KEYNOTE ADDRESS: The Role of Silviculture in Restoring Fire-Adapted Ecosystems[1]

James K. Agee[2]

Abstract

Across the drier forests of the western United States, historical fire was a natural silvicultural process--thinning stands from below, cleaning surface fuels, and maintaining fire-resilient conditions. The 20th century fire exclusion policy, although initiated with the best of intentions, has been a disaster in dry forests, converting them to high-severity fire regimes. Restoring fire-safe forests will require the use of fire or silvicultural options that mimic fire to reduce surface fuels, reduce ladder fuels, and reduce crown density, while in the process retaining the largest, most wildfire-tolerant trees. Challenges include the lack of markets for small material, perceived environmental effects of large-scale operations, and the need to act within a global warming context.

Introduction

Forests across the West are in trouble. Wildfire area appears to be increasing year by year, and the severity of these fires appears to be outside of the historical range of variability. Yet the gamut of solutions ranges from "heavy harvest" to "do nothing". Only in limited instances do we seem to be able to develop consensus approaches for action. I'd like to provide a broader view of the problem and potential solutions, recognizing the importance of priorities and place when applying these principles.

How Did We Get Here?

The fire problems we now face have a complex history. They start with an attempt to forge a national forest management policy in the early 1900's, and the critical role that the large fires in Idaho and Montana in 1910 played in creating that policy (Pyne 2001). Foresters believed that European-style forest management could never be applied in America unless fire was controlled, and the fires of 1910 were the catalyst for a new fire exclusion policy. Up into the 1920's, there were voices of dissent, which advocated for the use of prescribed fire. The case for "light burning", as it was then called, was made primarily by industrial foresters, who were concerned that their old growth would be burned by intense fires due to fuel buildup before they could cut it. Their pleas for short-term conservation of fire in dry forests were rejected (Agee 1993), and a century of fire exclusion resulted.

---

[1] A version of this paper was presented at the National Silviculture Workshop, June 6-10, 2005, Tahoe City, California.

[2] Virginia and Prentice Bloedel Professor of Forest Ecology, College of Forest Resources, University of Washington, Seattle, Washington.

What happened? "Enormous areas are growing up in dense, even-aged stands… of reproduction." "Fire hazard has increased tremendously." "Fires, when they occur, are exceedingly hot and destructive…" These statements are as true in 2005 as they were in 1943, when they were penned by Harold Weaver (Weaver 1943) in the Journal of Forestry. In dry forests, this turned out to be the disaster predicted by Harold Weaver in the 40's. The high-canopied, low-fuel forests of the turn of the century morphed into fuel-choked forests that now burn with high severity--but not everywhere did this happen, and not everywhere was high-severity fire out of character--it was an ecology of place.

In places where severe fires have replaced those more benign, Smokey Bear has been blamed for being too effective. But fire prevention, as exemplified by Smokey, is still an important part of fire management, and is not the sole source of problems where they occur. Pick-and-pluck selective logging removed the most fire-tolerant trees from the forest, and where the forests were predominately large trees, the forest was functionally clearcut. Even low-intensity fires will have more severe effects when smaller trees, and trees of less fire-resistant species, replace large old ponderosa pines. Grazing removed many of the fine herbaceous fuels that carried pre-European fires. Over regional scale landscapes, the proportion of low-severity fire declined and the proportion of high-severity fire increased. In Forest Service regions 1 through 6, the area covered by historical fire regimes was about evenly divided between low, mixed, and high severity, but is now almost all mixed and high severity.

An Ecology of Place

High severity fires were always part of western landscapes, typically occurring in wetter coastal areas or in forests at high elevation. But they were uncommon in the drier forest types. We can provide a context for this variability using the concept of the historical fire regime (Agee 1993). High severity fire regimes historically had fire return intervals exceeding 100 years, and, when fires occurred, they tended to be mostly stand-replacement in character. Forest types included here would be subalpine fir, mountain hemlock, Pacific silver fir, and western hemlock (both the Douglas-fir and spruce types).

The fire ecology of western hemlock/Douglas-fir forests is described elsewhere, but fires were typically separated by centuries. After a fire, the growing space opened up for Douglas-fir allowed it to become a stand dominant in the next generation, and because it is long-lived, the stand dominant for hundreds of years. Without fire, the stand would eventually become dominated by western hemlock and western redcedar, but few stands ever reached this stage before another stand-replacement fire occurred. These fires were often weather-driven events, such that fuels were a secondary consideration in the definition of either fire size or severity (Agee 1997). Forests with historical high-severity fire regimes are a low priority for active management to reduce fire hazard. Fire risk is low--many of these stands have persisted for centuries with very high fuel loads, so that short-term mitigation of hazard is not justified except in limited circumstances: other catastrophic events that excessively increase dead fuels, or when adjacent to urban interface areas.

