Fuel Treatments to Prevent and Manage Wildfires [1]

Philip N. Omi [2]

Abstract

Wildland fire prevention and management techniques are needed for forests, shrublands, and grasslands that burn recurrently. A variety of fuel treatments can be used for fuel hazard reduction, including disposal on-site, redistribution, physical removal, type conversion, and isolation. The most appropriate fuel treatments are consistent with stand and landscape ecological attributes, most importantly the historical fire regime for the area under consideration. In the USA, prescribed fire and mechanical thinning are two popular treatments that can be used to both reduce fuel hazards and restore ecosystems, especially in forests that historically experienced frequent, low severity fires. Multiple entries may be required to reduce fuel hazards in forests that have missed fire rotations due to aggressive fire control policies. In these areas, managers can create forests that are safe for both prescribed and wild fires. In other wildland vegetation types, prescribed fire and mechanical thinning may not be ecologically sustainable. Sustainable fuel treatments are those that are feasible from ecological, economic, and socio-political standpoints.

Introduction

Recurrent wildfires in forests, shrublands, and grasslands illustrate the need for wildfire prevention and management activities. Worldwide, an area half the size of mainland China may burn annually, with humans responsible for about 90% of the ignitions (Omi 2005). In the US, the severity of recent fire seasons seems to be on the increase in recent years, at least as measured by the average area burned and average fire size, due to a variety of hypothesized, but as yet unverified causal influences. Among the possible causes for recent increases in fire season severity include climate change, fuel accumulations in ecosystems subjected to previous fire exclusionary practices, and population increases in the wildland urban interface.

Statistics are not available for the various cover types that burn annually in US fire environments, but suffice to say that the nation’s forests, shrublands, and grasslands burn with apparent regularity, driven primarily by climatic cycles. As exurban populations push into formerly wild lands, more homes are damaged while others remain at risk to catastrophic wildfire losses. Management of these fires, including maintenance of the appropriate balance between too much and too little fire in various ecosystems, remains one of the major challenges confronting fire managers. Regardless of the cause(s) of fire ignitions, fuels remain the main contributor to a fire’s environment (i.e., fuel, topography, and air mass) that humans can control or manage (Countryman 1972).

---

[1] An abbreviated version of this paper was presented at the Wildfire2007 conference, 13-17 May 2007, Sevilla, España.

[2] Professor Emeritus, Colorado State University, Department of Forest, Rangeland, and Watershed Stewardship, 1472 Campus Delivery, Fort Collins, CO 80523-1472.

The papers in this session draw focus to forestry, ecology, biodiversity, and societal needs. As fire management issues increasingly inform forest practices in the US, I have chosen in this paper to summarize the role of fuel treatments in preventing and managing wildfires. At the same time fire's ecological impacts, ranging from effects on individual organisms to indicators of ecosystem resilience, need to be considered insofar as these affect societal needs.

Wildfire Risk and Hazard Fuel

Risk is defined as the chance of fire starting as determined by the presence and activity of causative agents (National Wildfire Coordinating Group 2006). It also can be thought of as the chance or probability of incurring fire loss or harm. Risk is distinguished from *hazard*, or any real or potential condition that can cause injury, illness or death of personnel, loss of equipment or damage to property. Risk is also distinguished from *hazard fuel*, i.e., a fuel complex defined by kind, arrangement, volume, condition, and location that presents a threat of ignition and resistance to control (National Wildfire Coordinating Group 2006).

Fire prevention activities generally aim to reduce wildfire risk, through engineering, enforcement, and educational activities aimed primarily at human causes. Activities that manage fuels can affect the likelihood of ignition, especially of larger, more destructive wildfires. But fuels management is more often associated with efforts to reduce fuel hazards in an area or over a landscape, rather than activities aimed at mitigating sources of fire risk.

