year period, so residence is longest for these snags. However, it is worth mentioning that we never encountered any cavities in retained incense-cedar snags. Thus, if there is any benefit for cavity nesters it is not in evidence during the first 10 years after fire.

Timely natural regeneration of conifers has not taken place in the time that these units have been in place but this appears to have nothing to do with salvage activity. Numerous factors can influence natural regeneration (Stein 1981). The primary driver for natural regeneration at Blacks Mountain appears to be the presence of a nearby seed source and presence of a mineral soil seedbed (Roy 1983). Although the fire effectively prepared a seedbed, the uniformly high severity of this particular burn left few trees for seed. We observed seedling densities below 10 trees acre^{-1} for plots more than 200 ft from a seed source. Thus, natural regeneration cannot be relied on to reestablish a conifer stand in this area in the foreseeable future.

Artificial regeneration of ponderosa pine, while successful in most areas was also highly variable due primarily to soil depth and areas within the burn with very rocky soil. Effects of skidding on soil compaction and subsequent growth has been reported in some situations (e.g., Youngberg 1959), although current practices often minimize this by employing low-pressure machinery and monitoring of soil conditions during operations. Because of the high degree of underlying plot-to-plot variability at Blacks Mountain and the fact that our salvage activity took place during dry months before winter rains and snow, it is not surprising that we did not find evidence of soil disturbance or compaction from harvest activity sufficient to reduce observed growth of conifers (Williamson and Neilson 2000).

Because this was a designed study with randomized treatment application, we avoided many potential problems with confounding that would typically be encountered when comparing salvage treatments in an observational study. Furthermore, the dynamic nature of snags suggests that a full appreciation of the effects of salvage harvesting cannot be determined from short-term observational studies.

Because of the differentiation between species observed in this study, the results for surface fuel accumulation cannot be extrapolated to areas where the species mix differs. Further study is needed for areas where either species or size distribution differs from that encountered at Blacks Mountain. Furthermore, the effects of heavier snow loading or generally higher levels of precipitation found on west-side forests may also impact the rates at which snags decay and fall over time, yielding different surface fuel trajectories. Finally, topographic position is one more factor that could influence response over time. Ridge tops exposed to high winds or valley bottoms that are more protected than our midslope experiment might also produce different results.

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