Historical mixed-severity fire regimes present a more intermediate situation. Drier Douglas-fir forests (southern Oregon/northern California), red fir, and grand fir/western larch forests fit into this category. Fire return intervals might range from

30-100 years, with intermediate-sized patches of varying severity. At a landscape scale, this provided diversity in both species composition and structure of these historical forests. This variability had significant effects on the ability of subsequent fires to spread, and helped to maintain this patchy character on the landscape. Fuels, topography, and weather interacted to affect both fire spread and severity. Fires in these forests might have started in July and burned into October, under a wide variety of weather patterns, in a wide variety of forest patches with different structures and fuels, and across topography where it burned upslope, downslope, at night, and during the day.

The case for active management in the mixed-severity fire regimes is easier to make than in the high-severity fire regimes. Fire risk is higher, and portions of these landscapes historically experienced low-severity fires. The case is weaker than in the low-severity fire regimes, where fire has been removed for many more “cycles”.

Low-severity fire regimes historically occurred in the warmer, drier forests where a substantial snow-free dry season existed. These forests, usually with some ponderosa pine or pine mixed with Douglas-fir, white fir, or grand fir, are found broadly across the western United States. Although some of the Colorado Front Range and South Dakota pine forests appear to fit into mixed-severity fire regimes, the Southwest, California, and Pacific Northwest pine forests appear to fit the classic low-severity fire regime pattern of frequent, low-intensity surface fires (Allen et al. 2002). It is these forests where the most dramatic shifts in fire severity have occurred.

Restoration of Firesafe Conditions

The principles of firesafe forests are clear (Agee et al. 2000, Agee 2002a, Brown et al. 2004): reduce surface fuels, reduce ladder fuels (those fuels that bridge the gap between surface fuels and overstory canopy fuels), keep the large trees, and reduce crown density. Also implied here is an order. At the end of treatment, the most important actions are also in the same order. Lowering surface fuels reduces the flame length of a potential wildfire. Removing ladder fuels reduces the probability that a surface fire will transition to a crown fire. Retaining large trees keeps the most fire-tolerant trees in the stand. Reducing crown density lowers the probability that an independent crown fire will occur.

We know that prescribed fire does a pretty good job of reducing surface fuels – those are the fuels that carry the fire, so by definition they have to decline after a burn. But like most resource management actions, prescribed fire can be applied in many forms, under different weather conditions, and as a heading, flanking, or backing fire. One thing that is often overlooked is that prescribed fire also creates fuels by killing live vegetation that is not consumed in the first fires. It can replace much of the original fuel load in five years, although usually resulting in a much higher height to live crown. Pile burning, chipping, mastication--in short, any treatment that removes or compacts surface fuels -- will reduce the surface fire flame length of a potential wildfire.

Increasing the height to live crown reduces ladder fuel contributions that might help a surface fire transition to a crown fire. The torching phenomenon is basically an interaction between the potential surface fire flame length, the moisture content of the understory foliage, and the height that the foliage occurs above the ground. Two of these three variables are under managerial control. By reducing surface fuels, potential surface fire flame length is reduced, and by increasing height to live crown by thinning understory trees, the required surface fire flame length to initiate crowning is increased. Prescribed fire can be effective in doing both if properly scheduled.

At the same time, it is important to keep the large trees, and conversely lower the density of the small ones. The efficacy of reducing the crown density depends largely on a tree removal process that does both: reducing crown density while keeping the large trees. It's also important to remember that as thinning intensity increases, there are tradeoffs with surface fire intensity caused by drier surface fuels and increased mid-flame wind speeds in the thinned stands. Often in the debates about active management, we hear, "Oh, we must thin the stand to save it!" But thinning comes in many forms, and only some forms will result in a firesafe forest condition. Consider three types of classic thinning. A low thinning removes trees from below: the smallest ones. A crown thinning takes a wider group of trees, and a selection thin is a thin from above: the largest ones first. These classic graphs suffer from the exclusion of a structural component found in most current mixed-conifer stands: an unmerchantable tree layer (*fig. 1*).