Fuels Management: an evolutionary concept

Fuels management is defined as the manipulation of flammable biomass to achieve management objectives (Omi 2005). The concept of fuels management has been around for decades although not formally mentioned by name in the forestry or fire literature until recently (Husari and others 2006). Previously, fuels management activities focused primarily on fulfilling fire control objectives through reduction, removal, or elimination of fuel hazards (Brown and Davis 1973). Activities undertaken to reduce hazards or mitigate fire effects include on-site reduction (e.g., through prescribed burning), redistribution (lop and scatter, mastication), physical removal (yarding unmerchantable material), type conversion (to less flammable vegetation), and isolation (i.e., fuelbreaks). Historically, these activities were consistent with fire control efforts that attempted to exclude fire from wildland ecosystems. The US Forest Service essentially institutionalized efforts aimed at excluding fire in 1935 through its 10AM policy that rationalized massive expenditures on initial attack in an effort to keep fires as small as possible. This view was consistent with agency goals in its Organic Act, and later with harvesting timber under multiple-use, sustained yield guidelines legislated in the 1960s. Through these times the idea of fuels management was carried out through slash or brush disposal techniques aimed at creation of spots for planting the next forest. Back then fuels management generally was not implemented programmatically by land management agencies. A notable exception included the National Park Service's prescribed fire program in the Everglades during the 1950s (Kilgore 1975). Another notable exception was the designated controlled burn system (DESCON) installed in one or two national forests in the southern US in 1973. This system allowed for both natural and human-caused ignitions to be managed or herded under pre-established and approved prescriptions that met land management objectives (Devet 1976).

Since then, the concept of fuels management has been reinforced and/or mandated by various initiatives and policy reviews. A summary of the more relevant motivations for fuels management might include the following keystones. For example in 1972 the US Forest Service underwent an agency-wide planning process for pre-suppression activities including fuel treatments. As a result, a planning standard was adopted such that treatment expenditures were planned to keep fires at about 4 ha (10-ac) size or less (Omi 1977). The concept of managing fuels provided partial motivation for the practice of managing lightning ignitions, which has evolved as a strategy for managing fuels in remote areas, previously known as "let burn" then "natural fire management" then "prescribed natural fire" events. This practice was developed to allow herding strategies on lightning fires until extinguishment by natural rain or snow events. Currently referred to as "wildland fires used for resource benefit," these herding fires reflect adherence to policies expressing a desire for naturalness (e.g., as embodied in the 1964 Wilderness Act) or restoration (i.e., the 1963 Leopold Report for the National Park Service). The 1988 Yellowstone fires, some of which were managed under these same guidelines, spurred extensive reviews of the role of natural fire management programs in manipulating fuel loads and restoring fire to ecosystems. By contrast, the 1995 Policy Review following the 14 fatalities in the 1994 South Canyon fire reaffirmed the importance of fuel treatments for hazard reduction. Following the 2000 and 2002 fire seasons in the western US, fuel treatment was identified as an important priority for a cohesive strategy to be developed by federal agencies in order to combat destructive wildfires (GAO 1999).

Contemporary fuel treatments continue to focus primarily on fuel hazard reduction but also may aim to restore or alter an ecosystem's projected successional trajectory over time. Hazard reduction aims to reduce wildfire costs and losses while ecological restoration efforts may focus on improving sustainability through changes in ecosystem structure and function. These two aims may or may not be complementary. For example, hazard reduction in ponderosa pine (*Pinus ponderosa*) forests may augment restoration objectives by perpetuating frequent, low severity fires. By contrast, fuel hazard reduction may be inconsistent with southern California chaparral ecosystems that typically burn with high severity (Keeley and others *in prep.*).

Perhaps surprisingly, relatively few studies until recently have focused on the effectiveness of fuel treatments in either capacity, i.e., hazard reduction and/or ecosystem restoration. Additional nuances have evolved as the fuel treatment notion has matured, including the importance of scale (i.e., project vs. landscape area treatment) and land type (i.e., wildland urban interface vs. managed vs. natural stands).