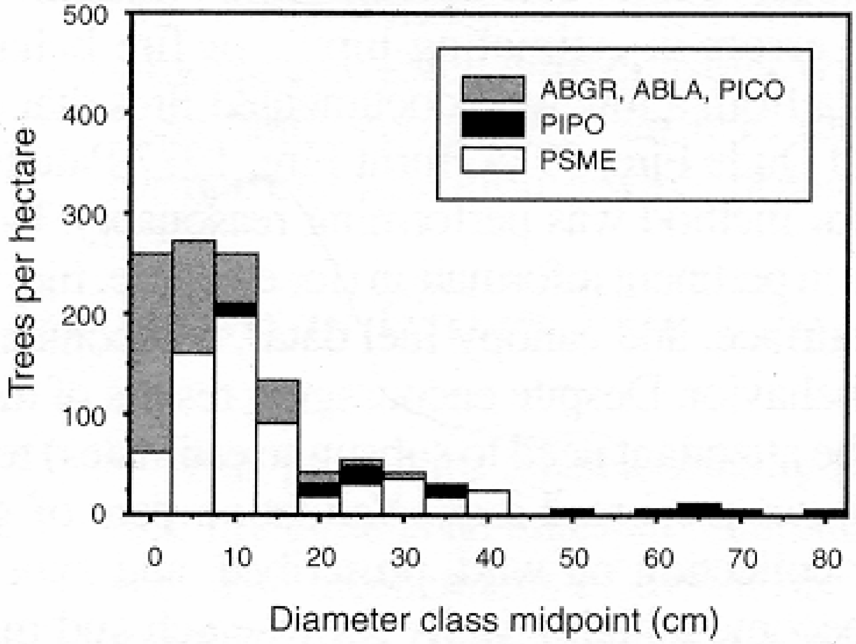

Figure 1—A typical dry forest size class distribution. Larger trees are mostly ponderosa pine (PIPO, *Pinus ponderosa*), intermediate sizes are dominated by more shade tolerant species like Douglas-fir (PSME, *Pseudotsuga menziesii*), and small size classes are other species (grand fir, ABGR, *Abies grandis*; subalpine fir, ABLA, *Abies lasiocarpa*; lodgepole pine, PICO, *Pinus contorta*). A majority of the trees are too small to be commercially viable. From Scott and Reinhardt (2001).

A simulation of the effect of various thinning and fuel treatment options was done using a stand much like this one (*fig. 2*). It has large trees (up to 100 cm [40 in] in diameter), but there are also a lot of small ones. It was assumed for this exercise that a commercial diameter limit was 15 cm (6 in). The simulation first applied a variety of alterations to the tree list in order to reduce basal area to a threshold of 15 m^2 ha^{-1} (60 ft^2 ac^{-1}). The simulated thinning treatments included no thin, low thin (start with smallest tree, increase tree size removed until basal area threshold is met), low thin-commercial limit (start with 15 cm tree, then increase as before until threshold is met), and selection thin (start with largest tree and move down in size until threshold is reached). The simulated fuel treatment options included no treatment, or a prescribed fire with a 0.6 m (2 ft) flame length to reduce post-treatment fuels. Then a worst-weather wildfire was simulated to burn across each stand, and survival was estimated using FOFEM (First Order Fire Effects Model [Reinhardt et al. 2002]). FOFEM essentially applies a flame length to the tree list and calculates mortality as a function of crown volume killed and bark thickness for each species/diameter class. Obviously, many other combinations could have been applied, and many other beginning stand structures could have been used. But some basic principles emerge from this analysis.

The treatments are arrayed from lowest to highest survival. The unmanaged stand (at left, *fig. 2*) suffers a stand replacement event. The surface fire flame length enables substantial torching in this stand. Equally severe was the selection thin with no fuel treatment, as the fire burned across increased surface fuels with increased fireline intensity, and only small trees were present. The first treatment with any residual survival were the low thin-commercial limit with no fuel treatment and the selection thin that had fuel treatment. In the former case, the unmerchantable understory, combined with additional surface fuels from the thinning, resulted in some torching and an intense surface fire, while in the latter case, survival was minimal because all the trees in the residual stand were small.