Fire Regimes and Fuel Treatments

The fire regime concept provides a useful, even if artificial, conceptual construct for categorizing historical fire activity for an area or landscape. Fire regime descriptors typically include the frequency, severity, seasonality, and patch size of historic fires that characterize an area. The fire regime concept recognizes that fires have an important role in most wildland ecosystems. Further, attempted exclusion of fire from ecosystems may produce undesirable consequences (Arno and Brown 1991). Departures from historic fire regime descriptors may indicate degrees to which ecosystem management practices are sustainable or not. For example, attempts at excluding fire from ponderosa pine forests in the southwestern US have reduced the frequency of fires. Historically, these forests burned with characteristic low-intensity surface fires that previously cleared out the forest understory of surface and ladder fuels and allowed the survival of the larger trees. As consequence of fire exclusionary practices, infrequent stand-destroying crown fires may have replaced the more characteristic frequent low-intensity fires that facilitated survival of the dominant ponderosa pine trees.

Other management practices, such as timber harvest and grazing, have led to alterations in historic fire regimes, sometimes with negative impacts on biodiversity in return for economic returns in the market place. However, tradeoffs that were once acceptable from a financial standpoint have come under increasing scrutiny as changes in consumer tastes have affected consumption patterns. In such cases, concerns for environmental impacts and aesthetics may trump the desire for tangible, natural resource products. Similarly, expansion in scientific knowledge over time has affected societal willingness to pay for certain services, such as fire control. Thus, drastic changes in fire management philosophies have resulted from knowledge that aggressive fire suppression policies aimed at excluding all fires may disrupt the sustainability of certain ecosystems. For example, knowledge that fire suppression can disrupt the frequency, severity, and magnitude of fire activity in ponderosa pine landscapes has shown that fire exclusion can lead to resultant increases in fuel loadings. This revelation has revolutionized thinking about the desirability of fire exclusion in these ecosystems. Rather than less fire, many ponderosa pine forests are now targeted for increased levels of mechanical thinning and/or prescribed frire treatments. Consequences of these changes vary depending on location, vegetation type, duration and extent of altered fire influences, and proximity to human developments, among other factors.

The likelihood of fuel treatment success in reducing the severity of future wildfires seems to be linked to the creation of fuel beds that provide consistency with historic fire regimes (Martinson and Omi 2006). This is certainly the case for ponderosa pine forests in the western US, where fuel loads have increased due to decades of fire exclusionary practices (Covington and others 1997, Pollet and Omi 2002). Restoring these forests so that fires can once again burn safely (as they did before euro-American settlement) is more likely achievable than trying to keep fires out (Agee and Skinner 2005). In attempting the latter, managers essentially are only forestalling (i.e., not preventing) the inevitable catastrophic wildfire, such as evidenced in the US during the 1994, 2000, and 2002 fire seasons.

Mechanical Treatments

Mechanical fuel treatments range from removing excess trees with chain-saws to thinning forest ladder fuels and/or reducing stem density (i.e., to reduce crown fire potential) using whole-tree harvesters or feller-bunchers. Crushing or mastication of shrubs in shrublands may precede dessication and burning. Mechanical techniques may involve crews with chainsaws, whole tree yarding, fire wood sales, or other processes involved with biomass removal and utilization. Silvicultural thinning regimes that are consistent with fuel hazard reduction are discussed in Peterson and others (2005), Graham and others (2004).

Advantages of mechanical treatments include silvicultural control over forest stand structure, including basal area and stem density, possibility of product revenues, and reduced risk compared to alternative treatments involving fire. Even so, subsidies may be required (Abt and others 2003) especially where markets are poorly developed for small diameter materials. Also treatment costs for mechanized procedures and equipment are generally higher than for prescribed fire treatments (Omi 2005).

Prescribed Fire

Prescribed fire, or the intentional application of fire under pre-specified environmental conditions, is often a treatment of choice to achieve a variety of specific management objectives. The controls over fire application include fuel moisture, wind, condition of the fuelbed, and firing technique. Fuel moisture of small diameter fuels, wind speed and direction directly affect fire rate of spread and intensity. Loading, depth, and packing or compactness can be manipulated in advance of fire application. Firing techniques (e.g., strip vs. head or back fire) and ignition techniques (i.e., drip torch, helicopter, or terra-torch) also influence fire intensity and severity.