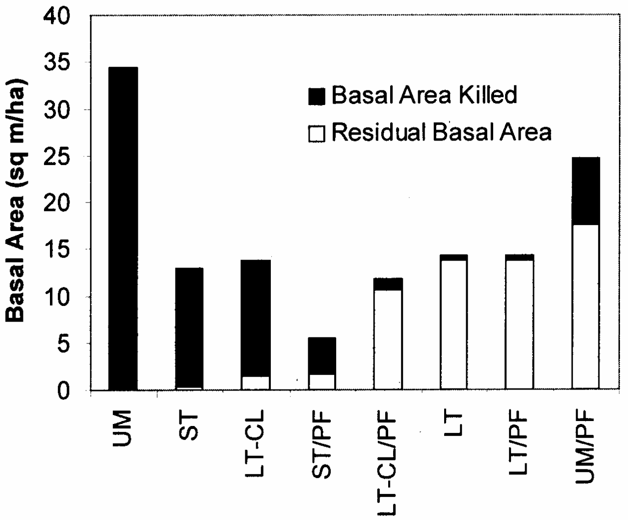

Figure 2—Survival from a simulated severe fire weather wildfire of the stand structures shown in fig. 1. Columns are organized by absolute amount of residual basal area (white part of column). UM= unmanaged, ST = selection thin, LT = low thin, CL = commercial limit (>15 cm), PF = prescribed fire. The unharvested stand was assumed to be NFFL (Northern Forest Fire Lab) fuel model 10, harvested stands with no prescribed fire were assumed to be NFFL Model 11, and any stand treated with prescribed fire was assumed to be NFFL model 9. Fuel moistures for 1-, 10-, and 100-hr fuels were 4, 5, and 6 pct for models 9 and 11 and 5, 6, and 7 pct for model 10. Open wind speed of 36 km hrP^{-1P} was adjusted to 0.4 for models 9 and 11 and 0.2 for model 10. From Agee and Skinner (2005).

The four options to the right had better survival. They all had either a low thinning (one with a commercial limit) or fuel treatment by prescribed fire. In this stand, the best result was obtained with the stand that was not thinned at all, where a prescribed fire had been applied that reduced surface fuels and raised the height to live crown. Of course, in the real world, such prescribed fires also create dead fuels, and those are not included in the simulation. Inclusion of those fuels would have shown the option of prescribed fire only to have been less effective.

This simulation involved a set of "worst-case" wildfire conditions that might vary across the West. The absolute outcomes of this set of simulations would be different if a wildfire with a different flame length had been applied using more or less severe weather (fuel moisture and wind speed). However, the relative order of treatment effectiveness would remain the same due to the deterministic nature of the fire behavior and fire effects programs used here.

The basic principles emerging from this analysis are that "no action" is a disaster, thinning from above is also a disaster as it removes the most fire-tolerant trees, and low thinning is the best thinning method (from the standpoint of creating firesafe forest structures). Prescribed fire shows up as being valuable, but in this simulation, the dead fuels it creates are not included. Treatments that reduced surface fuels, treated ladder fuels, and kept the large trees fared best.

Empirical Evidence for Firesafe Forests

The theory of firesafe forests derives primarily from research and empirical constants obtained from boreal (high latitude) forests. Experimental crown fires there have been studied for decades. Quantitative estimates of the relations between flame length and height to live crown, for example, or thresholds of mass flow rate (the quantity of crown fuel below which crown fire cannot operate) are largely derived from black spruce and jack pine forests. Over the last decade, evidence from the lower 48 states suggests that these principles also apply to western forests. Four examples illustrate how these firesafe principles have been successfully applied and mitigated wildfire damage.

1987 Hayfork Fires

These fires occurred during a massive outbreak of fires in northern California and southern Oregon. Weatherspoon and Skinner (1995) evaluated fire severity as evidenced by crown scorch visible on post-fire aerial photography. The forests burned in this study, mostly mixed-evergreen forests, were not specifically treated with firesafe principles in mind, but treated forests were classified as either cut-treated or cut-untreated. Cutting was largely selective overstory removal, so cut units were implied to have average tree size smaller than uncut units. Fuel treatment was either lop and scatter or patchy prescribed fire. Forests experiencing the least damage were uncut-untreated forests that had the largest trees. However, cut-treated forests did not significantly differ from uncut forests. Fire severity in cut-untreated forests was significantly higher.

Megram-Onion Fire, 2002

This fire in northwestern California burned largely in fuels created after a large wind-snap event in the winter of 1995-1996. The Forest Service created limited fuelbreaks in this Douglas-fir/white fir forest. In some fuelbreaks, surface fuels, ladder fuels, and crown density were reduced, while in others only the surface and ladder fuels were treated. From the air and the ground, the fuelbreak edge is obvious (*fig. 3*), and even though substantial crown density was left, the fuelbreak forest, although it burned, suffered only a low severity fire compared to the untreated area.