A general distinction in prescribed fires can be drawn between *restoration burns*, in which the current ecological condition is modified, and *maintenance burns*, in which existing conditions are kept within a specified range (Husari and others 2006). Typical goals for restoration prescribed burns include reductions in hazardous dead and live fuels, stimulation of fire-dependent species, creation of plantable spots, control or removal of noxious or non-native plants, improvement of range condition, or creation of desired wildlife habitat.

A variant of the prescribed fire motif is provided by the movement toward increased use of lightning fires to manage landscapes. The National Park Service has been experimenting with lightning fires burning under prescription since 1968. Lightning ignitions allowed to burn now fall under the general rubric of wildland fires used for resource benefit, or sometimes abbreviated as wildland fire use (WFU) incidents. Much like maintenance prescribed burns, areas in which lightning ignitions are allowed to burn are generally considered to be within historic or natural ranges in variability (Husari and others 2006). In a way, the use of lightning fires to manipulate landscapes recognizes the legitimacy for the role of fire in managing wildlands. This recognition has been long-overdue for some, but not all, wildland ecosystems.

Mechanical Treatments, Prescribed Fire and Biodiversity

Multiple entries, including mechanical thinning followed by prescribed fire, may be required in some forests that support excessive fuel loads due to decades of fire exclusion. In these forests, reductions in understory vegetation and coarse woody materials may be required before prescribed fire can be applied safely. A plausible long-term treatment goal for such forests might be to create forests that are safe for both prescribed and wild fires by reducing surface fuels, increasing canopy base height, decreasing crown bulk density, and retaining larger fire-resistant trees (Agee and Skinner 2005).

Like fire, mechanical treatments will create openings that allow solar insolation to reach the forest floor. Even so, mechanical treatments may not replicate fire effects in terms of impacts on structure or functioning.of ecosystems, and will poorly approximate the expected mosaic patchwork of high and low severity fuel consumption burn areas following fire. Further, heat effects on organisms, soil albedo, and nutrient cycling processes unique to fire are not replicated by mechanical treatments. As such, mechanical treatment effects may be poor replicates for effects of fire except in limited circumstances. Mechanical treatments thus differ substantially from fire effects on biodiversity, especially of understory flora and fauna, specifically on the biotic and abiotic environments for native species.

Prescribed fires are considered to mimic more closely the natural processes that have been shaping ecosystems for thousands of years. Anecdotally, managers have observed that areas subjected to prior prescribed burns do not burn as severely during wildfires as comparable untreated areas, an observation confirmed by several studies including Weatherspoon and Skinner (1995), Pollet and Omi (2002), Omi and Martinson (2002), and Omi and others (2006). Prescribed fire tends to be favored over mechanical treatments by environmental groups who question the rationale and impacts of logging or other mechanical methods for removing biomass from an area, as compared to burning. However, our understanding of prescribed fire impacts is based on a relatively shallow database of studies that is based primarily on findings from one or several prescribed fire treatments. Certainty is lacking about the effects from repeated prescribed fire treatments over the long-term (Agee 1997).

Recently, concerns have been aired that low intensity prescribed fires may produce fire behaviors (and subsequent fire effects) that are inconsistent with historical fire activity. Contemporary prescribed fires would be expected to differ from historical fires with respect to intensity and severity, but also in size and shape due to fire control lines and firing strategies. In this context, questions are being raised about potentially negative consequences on structure and function of affected ecosystems, including the possibility that invasive plants will reduce the biodiversity of native flora and fauna.