Figure 3—Area burned by the Megram Complex Fire in the vicinity of a fuelbreak. Untreated areas are upper left, and treated areas (surface and ladder fuels) are to the lower right. Untreated areas experienced high severity fire, while the fuelbreak survival was very high. Photo courtesy of USDA Forest Service.

Tyee Fire, 1994

A large Washington wildfire burned across ponderosa pine/Douglas-forest, and created huge patches of stand replacement fire. Areas where thinning and prescribed burning had been done fared much better than untreated areas, although scale of treatment was important. One area had trees less than 15 cm (6 inches) removed within three years of the fire, residual trees pruned, and surface fuels piled and prescribed burned. The crown fire approached this area, dropped to the ground within one tree length, and burned through as a surface fire, scorching about 50 percent of the crown volume and allowing a nearby residence to be saved. An older, nearby narrow fuelbreak also showed better survival than untreated areas outside. The fuelbreak was created in the 1970s, and the trees in this thinned area had grown such that their average diameter was about 50 percent greater than in adjacent unthinned areas. Again, a crown fire quickly transitioned to a surface fire upon encountering the fuelbreak, and then retransitioned to a crown fire on the far side of the fuelbreak.

Cone Fire, 2002

This fire entered Blacks Mountain Experimental Forest in northeastern California where thinning and burning experiments had been underway for several years. All treatments had been completed within five years of the wildfire. In areas thinned and burned, the wildfire would not even spread. A rapid transition in mortality occurred as one crossed into the boundary of treated units.

As a caution, the Hayman fire of Colorado (2002) must also be mentioned. Here, fuel treatment appeared to be effective under "normal" wildfire conditions, but treatments were not effective during exceptionally severe fire weather when the fire ran 29 km (18 miles) in one day. We appear to have good guidelines for stand-level treatment, and if the proper steps are taken, high-severity fire can be altered to low-severity fire under almost all conditions. Fuel does make a difference in low-severity fire regimes. Weather historically was responsible for the larger spread of these fires, but severity was fuel-related. This is still true. Several issues remain outstanding, though.

How much of a landscape need be treated? This depends on assumptions about what will be done when a wildfire occurs (Finney 2001). With aggressive fire suppression, probably 20-35 percent of a landscape will fragment fuels such that suppression can be effective. If an aggressive fire suppression response is unlikely, then untreated areas of the landscape will burn severely, and treated area will burn less severely. How much of the landscape do we want to place at risk? If suppression forces will concentrate on the wildland-urban interface, at the cost of more wildland area burned, then this argues for wider-scale treatment in the wildland.

How long are these treatments effective? The answer depends on what is meant by “effective”. Historical research (e.g., Heyerdahl et al. 2001, Wright and Agee 2004) shows that historic fires in ponderosa pine forests often stopped at the boundaries of areas burned in the previous two years. After that, spread was likely to pass over into previously burned areas. So, the effectiveness from a spread perspective is probably five years or less. From a perspective of severity, which would appear to be a more relevant criterion, the effectiveness depends on how long ladder fuels and surface fuels remain low, and how they interact with the residual tree fire tolerance in the face of wildfire. In most cases, where the first fuel treatment was effective, the answer might be 10-20 years.

Many constraints on active management face today’s land managers. Some segments of society so fear active management that they apply the precautionary principle to an extreme, ignoring the fact that in dry forests the “no action” option is itself a large risk. Species impacts, from large species, such as hawks or owls, to small organisms, like mollusks and lichens, often constrain even “light on the land” management. Soil impacts from any harvest, and effects of possible roadbuilding, limit the ability to treat large areas with thinning. Some harvest techniques, like helicopter, have minimal soil impacts, but require leaving much more surface fuel (tops, etc.) in the woods. The biggest constraint for wildlands is the focus on the urban interface, as if there were no values at all to protect away from the interface. That problem will only grow larger with time.

If we ever get serious about global climate change and carbon balances, more regulation of prescribed fire from strictly a carbon balance perspective is likely. But how will that affect the tradeoff between wildfire carbon emitted and that emitted by practices like prescribed fire intended to reduce wildfire carbon emissions? All of the issues involve risk management, and we do a very poor job of placing the choices for managers in a policy context. Current climate projections suggest that across the West, we are likely to experience warming temperatures and lower annual precipitation, concentrated in winter months (Lenihan et al. 2003). Fire seasons might be longer. Silviculture to restore firesafe forests can only become more important in the future.

Healthy Forests Restoration Act (HFRA) of 2003

I’d like to close by moving a bit closer to a policy issue at our doorstep: the Healthy Forests Restoration Act (HFRA) of 2003. In my view, the Act provides the appropriate technical policy guidance for "doing the right thing" in our drier forests. It is generally limited to drier forests (with some reasonable exceptions), it has an area limit, it directs a focus on small diameter trees, and allows both thinning and prescribed fire. But the effectiveness of HFRA remains to be demonstrated. If the agencies and their administrators choose to follow the intent of the HFRA, I think it will improve forest health across the West. It will engender trust on part of interest groups and help to move the restoration process forward. But if it used only to justify allowable cut quotas, it will fail both in the public eye and only exacerbate the fire problems we face today.

In our dry forest types, our 20th century choice, for better or worse, turned the friendly flame into a demon. As a society, we have difficult choices about how to correct this policy nightmare that covers millions upon millions of acres across the West. There are risks of action and no action, and people on both sides who want to do the right thing, and the wrong thing. If the larger, broader society has a better understanding of what the "right thing" is, we will take back the forests from the advocates of the extremes, and allow fire and its silvicultural surrogates to play ecologically appropriate roles in forest restoration.

References

Agee, J.K. 1993. **Fire Ecology of Pacific Northwest Forests**. Island Press. Washington, D.C.

Agee, J.K. 1997. **The severe weather wildfire: too hot to handle?** Northwest Science 71: 153-156.

Agee, J.K. 2002a. **The fallacy of passive management: managing for firesafe forest reserves**. Conservation Biology in Practice 3(1):18-25.

Agee, J.K.; Skinner, C.N. 2005. **Basic principles of forest fuel treatment**. Forest Ecology and Management 211: 83-96.

Agee, J.K.; Bahro, B.; Finney, M.A.; Omi, P.N.; Sapsis, D.B.; Skinner, C.N.; van Wagtendonk, J.W.; Weatherspoon, C.P. 2000. **The use of shaded fuelbreaks in landscape fire management**. Forest Ecology and Management 127: 55-66.

Allen, C.D.; Savage, M.; Falk, D.A.; Suckling, K.F.; Swetnam, T.W.; Schulke, T.; Stacey, P.B.; Morgan, P.; Hoffman, M.; Klingel, J.T. 2002. **Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective**. Ecological Applications 12: 1418-1433.

Brown, R.T.; Agee, J.K.; Franklin, J.F. 2004. **Forest restoration and fire – principles in the context of place**. Conservation Biology 18: 903-912.

Finney, M.A. 2001. **Design of regular landscape fuel treatment patterns for modifying fire growth and behavior**. Forest Science 47: 219-228.

Heyerdahl, E.K.; Brubaker, L.B.; Agee, J.K. 2001. **Spatial controls of historical fire regimes: a multiscale example from the interior West, USA**. Ecology 82: 660-678.

Lenihan, J.M.; Drapek, R; Bachelet, D; Neilson, R.P. 2003. **Climate change effects on vegetation distribution, carbon, and fire in California**. Ecological Applications 13: 1667-1681.

Pyne, S.J. 2001. **Year of the Fires: Story of the Great Fires of 1910**. Viking Press. New York.

Reinhardt, E.D.; Keane, R.E.; Brown, J.K. 2002. **First Order Fire Effects Model: FOFEM 4.0, user's guide**. USDA Forest Service Gen. Tech. Rep. INT-GTR-344. (updated to Windows™ version 5.0)

Scott, J.H.; Reinhardt, E.D. 2001. **Assessing crown fire potential by linking models of surface and crown fire behavior**. Res. Paper RMRS-RP-29. Fort Collins, CO: Rocky Mountain Research Station, USDA Forest Service.

Weatherspoon, C.P.; Skinner, C.N. 1995. **An assessment of factors associated with damage to tree crowns from the 1987 wildfires in northern California**. Forest Science 41: 430-451.

Weaver, H. 1943. **Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope**. Journal of Forestry 41: 7-15.

Wright, C.S.; Agee, J.K. 2004. **Fire and vegetation history in the eastern Cascade Mountains, Washington**. Ecological Applications 14: 443-459.