As wildland fire use expands to areas outside remote wildernesses, similar concerns will likely arise regarding variances from historical norms of fire behavior and effects. Fires managed under WFU guidelines tend to be applied at the same time of year as wildfires and often with the sole objective of reducing fuel loads (Cohen 2006). For creating defensible space around or adjacent to urban interface areas there may be no conflict. However conflicts will arise where the goal is restoration of natural processes and ecosystem health, especially where prescribed fires may not replicate historic natural fires. Examples where disparities may occur include chaparral shrublands and high elevation conifer forests. Chaparral shrub species, as in southern California, are uniquely adapted to survive and prosper in the presence of high severity fires that recur after several decades. Many of the plants in these ecosystems exhibit adaptive regenerative mechanisms, such as sprouting from root crown and soil seed banks insulated from but also stimulated by surface heating. High intensity fires tend to favor these fire-dependent native species over less successful competitors, such as plants whose seeds are destroyed by heat. By contrast, the recurrence interval in high elevation conifer forests may extend for hundreds of years between successive high severity fires. Although every ignition may not result in a large fire, historic hold-over fires may have burned with sporadic fire outbursts or runs covering thousands of hectares over months of protracted burning. In either case (chaparral or high elevation forests) low intensity fire prescriptions may not fulfil restoration objectives.

Fuel Treatments and Sustainability

Concerns that management activities, i.e., logging, grazing, and fire exclusion, might alter fire regimes reflect a concern for sustaining the biodiversity or ecological integrity for an area. Similar concerns have been expressed recently about fuel treatment insofar as hazard reduction treatments also manipulate structure and function of wildland ecosystems. Thus benign prescribed fires might not be appropriate in some high severity fire regimes or else multiple entries for treatment could induce unintended consequences.

Both intentionally-set prescribed fires and natural ignitions allowed to burn within pre-determined environmental limits may be appropriate for reducing fuel hazards and restoring ecosystems in some areas to prehistoric, sustainable conditions. Examples include long-needled pine systems in the western and southern US, as well as certain grass/shrublands and oak/pine (*Quercus/Pinus* spp.) savannas in the southwestern US.

At the same time, as research continues investigators may find that treatments can result in unforeseen impacts, such as conversion to plant species that are adapted to lower-severity burning or allowing invasive plants to secure a foothold in formerly pristine areas (Freeman 2006). Causative factors for the latter include crews and vehicles transporting exotic plant propagules, and improved light and nutrient availability in created openings (Hunter and others 2006). Further, the legacies of pre-wildfire treatments in US southwestern ponderosa pine ecosystems, such as species composition and stem densities, may linger for decades or even centuries based on stand simulations (Strom and Fule 2007). Regardless, consequences of fuel treatments should be compared against impacts of areas remaining untreated, including the higher wildfire burn severity associated with areas from which treatments are withheld.

A similar perspective may be required in terms of evaluating the consequences of fire use decisions. Smoke and risks of escape are among the biggest negatives of prescribed fire, but these should be evaluated against the likelihood of undesirable outcomes in an uncontrollable wildfire. Likewise, wildland fire use or herding of lightning ignitions needs to be compared to non-treatment and treatment alternatives. For example, Seydack and others (2007) found that allowing lightning ignitions to burn in so-called natural fire management zones may be preferable to intentional, i.e., prescribed fire, ignitions for sustaining biodiversity in some areas.

Sustainability refers to the maintenance of the *potential* for forests and wild lands to produce the same quantity and quality of goods and services in perpetuity (Franklin 1995). Focusing on potential implies the option of returning a forest or collection of stands to alternative conditions or prior states of nature that facilitate regulation of streamflows, minimize erosion losses, or provide suitable habitat for desired plants and animals, for example. Maintenance of the ecological integrity of systems, including the biodiversity of native species, would be consistent with this view. Further, fuel treatments that maintain and/or restore historic fire regimes would seem to be essential for facilitating the sustenance of ecosystems over the long term.

Seen another way, sustainability also has been defined to include ecological concerns but also as an intersection between sometimes competing and complementary concerns, for example between ecological, technological, economic and social interests (e.g., Williams and other 1993). A key distinction between these two approaches for defining sustainability is the focus on the land or ecological potential in the former vs. incorporation of human dimension(s) in the latter.

Examples abound about the importance of incorporating ecological concerns along with economic and social interests. For example, clearcutting in Pacific Northwest Douglas-fir (*Psuedotsuga menziesii*) forests may have been ecologically, technically, and economically feasible, but ultimately proved socially unacceptable. Fire exclusion in southwestern ponderosa pine ecosystems was economically and socially acceptable initially through the mid-20th century, but is now considered ecologically unsustainable. Salvage of fire-killed timber may be economically feasible near the wildland urban interface with adequate markets and milling capacity, but may be unsustainable ecologically if biological legacies are destroyed.

In a democratic society social acceptability may override any treatment's ecological feasibility if public interests become strong enough and garner sufficient political support. Even so, scientific knowledge is absolutely critical for making informed decisions about fire and fuel treatments—and will be ever-important as impacts of climate change become better-known. In this context, adoption of an adaptive management framework makes compelling sense, whereby management decisions are viewed within the framework of scientific experiments that allow mid-course corrections in management direction as new and improved information becomes available.

Conclusions

Prevention of unwanted ignitions is an important goal for managing wildlands but may be less achievable than managing the fuel hazards once an ignition occurs. Fuel treatments such as mechanical thinning and prescribed fire at project and landscape scales can be used to reduce the spread and severity of wildfires, but may not be appropriate across all ecosystems and fire regimes. Sustainability would seem to be a key planning and implementation consideration for deciding about the appropriate and desired levels of fuel treatments across the landscape. Understanding of human dimensions is critical to assuring the sustainability of fuel management strategies. This perspective is especially relevant in an era of heightened awareness of climate change and the need for adaptive management strategies.

Properly applied fuel treatments facilitate sustainability by making some forest ecosystems safe for both wild and prescribed fires. However, a landscape perspective is required that acknowledges both the limits of current knowledge and the interdependency of ecosystem parts.

Our understanding of fuel treatments continually evolves, especially with new knowledge and improved understanding about forestry, ecology, biodiversity, and a changing climate. Yet the human dimensions of forest practices may ultimately prove as important for improving our abilities to live with fire in the environment, especially as societal needs are met through enlightened fuels management.

References

Agee, J.K. 1997. **Fire management for the 21st century.** Chapter 12 *In*: K.A. Kohm and J.F. Franklin (eds.) Creating a forestry for the 21st century. Washington, D.C.: Island Press.

Agee, J.K. and C.N. Skinner. 2005. **Basic principles of forest fuel reduction treatments**. Forest Ecology and Management 211 (2005): 83-96. Online at http://www.fs.fed.us/psw/programs/ecology_of_western_forests/publications/publications/2005-01-AgeeSkinner.pdf

Abt, K.L., J. P. Prestemon, K. Ince., J. Barbour, R. Fight, and R. Rummer. 2003. **The market economics of mechanical fuel treatments.** Pre-prints for the 5th Symp. On Fire and Forest Meteorology and 2nd International Wildland Fire Ecology and Fire Mangement Congress, Orlando FL, 16-20 Nov. 2003. American Meteorology Society. Online at http://ams.confex.com/ams/FIRE2003/techprogram/paper_65871.htm

Arno, S.F. and J.K. Brown. 1991. **Overcoming the paradox of managing wildland fire.** Western Wildlands, Spring 1991: 40-46.

Brown, A.A. and K.P. Davis. 1973. **Fire control and use.** 2nd Edition. New York: McGraw-Hill.

Cohen, D. 2006. **Wildland fire use as a prescribed fire primer.** Fire Management Today 66(4): 47-49.

Countryman, C. 1972. **The fire environment concept.** Berkeley, CA: USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

Covington, W.W., P.Z. Fule, M.M. Moore, S.C. Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, and M.R. Wagner. 1997. **Restoring ecosystem health in ponderosa pine forests of the southwest.** Journal of Forestry 95: 23-29.

Devet, D.D. 1976. **DESCON: Utilizing benign wildfires to achieve land management objectives.** Fire and Land Management Symp. Proc. Tall Timber Fire Ecol. Conf. 14:33-44.

Freeman, J.P. 2006. **Rapid Response to Post-fire Plant Invasion.** M.S Thesis. Colorado State University, Fort Collins.

Franklin, J.F. 1995. **Sustainability of managed temperate forest ecosystems.** Chapter 23 *In:* M. Munasinghe and W. Shearer (editors). Defining and measuring sustainability: the biogeophyscial foundations. Washington, D.C.: The World Bank.

GAO, 1999. **Western national forests: A cohesive strategy is needed to address catastrophic wildfire threats.** Washington, D.C.: Government Accounting Office, Report to the Subcommittee on Forests and Forest Health, Committee on Resources, House of Representatives. Online at http://www.gao.gov/archive/1999/rc99065.pdf

Graham, R.T., S. McCaffrey, T.B. Jain. 2004. **Science basis for changing forest structure to modify wildfire behavior and severity.** Gen. Tech. Rep. RMRS-GTR-120. Ogden, UT: Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 43p. Online at http://www.fs.fed.us/rm/pubs/rmrs_gtr120.pdf.

Hunter, M.E., P.N. Omi, E.J. Martinson, and G.W. Chong. 2006. **Establishment of non-native plant species after wildfires: effects of fuel treatments, abiotic and biotic factors, and post-fire grass seeding treatments.** International J. Wildland Fire 15:271-281.

Husari, S., H.T. Nichols, N.G. Sugihara, and S.L. Stephens. 2006. **Fire and Fuel Management.** Chapter 17 Pp. 44-465 i*n:* Sugihara, N.G., J.W. van Wagtendonk, K.E. Shaffer, J. Fites-Kaufman, and A. E. Thode. Fire in California's Ecosystems. Berkeley: University of California Press. 596 p.

Kilgore, B.M. 1975. **Restoring fire to National Park wilderness.** Amercan Forests 81(3):16-19, 57-59.

National Wildfire Coordinating Group. 2006. **On-line glossary of wildland fire terminology.** Online at http://www.nwcg.gov/pms/pubs/glossary/index.htm.

Martinson, E.J. and P.N. Omi. 2006. **Assessing mitigation of wildfire severity by fuel treatments - an example from the Coastal Plain of Mississippi.** USDA Forest Service Proceedings RMRS-P-41:429-439. (http://www.fs.fed.us/rm/pubs/rmrs_p041.html).

Omi, P.N. 2005. **Forest fires: a reference handbook**. Santa Barbara: ABC-CLIO Press, 347 p.

Omi, P.N. 1977. **Long-term planning for wildland fuel management.** Ph.D. Diss., University of California, Berkeley.

Omi, P.N. and E.J. Martinson. 2002. **Effect of fuels treatment on wildfire severity.** Final report submitted to the Joint Fire Science Program Governing Board. Colorado State University, Fort Collins.

Peterson, David L, M.C. Johnson, J.K. Agee, T.B. Jain, D. McKenzie, and E.D. Reinhardt. 2005. **Forest structure and fire hazard in dry forest of Western United States.** Gen. Tech. Rep. PNW-GTR-628. Portland, OR: U.S. Department of Agriculture, Forest

Service, Pacific Northwest Research Station. 30p. Online at http://www.fs.fed.us/pnw/pubs/pnw_gtr628.pdf.

Pollet, J. and P.N. Omi. 2002. **Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests.** International J. of Wildland Fire 11: 1-10.

Seydack, A.H.W.,S.J. Bekker, and A.H.Marshall. 2007. **Shrubland fire regime scenarios in the Swartberg Mountain Range, South Africa: implications for fire management.** International J. Wildland Fire 16(1):81-95.

Strom, B.A. and P.Z. Fulé. 2007. **Pre-wildfire treatments affect long-term ponderosa pine forest dynamics.** International J. Wildland Fire 16(1):128-138.

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

Williams, J.T., R.G. Schmidt, R.A. Norum, P.N. Omi, and R.G. Lee. 1993. **Fire related considerations and strategies in support of ecosystem management.** Washington, D.C.: USDA Forest Service, Washington Office, Fire and Aviation Management Staffing Paper.